GEOLOGICAL SURVEY OF CANADA

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Rare Element Minerals of Canada

H. V. Ellsworth

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Natural Resources Canada
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RARE ELEMENT MINERALS OF CANADA

CHAPTER I

INTRODUCTION

The revolutionary advances in pure science and the amazing results of the utilization in a practical way of discoveries which at first seemed to be of purely scientific interest, are outstanding features of our time. Research in both pure and applied science is being carried on to a degree hitherto entirely unprecedented, not only as regards the number of those engaged, but more particularly as regards the character of the organizations sponsoring such research. Whereas, not so long ago practically the only investigator in pure science were university professors working more or less in spare time and often hampered by inadequate equipment and lack of funds, today many of the larger manufacturing corporations find it to their advantage to maintain at an annual cost of millions of dollars great research organizations, not only for the investigation of technical problems but also for fundamental researches in pure physics and chemistry. The work of such organizations frequently results in the technical utilization of substances for which formerl there was no commercial demand. New uses are also being found for ol familiar materials and even some of the rarest and least known elements, existing in only the most extremely minute quantities in the earth's crust, have achieved prominence and are playing more or less important roles in technical applications. For certain of the rarer elements no particular uses have yet been found, but it is safe to predict that sooner or later every known element obtainable in appreciable quantities will be utilized in some way in the arts.

It is the purpose of this report to discuss less common elements which are found as constituents of minerals occurring in Canadian pegmatites. These elements are: uranium and thorium with their associated transformation products, of which radium and mesothorium are the most important; tantalum;columbium; the rare earth elements; zirconium; hafnium; beryllium; lithium; rubidium; and caesium. Most of these elements or their compounds already are being used more or less and are articles of commerce, though there is not much demand for some of them. Numerous inquiries received by the Geological Survey have emphasized the necessityfor a survey of Canadian resources of these elements. Popular interest in the ores of radium has been particularly marked owing to the high price of radium, its unique properties, and the fact that various radium-bearing minerals are often encountered in the course of mining for feldspar in Ontario and Quebec. The finding of such minerals, also, unfortunately, has sometimes given rise to entirely unjustified hopes of achieving production on a commercial scale and it is believed that a useful service is rendered to both the would-be promoter and the public in advising against such mining operations as would be more than ordinarily speculative and altogether unlikely to result in success, in the financial sense at least. Nevertheless the frequent occurrence of these rare element minerals in pegmatites over great areas of the Precambrian in Ontario and Quebec, as shown by the early field work of the writer, suggested that somewhere concentrations of commercial size might exist. One major object of the survey, therefore, was to study carefully all the known occurrences with a view to ascertaining the feasibility or otherwise of attempting the commercial production of rare element minerals, also to determine so far as possible, the most favourable geological and mineralogical conditions for the occurrence of such minerals, their probable areal distribution, and the indications, if any, which might be useful to the prospector in searching for these minerals. Another important consideration was concerned with the correlation of Canadian rocks. It was thought that by a study of the radioactive minerals which they contain, or may contain, the age of certain igneous rocks might be determined with sufficient exactness to assist in solving geological problems involving the correlation of great areas of igneous rocks, the age relationships of which geologists have not been able to ascertain by the ordinary methods. An outstanding instance for the need of such correlation is afforded by the difficulties encountered in attempting to define the contact of the Huronian rocks of western Ontario with the Grenville of old Ontario and Quebec. At Killarney, on the north shore of lake Huron, the massive Huronian quartzites composing Cloche mountains are cut off abruptly by a band of porphyritic, very slightly gneisso

Killarney granite which extends for many miles in a northeasterly direction. To the east of this band of granite the typical Huronian quartzite as a distinct formation is no longer to be seen, though large fragments of what appears to be the altered quartzite occur as inclusions in the granitoid rocks for some miles east of Killarney. Passing eastward along Collins inlet the rocks become more and more gneissoid and pass gradually and imperceptibly into types that a geologist accustomed to the Laurentian-Grenville area would at once conclude belonged to the rocks of that area. On the other hand a geologist familiar with the Huronian might consider that the granite-gneiss and paragneisses of the supposed Laurentian-Grenville complex are merely more altered and more gneissoid phases of the Killarney granite and the Huronian sediments to the westward. This doubtful area has been studied in detail in recent years by W.H.Collins and T.T.Quirke[1], who have had in mind the possibility that the Grenville sediments may be at least in part of Huronian age and that some or all the granite intrusives of the Grenville area may correspond to the Killarney granite. The most reliable radio-active age data so far obtained that has any bearing in this connexion is afforded by the uraninite of the Besner mine, Henvey township, and the uraninite of Conger township, both in Parry Sound district. The Besner mine pegmatite cuts a porphyritic

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[1] Collins, W.H.:"North Shore of Lake Huron"; Geol.Surv.,Canada, Mem. 143, (1925)
Quirke, T.T., and Collins, W.H.: "The Disappearance of the Huronian"; Geol.Surv.,Canada, Mem. 160, (1930)

granite-gneiss that Quirke, according to a personal communication, believes to correspond to the Killarney granite. The Besner uraninite yields a lead ratio of 0.11, whereas the lead ratio for the Conger township uraninite is 0.15. Thus these two uraninites differ in age by about three hundred million years. The average lead ratio for several other well-preserved uraninites of the Grenville area is also about 0.155.

As already indicated, this report has been prepared with the object of assembling such information as is at present available regarding Canadian occurrences of certain of the rarer elements, more especially those which are typically of pegmatitic origin. Much of the descriptive matter, particularly that referring to occurrence in Ontario, Quebec, and eastern Canada, is based on recent first hand field observations and laboratory work by the author, but for completeness an effort has been made to include all published pertinent information and the recent notable mineralogical contributions to this field by T.L.Walker and collaborators of the University of Toronto have also been made use of.

In the course of the field examination thousands of specimens were collected of which it has been impossible so far to study in detail more than a comparatively small number of representative exam ples, owing to the necessity of making time-consuming, complete chemical analyses of the more complex minerals in order to learn their exact composition. It is usually possible to identify the commoner, simple minerals by inspection or by a few comparatively simple tests and once the identification is certain the composition of the mineral is known, for the most practical purposes, within reasonably close limits; but unfortunately in the case of many of the rarer minerals, particularly those containing as their chief constituents uranium, thorium, the rare earths, titanium, tantalum, and columbium, it appears to be quite impossible to predict the approximate percentage composition by qualitative tests or by the physical properties, as these minerals exhibit so marked a tendency to isomorphous replacements of the various elements present with resulting wide variations in percentage composition, that even complete qualitative tests are of little value. Hence quantitative chemical analyses are necessary. The analysis of such minerals is unquestionably one of the most difficult and complicated problems of analytical chemistry and if the analyses are to be used in calculating the age of the mineral it is necessary to check and recheck the results for uranium, lead, and thorium with the greatest possible care. Weeks or months may be required for the complete study of a single mineral. Further, much of the time available for these investigations has been devoted to a critical study of the conventional methods of analysis of these minerals and to attempts to devise more rapid and exact ways of working up the fairly large quantities of material which must often be taken in order to obtain accurate results for Pb, U, and Th on low-grade minerals.

Thus it has not been possible to study in detail more than a very small portion of the specimens collected and as the active prosecution of feldspar mining in Ontario and Quebec is constantly adding to the list of occurrences this report should be considered as only a partial preliminary statement.

The writer is greatly indebted to the numerous mine operators, prospectors, and others who have assisted in procuring specimens and in many other ways. The never-failing kindness, hospitality, and ready co-operation of the mining fraternity has always been a notable and much appreciated feature of geological field work in this country.

In respect to the laboratory work invaluable assistance has been rendered by the Director and officers of the Mines bBranch, Department of Mines, in supplying laboratory apparatus and facilities, without which much of the chemical work could not have been carried out. The Ore Testing Division of the Mines Branch has also very kindly made several concentration tests and has loaned apparatus, for all of which thanks are here tendered.

Numerous standard works and professional papers have been drawn on, which are referred to as occasional arises.

The writer is indebted to numerous workers in the United States and foreign countries for copies of papers and for the discussion of problems in some cases.

Prof. A.C.Lane, chairman of the United States National

Research Committee on the Measurement of Geological Time by Atomic Disintegration, has been particularly helpful in supplying data of all kinds by which the writer has been kept in touch with the important work in this field going on not only in the United States but throughout the world.

Through the courtesy of Dr. A.L.Day, director of the Geophysical Laboratory, Dr. E.S.Shepherd made the analysis of the gases of the Parry Sound thucholite. Dr. C.N.Fenner checked the Pb, U, and Th content of the Maberley euxenite, and Dr. Ziess made certain spectroscopic determinations.

Miss F.H.B.Richardson has rendered great assistance in searching the literature, assembling the material, and performing the clerical work in connexion with the report.

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THE RARE ALKALI METALS

LITHIUM, RUBIDIUM, CAESIUM.

The alkali metals, lithium, sodium, potassium, rubidium, caesium, comprise a series of elements closely related in chemical properties of which sodium and potassium are very common and abundant entering into the composition of the majority of rocks and many minerals and forming great bedded deposits of soluble chlorides and sulfates resulting from the evaporation of sea water. The other three members, lithium, rubidium, caesium, are rare though lithium is much more abundant than rubidium and caesium. All the alkali metals are silver white when fresh and unoxidized, with a brilliant metallic lustre. On exposure to the air they tarnish at once becoming covered by a coating of oxides Caesium melts and takes fire on exposure to air. Owing to their rapid oxidation in air they are preserved by immersion in petroleum oil. They all decompose water rapidly at ordinary temperature forming hydrogen and the alkali hydroxide. Except in the case of lithium the heat of the reaction melts the metals and in the case of potassium, rubidium and caesium is sufficient to ignite the liberated hydrogen. Lithium, sodium and potassium are lighter than water and lithium is the lightest element solid at ordinary temperature. They are all very soft and ductile. Sodium may be squeezed with the fingers at ordinary temperature. The metals are very active chemically and enter into a great variety of chemical combinations. Salts of the alkali metals impart characteristic colors to a non-luminous flame. Lithium gives a vivid carmine red; sodium intense yellow; potassium, rubidium and caesium color the flame reddish violet, and are not easily distinguished without using a spectroscope. All are readily identified by the occurrence of characteristic lines in the visible spectrum. The limits for the recognition of the alkali metals by the visible flame and visible spark spectra are, in milligrams:

	Li	Na	K	Rb	Cs
Flame Spectrum	$\frac{1}{600,000}$	$\frac{1}{14,000,000}$	$\frac{1}{3,000}$	$\frac{1}{1000}$	$\frac{1}{25,000}$
Spark Spectrum	$\frac{1}{40,000,000}$	—	$\frac{1}{400}$	$\frac{1}{1000}$	$\frac{1}{4000}$

Potassium and rubidium are measurably radioactive and some samples of caesium have been reported to exhibit ~~xamplxsx ofxcaesium~~ very feeble radioactivity but caesium is not generally considered to be radioactive. Lithium and ~~radium~~ sodium show no detectable radioactivity. Potassium and rubidium emit only β rays, the rays from potassium being more penetrating than those from rubidium but the total activity of rubidium is greater than an equal weight of potassium. The β ray activity of rubidium[1] is about one-fifteenth that of uranium X_1, and the activities of rubidium and potassium[2] are as 1.39 to 1.00. Soddy[3] states that the B ray activity of potassium is about 1/1000 of the β ray activity of uranium. Holmes[4] has shown that owing to the abundance of potassium in the rocks of the earth's crust, it is in the aggregate of the same order of

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1- Hahn and Rothenbach-Physik. Zeit. 20, 194(1919)
2- Harkens and Guy, Proc. Nat. Acad. Science, 11, 628, (1925)
3- Chemistry of the Radio-Elements
4- Holmes, A, The Radioactivity of Potassium and its Geological Significance. Phil. Mag., Vol. ii, Dec. 1926.

importance as U and Th in generating heat in the rocks, while rubidium on account of its rarity is of no importance in this re~~port~~spect. It has also been suggested by Zwaardemaker[x] that the radioactivity of the potassium contained in human and animal organisms may be of fundamental physiological importance. He calculated the energy thus set free in the human body to amount to 1,900 ergs per day.

There appears to be a possibility that a very rare member of the alkali metal group still remains undiscovered. This would be the element of atomic number 87 with atomic weight around ~~200~~ 224, and it ~~might~~ probably would be very strongly radioactive.

Some of the more important properties of the alkali metals are summarized below:

	Lithium	Sodium	Potassium	Rubidium	Caesium
Atomic Weight....	6.939	22.997	39.095	85.44	132.81
Isotopes	7,6	23	39,41	85,87	133
atomic No.	3	11	19	37	55
atomic Vol.....	13.1	23.7	45.5	56.0	71.0
Specific gravity of solid at 20°..	0.543	0.9723	0.859	1.525	1.903
Expansion on Melting..........	1.51	2.57	2.60	1.657	1.383
Relative Hardness	0.6	0.4	0.5	0.3	0.2
Melting Point....	180°	97.6°	63.5°	39°	28.5°
Boiling Point...	+1400°	877.5°	759°	696°	670°
Radioactivity	None	None	β-rays	β-rays	None

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[x] Abstract in Science, December 23, 1927, by A. P. Mathews

RUBIDIUM

UTILIZATION:- Rubidium is not utilized commercially. Its compounds are used so far only as reagents in chemical analysis and for experimental purposes. Owing to its scarcity, rubidium and its compounds are rather expensive, being produced in only small quantities to supply the limited demands of scientific research.

OCCURRENCE:- Rubidium occurs with lithium (which see) widely distributed but in much smaller amounts. The richest source is lepidolite which sometimes contains as much as 3 percent Rb_2O. Most lithium minerals contain small amounts of rubidium, leucite, carnallite and most iron ores contain minute amounts. It is also found in spectroscopic traces with lithium in many spring waters, soils, meteorites, and the ashes of plants noted as containing lithium. Also sometimes in micas and alkali felspars. The amazonite (x) of Ilmen Mountains, Orenburg Province, Russia has been reported to contain as much as 3.12 per cent of Rb_2O besides traces of Cs Rhodizite (page) a very rare mineral occurring in minute amounts also contains Rb as an essential constituent.

(x) W. Vernadsky- Bull. Soc. Francaise de Min. Dec., 1913.

LITHIUM

OCCURRENCE- Lithium occurs in minute amounts along with Na and K and sometimes Rb and Cs in many natural spring waters, in sea water, soils, meteorites, the ashes of many plants such as tobacco, seaweed, sugar beet and sugar cane, coffee, cocoa; in human and amumal tissues, etc. The delicacy of the spectroscopic test for lithium renders it easy to detect the most minute traces and the element has been found to be widely distributed in minute quantities. Some 140 different minerals have been listed as containing lithium but in the majority of ~~XXX~~ these either the amount of lithium present is insiginificant or the mineral is rare.

The chief minerals used as commercial ores of lithium are:-

Amblygonite -	Contains	3.5 to 10 ~~m/m~~	percent,	average	9	per	cent	Li_2
Spodumene	"	1.2 " 7.6	"	"	4-7	"	"	"
Lepidolite	"	1.13" 6.06	"	"	4	"	"	"

Other minerals containing appreciable amounts of lithium, and which have been occasionally mined as sources of the element~~s~~ are:

Triphyl~~l~~ite	contains	about	9	per	cent	Li_2O
Lithiphyllite	"	"	9	"	"	"
Petalite	"	"		"	"	"
Zinnwaldite	"	"	3-5	"	"	"

CAESIUM

UTILIZATION:- Until recently there were no commercial uses for caesium or its compounds. Caesium salts had been used occasionally in very small quantities for chemical studies of theoretical interest and a few grams of such salts were usually to be found in well stocked laboratories, more for the sake of completeness than for any use which might be made of them. During the last ~~During the past~~ three or four years however caesium ~~s~~ has been used in the manufacture of the special type of radio tube known as the UX-200-A. The use of caesium is said to account for the superior sensitivity of this tube as a detector. The writer is indebted to Mr. C. H. O. Pook, Manager of Works, The Canadian Westinghouse Co., Hamilton for the following ~~letter~~ note dated June 13, 1928 on the use of caesium in radio tubes: "The only tube so far marketed which contains caesium is the UX-200-A. This tube was operated on the emission from a pure tungsten filament, the caesium served to make the tube more sensitive, similar to the effect produced by a small amount of gas. The caesium is introduced into the tube in regulated quantities and is not incorporated in the filament.

De. Langmuir in the article mentioned utilizes a tungsten filament operating at a low temperature, the caesium is introduced into the tube as in the UX-200-A and accumulates on or is absorbed by the filament in an extremely thin film. The reason given for the formation of this film is that the electron affinity or attraction of a tungsten filament surface is greater than that of caesium ions, so that the tungsten filament robs any caesium aton of its valance electron thus building up this film on the tungsten. The film is stable due to the reaction between the positive charge of the ion and the negative charge induced in the filament as a result of the proximity of the positive charge.

In a tube utilizing this principle the emission comes direct from the caesium and is at least three times as efficient as thoriated filaments. We know of no commercial use of this principle at the present time although undoubtedly some way will be found to utilize caes9um emission commercially in a receiving tube.

The latest information we can obtain on Hafnium is that it ranks below thorium as an electron emitter. This is contradictory to first published results, but the latest information comes from the same source so is undoubtedly correct."

T. S. Fuller (x) of the Research Laboratory of the General Electric Company says: "Caesium offers further possibilities in vacuum tube work for both detectors and amplifiers. The detector (UX-200-A) comprises the conventional three element tube with thoriated filament plus a small amount of metallic caesium. The latter is introduced in the tube in a nickel case as a pellet of caesium chloride and calcium, which is caused to react by heat produced by induction from a high frequency coil. Caesium interacts with the filament to produce a supply of positive caesium ions which affect the electrical characteristics of the tube in such a manner as to make it a sensitive detector. It is interesting to note that only the large atoms are efficient electron emtters and

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( ) Mining and Metallurgy, Oct. 1928.

further that at a given temperature the efficiency depends on the size of the atom. For example, barium is superior to thorium and caesium is better than barium." Fuller(loc cit) further states that the alkali metals are used in the manufacture of light-sensitive cells used in photometry,television and the talking movies. The action of such cells is due to their change in resistance tesulting from the varying electron emission from the cathode composed of photosensitive substance, with changing light intensity. Such cells consist of an evacuated glass bulb coated inside with a thin layer of one of the alkali metals which serves as the photosensitive cathode, the anode being supported in the centre of the cell. The photosensitivity of the alkali metals depends on the wave length of the light, all being more sensitive to the blue than to the red. Going down the series from lithium to caesium the sensitivity to red increases and for this reason the caesium cell offers most promise for general use.

Recognition of the value of caesium in vacuum tube~~s~~ work led the General Electric and Westinghouse companies to mine for it within the last few years in the Maine pegmatites where pollucite was known to have occurred. It is said that these mining operations have now ceased. (1928).

Caesium is the rarest of the alkali metals though widely distributed in spectroscopic traces along with the other alkalis, (See lithium, page) and particularly in lithium-bearing minerals. It occurs in appreciable amounts so far as known at present only in three minerals which may be considered as possible commercial sources, viz:

Pollucite- contains up to 36 per cent. Cs_2O.
Caesium beryl- may contain up to 3 per cent. Cs_2O.
Lepidolite- " " " "0.7 " " Cs_2O.

Rubidium and caesium are also said to have been extracted from carnallite occurring in the German potash deposits. Rhodizite is a very rare caesium mineral occurring in only the most minute quantities.

PRODUCTION:-

No figures are available regarding the amount of pollucite obtained by the recent mining operations in Maine conducted by the General Electric and Westinghouse Electric Companies. It is reported, however, that considerable quantities were obtained from the Newry deposit worked by the General Electric Company.

POLLUCITE:- Hydrous silicate of caesium and aluminium with some Na and K replacing Cs. $2Cs_2O.\ 2Al_2O_3.\ 9SiO_2.\ H_2O$. Theoretical composition Cs_2O 42.53, Al_2O_3 15.39, SiO_2 40.72, H_2O 1.36 = 100.00

Isometric- usually massive, sometimes in cubes,
Cleavage- traces
Fracture- Conchoidal, brittle.
Lustre- vitreous to dull oily or saccharoidal.
Colourless to white, also yellowish, grayish or greenish.

Transparent to translucent to opaque in hand specimens.

Hardness 6.5, S. G. = 2.86 to 2.89 Elba, 2.976 to 2.987 Hebron, 2.938 to 3.029 Rumford.

Refractive index- n = 1.5247 Na (Penfield)
1.525 (Larsen)

Analyses :
1. From Elba by Pisani (C. R. 58, 714, 1864)
2. From Hebron, Maine, by H. L. Wells,(A. J. S., 1891, p.213)
3. From Rumford, Maine by H. W. Foote,(A. J. S., 1896, p. 457).

	Cs_2O,	Na_2O,	K_2O,	Li_2O,	Rb_2O,	Al_2O_3,	Le_2O_3,	CaO,	SiO_2,	H_2O,	Total
1.	34.07	3.88	Trace	Trace	--	15.97	0.68	0.68	44.03	2.40	101.71
2.	36.10	1.68	0.48	0.05	none	16.30	- --	0.22	43.51	1.50	99.84
3.	36.03	2.11	0.42	0.13	trace	16.90	- --	- --	43.54	1.57	100.72

PYROGNOSTICS, ETC.- In the closed tube becomes opaque and yields water but only at a high temperature. In the forceps whitens, fuses with difficulty coloring the flame yellow. In hydrochloric acid slowly decomposes, with separation of pulverulent silica.

OCCURRENCE:- The original occurrence is on the island of Elba, where it occurs as small grains in granite, associated with petalite. It occurs in considerable quantities in certain of the lithium pegmatites/ of Maine, particularly at Newry where it was mined in considerable quantities by the General Electric Company. It is said that one mass weighing about 1000 pounds was obtained. The pollucite in the Maine dikes is associated with the white platy variety of albite-clevelandite, with pink lithia tourmaline; lithia mica and sometimes colorless(caesium?) beryl. The pollucite is sometimes cut by narrow veinlets of lithia mica. Sometimes it is colorless, clear and transparent like quartz, but much of it looks as though it had been crushed and finely granulated, with color white to yellowish or grayish and fine saccharoidal texture like alabaster. A soft, friable, decomposed variety is also obtained. It has been found in some six different dikes in Maine.

Pollucite also occurs in some of the lithium pegmatites of South Dakota near Custer.

The writer is indebted to Dr. F. L. Hess of the U. S. Bureau of Mines for much of the recent information on pollucite and for the opportunity to examine specimens from the various occurrences.

RHODIZITE: Borate of aluminium, potassium, caesium and rubidium.
$(K\ Cs\ Rb)_2O.\ 2Al_2O_3.\ 3B_2O_3.$
Isometric and tetrahedral like boracite. In dodecahedrons, faces o smooth and shining, d often uneven. Shows anomalous double refraction.
Lustre- vitreous to adamantine.
Color- white
Translucent- Pyroelectric.
Hardness 8. Specific Gravity 3.40
Index of Refraction n= 1.69 (Larsen)

Analysis:-

K_2O, Cs_2O, Pb_2O	Na_2O	Al_2O_3	Fe_2O_3	CaO	MgO	B_2O_3	Ign.
12.00	1.62	41.40	1.93	0.74	0.82	33.93	2.96=

Total- 95.40%

PYROGNOSTICS, ETC.: B. B. in the platinum forceps fuses with difficulty on the edges to a white opaque glass, ~~kingin~~ tingeing the flame at first green, then green and red and finally red throughout. Insoluble in acids.

OCCURRENCE:- Found as minute microscopic crystals on red tourmalines from the Urals and also in certain Madagascar pegmatites.

SICKLER~~L~~ITE:- Hydrous phosphate of manganese, iron andlithia.
MnO 33.60, CaO 0.20, Fe_2O_3 11.26, Mn_2O_3 2.10, P_2O_5 43.10, Li_2O 3.80, H_2O 1.71, Insol. 4.18, Total 99.95.

Orthorhombic-?- In cleavable masses.

Cleavable- two unequal cleavages at 90°.

Color- dark brown.

Hardness 4, S. G. 3.45.

Biaxial negative, α 1.715, β 1.735, γ 1.745.
pleochroic, yellow to orange red.

PYROGNOSITCS- Easily fusible, soluble in acids.

OCCURRENCE- In a lithium pegmatite near Pala, San Diego County, California.

FILLOWITE:- Hydrous phosphate of manganese, iron, calcium, and sodium. P_2O_5 39.10, FeO 9.35, MnO 39.42, CaO 4.08, Na_2O 5.74, Li_2O 0.06, H_2O 1.66, quartz 0.88.

Monoclinic- habit pseudo-rhombohedral. In granular crystalline masses.

Cleavage- c nearly perfect.

Fracture- uneven, brittle.

Lustre- subresinous to greasy.

Color- wax yellow, yellowish to reddish brown, colorless.

Transparent to translucent.

Hardness 4.5. G. 3.43.

Biaxial positive- α 1.672, β 1.672, γ 1.676. 2 V small.

PYROGNOSTICS, ETC.- Fusibility 2.5, soluble in acids.

OCCURRENCE- In albite pegmatite at Branchville, Connecticut.

DICKINSONITE:- Hydrous phosphate of manganese, iron, lime, sodium, potassium, lithium. P_2O_5 39.57, FeO 13.25, MnO 31.58, CaO 2.15, Na_2O 7.46, K_2O 1.52, Li_2O 0.17, H_2O 1.65, Insoluble 2.58 (quartz).

Monoclinic- Crystals tabular, pseudo-rhombohedral, triangular striations on C. Commonly foliated to micaceous, also curved lamellar, radiated or stellated.

Cleavage- c perfect, separable ~~with~~ into thin lamellae fracture

Lustre- vitreous, on c somewhat pearly.

Color- olive to grass green.

Hardness ~~2~~ 3.5-4. G. 3.338-3.343.

Biaxial positive- α 1.658, β 1.662, γ 1.671, pleochroic in green.

PYROGNOSTICS, ETC.- Fusibility- 2.5-3. Soluble in acids. Heated in closed tube gives water and magnetic residue.

OCCURRENCE- in pegmatite at Branchville, Connecticut.

MANANDONITE- Basic boro-silicate of lithium and aluminium. SiO_2 24.2, Al_2O_3 47.8, B_2O_3 9.4, Li_2O 4.0, H_2O 14.6.

Micaceous, in lamellar aggregates or crusts of hexagonal plates.

Cleavage- perfect.

Lustre- pearly.

Color- white.

S. G. 2.89.

Biaxial positive. β 1.6 ± Under microscope a basal section shows six segments with planes of optic axes parallel to the edges of the hexagonal plate.

PYROGNOSTICS, ETC.- Easily fusible, decomposed by H_2SO_4.

OCCURRENCE- Near the Manandona river, Madagascar.

TAENIOLITE- Silicate of magnesium, potassium, lithium, sodium, and aluminium. SiO_2,52.2, Al_2O_3 2.7, FeO 0.6, MgO 19.1, K_2O 11.5, Na_2O 1.8, Li_2O 3.8, Less 8.3.

Monoclinic- mica group.

Cleavage- c perfect, laminae somewhat elastic.

Colorless with tinge of blue.

Transparent.

Hardness 2.5-3. G. 2.86.

OCCURRENCE - at Narsarsuk, Southern Greenland.

BITYITE- Silicate of aluminium, calcium, beryllium and lithium. SiO_2 31.95, Al_2O_3 41.75, CaO 14.30, BeO 2.27, MgO 0.13, Li_2O 2.73, Na_2O 0.40, K_2O 0.16, H_2O 6.50.

Pseudo-hexagonal- in minute hexagonal plates which show division into six sectors in polarized light.

Cleavage- basal perfect.

Lustre- pearly.

Color- yellowish white.

Hardness 5.5, G. 3.05.

Biaxial negative, α1.62, β 1.63, $\gamma >$1.64.

PYROGNOSTICS. ETC.- Fusible, insoluble in HCl.

OCCURRENCE - as crusts of crystals coating tourmaline, quartz, etc. in pegmatites at Mt. Bity, Maharitra, Madagascar.

JEZEKITE- Fluophosphate of lime, soda and alumina with a little lithia. P_2O_5 30.30, Al_2O_3 21.92, CaO 13.50, Na 18.71, XXOX Li 0.86, F 8.15, OH 6.26, total 100.70.

Monoclinic- crystals.

Cleavage- (100) perfect, (001) imperfect.

Colorless to white.

Hardness 4.5, S. G. 2.94.

Biaxial negative, α 1.55, β 1.58, γ 1.59.

OCCURRENCE- At Ehrenfriedersdorf, Saxony.

CRYOLITHIONITE -Fluoride of aluminium, sodium and lithium.

F 60.79, Al 14.46, Na 18.83, Li 5.35, Ign. 0.36 =99.79.

Isometric- in rhombic dodecahedrons sometimes 17 cm.in diameter.
Faces usually rough.

Cleavage- dodecahedral, distinct.

Fracture- uneven, brittle.

Lustre- vitreous.

Colorless

Transparent

Hardness 2.5-3.G. 2.777.

Isotropic n = 1.339.

PYROGNOSTICS, ETC.- Fuses very easily. In the closed tube decrepitates violently and fuses to a colorless liquid. Soluble in water to the extent of 1 part in 1350.

OCCURRENCE- In the cryolite pegmatite at Ivigtut, Greenland, where it occurs sparingly embedded in the cryolite.

EUCRYPTITE: Silicate of aluminium and lithium SiO_2 48.13, Al_2O_3 40.50, Li_2O 10.90, K_2O 0.47 = 100.

Hexagonal- In symmetrically arranged microscopic crystals embedded in albite.

Cleavage- basal.

Colorless or white.

Tramsparent.

S. G. 2.67.

Uniaxial negative, W 1.545 B low.

PYROGNOSTICS, ETC.- Gelatinizes with acid.

OCCURRENCE- In lithium pegmatite at Branchville, Connecticut. Supposed to be an alteration product of spodumene.

ZINNWALDITE:- Ferruginous lithium mica. Silicate of aluminium, iron, potassium and lithium. Li_2O 3.28 to 5.0 per cent.

Monoclinic - Crystals often in rosettes or fan shaped groups.

Cleavage - Basal perfect. Laminae tough and flexible.

Lustre - often pearly.

Color - pale violet, yellow, brown, dark grey. Successive layers of different colors.

Hardness-2.5-3. S. G. 2.82- 3.20.

Biaxial negative, β 1.60 B = 0.03 2V to 68°(Larsen) pleochroic.

PYROGNOSTICS, ETC. Fusibility 1.5 to 2. Difficutly soluble in HCl.

OCCURRENCE- At Zinnwald in the Erzgeberge, and in Cornwall with tin deposits.

TRIPHYLITE-LITHIOPHILITE- Phosphates of iron, manganese and lithium. $Li_2O.2(Fe\ Mn)O.P_2O_5$. and $Li_2O.2(Mn\ Fe)O.\ P_2O_5$.

Orthorhombic: Crystals rare, usually massive.

Cleavage- c perfect b nearly perfect.

Fracture- uneven to subconchoidal.

Lustre- vitreous to resinous.

Colors: Greenish gray to bluish (triphylite)
Salmon to light brown, often nearly black on surface(lithiophilite).

Streak- colorless to grayish white.

Transparent to translucent.

Hardness 4.5-5. S. G. 3.42-3.56.

Biaxial positive- α1.676, β 1.679, γ 1.687, 2V=63.(lithiophilite)
α 1.688, β 1.688, γ 1.692, 2V=0± (triphylite)
Lithiophilite is pleochroic. With increasing FeO triphylite becomes optically negative.

Pyrognostics, etc.:- In the closed tube sometimes decrepitates, turn dark, and give traces of water. B. B. fuses at 1.5. With fluxes react~~s~~ for Mn Sol. in HCl.

OCCURRENCE:- In lithium pegmatites. Localities:- New England States, California, S. Dakota.

LEPIDOLITE:- Lithium mica. Hydrate fluosilicate of aluminium, potassium and lithium.

SiO_2 49 to 51, Al_2O_3 25 to 28, K_2O 11 to 13, Li_2O 4 to 5.88, F 5 to 8, H_2O 0.94 to 2.36.

Monoclinic:- Often in massive aggregates of small hexagonal plates or scales.

Cleavage :- basal, perfect.

Lustre :- pearly.

Color :- violet or lilac, grayish, brown.

Transparent to translucent.

H 2.5 -3, S. G. 2.8-2.9.

Biaxial begative, α1.560, β 1.598, γ 1.605. $2V=40^\circ\pm$ (Larsen)

Pleochroic

PYROGNOSITCS, ETC. In closed tube gives water and reacts for fluorine. B. B. fuses with intumescence at 2.5 to a white or grayish glass.

OCCURRENCE:- Occurs in lithium pegmatites, sometimes with spodumene and amblygonite and other lithium minerals, but often alone. Localities;- California, South Dakota, New England States, S. E. Manitoba, Madagascar, Sweden, Saxony, Urals, etc.

Produced commercially from California, S. Dakota and Manitoba.

PETALITE:- Silicate of aluminium and lithium. $Li_2O.\ Al_2O_3.\ 8SiO_2$. Lithium is usually partly replaced by sodium and potassium.

Monoclinic- Crystals rare, usually massive.

Cleavage- c perfect, O(201) easy.

Fracture- Imperfect conchoidal, brittle.

Lustre- vitreous, on c pearly.

Colorless, white, gray, reddish or greenish. Streak uncolored.

Transparent to translucent.

Hardness 6-6.5. S. G. 2.39-2.46.

Biaxial positive, α 1.504, β 1.510, γ 1.516, 2V=840(Larsen)

PYROGNOSTICS, ETC.- Gently heated emits a blue phosphorescent light. B. B. becomes glassy, white, subtransparent, melting on the edges. Fusibility 5. Insoluble in acids.

Occurrence- In lithium pegmatites. Localities, Sweden, New England States, Elba.

AMBLYGONITE:- Fluophosphate of aluminum and lithium.

$Al_2O_3.P_2O_5.2LiF$. Al_2O_3 34.4, Li_2O_5 10.1, F12.9, P_2O_5 47.9= 105.3 (deduct O= 2F=5.3). The lithium is usually replaced in part by sodium and potassium and the fluorine by hydroxyl.

Triclinic:- crystals large and coarse:forms rarely distinct.

Cleavage:- C perfect with pearly lustre; a(100) somewhat less so, vitreous, e(0$\bar{2}$1) sometimes equally distinct, M($\bar{1}$10) difficult.

Fracture:_ uneven to subconchoidal. Brittle.

Lustre:- vitreous to greasy, on c pearly.

Color:- white to pale greenish, bluish, yellowish, grayish, brownish. Streak white.

Subtransparent to translucent.

Hardness = 6. Sp. G. = 3.01 to/ 3.09.

Biaxial negative, α 1.579, β 1.593, γ 1.597 (Larsen) 2V= 52°±

Polysynthetic twinning in two directions at 90°.

PYROGNOSTICS, ETC.- In closed tube yields acid water which corrodes the tube. Fusible ~~xxxxx2~~ at 2 with intumescence, becoming opaque white on cooling. Readily soluble in H_2SO_4, more slowly in HCl.

OCCURRENCE:- ~~Occursxtypicallyxwithxlepidolite,xxxxxspodumenex~~

Occurs in lithium pegmatites often with lepidolite, spodumene, lithia, tourmaline and albite. Localities:- Norway, Madagascar, Maine, South Dakota, South east Manitoba.

SPODUMENE:- Silicate of aluminium and lithium. $Li_2O.Al_2O_3.4SiO_2$. Li_2O 8.4, Al_2O_3 27.4, SiO_2 64.5, The lithium is usually partly replaced by Na and K.

Monoclinic:- Crystals prismatic, sometimes very large, as much as 40 feet long and weighing up to 37 tons, also massive. At the Etta mine, South Dakota.

Cleavage :- m(110) perfect. Lamellar structure parallel to a sometimes prominent.

Fracture:- uneven to subchonchoidal, Brittle.

Lustre :- vitreous, somewhat pearly on cleavage surfaces.

Color :- greenish white, grayish white, yellowish green, emerald green, yellow, purplish. Streak white.

Transparent to translucent.

Hardness 6.5-7. S. G. 3.13 & 3.20.

Biaxial positive, α 1.660, β 1.666, γ 1.676 (Larsen)

2V=58°± Pleochroism strong in colored varieties.

PYROGNOSTICS, ETC. B. B. becomes white and opaque: swells and fuses at 3.5 to a clear or white glass. Insoluble in acids.

OCCURRENCE:- in lithium pegmatites often with lepidolite, amblygonite, lithium tourmaline, etc.

Localities:- Sweden, Madagascar, New England States, South Dakota, South east Manitoba.

VARIETIES:- Hiddenite: Clear, transparent, yellow green to emerald green, pleochroic, used as a gem. Occurs in N. Carolina.

Kunzite : clear transparent, pink to lilac, ~~and~~ used as a gem. Occurs in California and Madagascar.

FREMONTITE- Sodium amblygonite- a fluo-phosphate of aluminium and sodium with some lithium replacing sodium. Li_2O 3.2 per cent.

Monoclinic, usually in cleavable masses.

Cleavage: c and a distinct.

Lustre- vitreous to greasy.

Color- grayish to white.

Translucent to opaque.

H= 5.5. S. G. = 3.04.

Biaxial positive, α 1.594, β 1.603, γ 1.615, 2V very large. Polysynthetic twinning.

PYROGNOSTICS:- Easily fusible with slight intumescence to an opaque white enamel. In closed tube yields water.

OCCURRENCE- In a pegmatite dike with lepidolite in Fremont Co., Colorado.

DURANGITE - Fluo-arsenate of sodium and aluminium.

As_2O_5 55.3, Al_2O_3 24.5, Na_2O 14.9, F 9.2= 103.9, deduct O=2F=3.9.

Contains 0.65-0.81 Li_2O.

Monoclinic- in crystals.

Cleavage- m distinct.

Fracture- uneven, brittle.

Lustre- vitreous.

Color- orange-red, streak cream-yellow. Translucent.

Hardness 5. S. G. 3.94 - 4.07.

Biaxial negative, α1.634, β 1.673, γ 1.685. 2V= =45°. Pleochroic.

PYROGNOSTICS- ~~[illegible]~~ Fuses at 2 giving an intense soda flame. In the closed tube blackens at a moderate temperature but regains its color on cooling. At a higher heat fuses easily to a yellow glass and gives a faint white volatile sublimate. Decomposed by sulfuric acid.

OCCURRENCE- in a tin-bearing vein ninety miles north east of the city of Durango, Mexico. Also sparingly near Lake Ramsay, New Ross, Nova Scotia, in a lithium pegmatite dike with amblygonite, cassiterite, etc.

Lithium also sometimes occurs in appreciable amounts in:

Beryl, variety alkali beryl

Tourmaline, variety alkali tourmaline

Leucite

Muscovite

Biotite

Orthoclase

Microcline, especially amazon stone

Psilomelane.

BERYLLIUM

Beryllium is one of the lightest metallic elements, being related to magnesium and aluminium. Its atomic weight is 9.02, atomic number 4 and it has no isotopes.

The properties of metallic beryllium have been somewhat differently described by different investigators, owing probably to the difficulty of obtaining the metal absolutely free from small amounts of impurities which doubtless considerably affect the physical properties. According to the latest researches it is a steel gray metal with bright metallic lustre and hardness between 6 and 7 on Moh's scale, so that it scratches glass. It is brittle at ordinary temperature but on heating becomes ductile and can be hammered, forged, rolled and polished, taking a fine polish like that of high grade steel. It is one of the lightest metals. Various values from 1.64 to 1.84 have been obtained for the specific gravity/ of samples prepared by different methods. The metal obtained by electrolysis of a fused mixture of sodium beryllium fluoride and beryllium barium fluoride has S. G. 1.84. It has thus about the same weight as magnesium (S. G. 1.7) and only two thirds that of aluminium (S. G. 2.7). Its melting point is 1285°C while that of magnesium is 651°C. and of aluminium 658°C. When heated to redness in the air it oxidizes on the surface, the oxide thus formed acting as a protective coating. ~~It is said to be four times as elastic as aluminium and twenty five per cent more elastic than steel.~~ It is not affected by air or water at ordinary temperature and is said to be very resistant to corrosive gases and liquids and to impart this resistance to corrosion to its alloys. The metal dissolves in dilute hydrochloric and sulfuric acids with evolution of hydrogen but nitric acid attacks it only slowly at the boiling temperature. It alloys with aluminium, magnesium, iron, nickel, chromium, molybdenum, tungsten copper, silver, tin, etc. and forms compounds with carbon and boron. It has been stated that beryllium is a better conductor of electricity than copper and silver. Others say that the electrical conductivity is rather low, which seems more probable.

PREPARATION:- Beryllium metal has been produced on a laboratory scale by various methods involving the reduction of anhydrous beryllium salts such as the chloride, fluoride and sodium or potassium beryllium fluoride by heating with metals such as sodium or potassium. By these methods the metal is obtained as a dark gray powder or minute hexagonal plates more or less contaminated by the reagents used. It has also been claimed that the oxide BeO can be reduced by ignition with magnesium or aluminium metal and while this is doubtless true, others state that the intense heat of the reaction volatilizes most or all of the beryllium metal. The metal cannot be produced by reduction of the oxide with carbon as beryllium carbide is formed. Methods based on the electrolysis of an aqueous solution of beryllium salts have been tried without success.

In researches having in view the commercial production of beryllium, however, electrolytic processes have apparently been used exclusively . Such processes are similar to that used in the production of aluminium, ie- electrolysis of a fused salt mixture in which a beryllium compound is dissolved. The pure fused beryllium halides are almost non-conductors of electricity so that they cannot be successfully used alone as electrolyte. For this reason they must either be mixed with other salts such as sodium fluoride which conduct the current or double salts such as sodium beryllium fluoride and barium beryllium fluoride must be used. In recent years much research has been done on such methods in Britain, United States and Germany. In the latter country the method using fused sodium beryllium fluoride mixed with barium beryllium fluoride as electrolyte was developed and is claimed to be the first and only method successful in producing solid masses of beryllium metal directly from the electrolyte. The method is described in detail by Kurt Illig (x) of the Research Laboratories, Siemens-Halske, A.G., Berlin, Germany, as follows :-

"Gratzel was the first to attempt to isolate beryllium by the electrolysis of fused electrolytes, which methods attracted wide attention towards the end of the last century, His methods proved to be as fruitless as those of Warren and of Borchers.

During the years 1898 to 1899,

(x) Can. Chem. & Met., November, 1928.

Lebeau obtained metallic beryllium by very painstaking experimentation. The electrolyte he used was fused sodium fluoride plus beryllium fluoride; the former fuses at a relatively low temperature, and in it the latter seems to be slightly dissociated.

The melting point of beryllium metal is 1,285 deg. C., well above the temperature of the bath; consequently only exceedingly small particles of metal were found dispersed through the mass of material at the cathode. Lebeau used a nickel crucible as the cathode, with a rather large surface, and a graphite rod as the anode. The large cathode surface led to rapid cooling, which assisted in crystallizing the metal within the surrounding matrix.

As will be shown later,this never favors the formation of compact masses of beryllium. In order to obtain beryllium metal in masses sufficiently large to make possible a superficial examination of its properties, Fichter, in 1913, used an indirect method of attack. He carefully separated the crystals of beryllium metal from the surrounding matrix, pressed them together in a small cylindrical mold and melted the mass in an atmosphere of hydrogen. He obtained a regulus of metal weighing about 1 gram, which he kindly put at the disposal ofOsterheld, who determined the melting point as being 1,278 deg.C., within an error of 5 deg.C.

The work which was decisive in the development ofberyllium manufacture was accomplished by the German investigators, Stock and Goldschmidt, with the co-operation of Preiss and Praetorius. They obtained metallic beryllium for the first time in the form of large regali, directly from a fused electrolyte. As mentioned before the earlier method failed because at the instant the metal was formed it was at once reoxidized or vaporized. The salt previously used as electrolyte was evaporated before the real reduction was started, or the viscosity of the fused salt was too high, or finally, the affinity between the anion and carion was too great to allow of a separation under the then existing conditions.

Accordingly, before starting their experiments Stock and Goldschmidt made an effort to find a method by which all of the above limiting conditions would be eliminated. They felt that the electrolytic separation of beryllium (melting at 1,285 deg. C.) from a fused salt mixture could only be possible if a salt be used, which at this temperature either did not evaporate at all, or at least did so only slightly. On the other hand, to avoid an unusually high potential drop between the electrodes, the salt must also possess at this temperature a very low viscosity; and furthermore the anions must be easily separated or removed from the electrolyte. It is only in this manner that the separated metal might be prevented from remaining in or being redistributed in the surrounding fused salt mass.

Investigations have shown that these conditions are fulfilled in general by the double fluorides of beryllium with sodium and barium. The barium-beryllium fluoride has an appreciable viscosity around 1,300 deg.C., but also has the advantage of being only slightly volatile at this temperature range; it has an appreciable dissociation within this range. The sodium-beryllium fluoride is strongly dissociated even at relatively low temperatures. This, therefore, offers a means of obtaining an electrolyte possessing a good conductivity. It has only one disadvantage, namely, that at very high temperatures the separated beryllium metal may be volatilized in appreciable quantities.

If the electrolysis is started with the sodium-beryllium fluoride and with rising temperatures some barium-beryllium fluoride is added in increasing amounts, there is obtained a useful mixture of the double salts for every temperature interval. When the final metal separating temperature of 1,300-1,350 deg.C. is reached, it is not difficult to continue the electrolysis for many hours, provided suitable additions of both double salts are made from time to time.

Stock and Goldschmidt protected this general method of procedure by letters patent in all large countries. They realized however, that much additional work was necessary, before all of the details for the continuous production of large quantities of beryllium would be established. In order to study the problems on thebroadest basis, the foremost German manufacturers organized a "Beryllium Research Institute" in 1923, under the chairmanship of the Siemens and Halske A. G., of Berlin. It was the aim of this institute to make a systematic study of the fundamental Stock-Goldschmidt method in all its details to determine whether or not it was possible to produce beryllium metal in commercial quantities from fused electrolytes. The numerous variables which had to be considered made the work tedious, especially so since the temperature range of 1,300-1,350 deg. C. had never been used previously in fused electrolytic work. Some of the details of these investigations of the institute to date are herewith recorded:

The question of crucible and of electrode materials had to be settled first. In the early experiments of Stock and Goldschmidt, a crucible made of graphite was used as the anode. Graphite containing as little iron as possible is the only material to use. Acheson graphite is the best. The difficulties encountered in mounting the electrodes of the crucible were soon overcome. Various metals were tried as cathode; the most satisfactory was a special iron, made up into a hollow water cooled electrode.

The electrolyzing current is sufficient to maintain the bath at the temperature required. At the start of the process the crucible is filled with pieces of carbon or graphite, iron carbide is pressed firmly against these pieces, and as soon as the proper temperature is reached the pieces are quickly dumped out of the crucible and a charge of low melting sodium-beryllium fluoride is immediately put in. Then barium-beryllium fluoride is added until the required temperature range is reached for the electrolysis to begin.

Only after a large number of experiments were made, was the best method for charging the crucible discovered, which method must be rigidly adhered to. Naturally there will be a relatively large burning loss of the graphite crucible, which, however, may be minimized by surrounding the crucible with another crucible packed with Kryptol, to prevent contact between the very hot external wall of the graphite crucible and the air. Another method is to coat the external wall of the graphite crucible with a fused mass of the electrolyte, making an impervious coating, which is in no way objectionable since no impurities will be introduced into the electrolyte.

At first, relatively small reguli, of several grams only, could be separated from a single charge, and it was an exciting moment when several reguli of about 20 grams each were obtained. These reguli were still contaminated with the melt, so were not fit for a scientific or technical investigation. Systematic and progressive development made it possible to obtain a single button of about 50 grams in weight, and at the same time containing only spots of very small amounts of impurities

It was this material that the several laboratories connected with the Beryllium Institute, as well as others not so connected, investigated. They determined the physical properties of beryllium metal.

Hand in hand with the scientific incestigations on fused electrolytes went the determination of authentic methods of analysis. The previous methods recorded inthe literature were either too incomplete or entirely too circumstantial to be of undisputed value for rapid work. Hellmuth and Fischer[1.] stated these analytical investigations, and most of these have been published. Very good methods are now available for the rapid determination of beryllium in the presence of aluminum and other metals.

In 1926 the Institute felt convinced that in the Stock-Goldschmidt method there was a means by which a commercial production of beryllium metal might be expected. At the same time the commercial applications of this metal were studied.

On the grounds of the results of the investigations of the Institute during 1926, the Siemens-Halske A. G. decided to make a systematic study of the applications to a commercial scale. The previous work had shown that the best scientific and technical production of beryllium would be possible only if the salts used were cheaply prepared; especially if they

[1.] Wissenschaft Veroffent. Siemens-Konzern, 5, part 2, 99 (1926); Zeitsch. anal. Chem., 73, 54 (1928).

were not hygroscopic, such as the double fluorides. The preparing of the salt from the crude mineral beryl was next investigated, Both of these problems were solved in the past two years. Simply and cheaply prepared salts, such as the double fluorides, which also give good material yields, are being investigated now.

In the older methods the electrolyte became more and more enriched in barium fluoride, thus shortening the time of a single charge, but with the advent of the new salts it is now possible to make the process continuous and without interruption. Practically speaking, this continuous method is now limited only by the burning of the graphite crucible.

The fluoride which is liberated attacks the anode, forming carbon oxyfluoride; this by interaction with oxygen forms carbon monoxide in considerable amounts. It is hoped that by purely mechanical means a continuous method may be developed, such as is used for feeding electrodes into large ovens, so that the crucible question will no longer influence the duration of the electrolysis. Letters patent for the use of the new salts have been applied for in all the large countries, but since the patents have not yet been granted, details cannot be given here.

Special note should be made of the valuable sublimation products, which are inevitably formed during the electrolysis, and which come out of the crucible, and are recovered, reprecipitated and reused. At the same time the poisonous gases, fluorine and CO, are drawn off. With the salts used to-day it is possible to get a material yield of about 95 per cent and a current yield of about 80 per cent.

The beryllium metal is in convenient reguli of about 150 grams.

varying with the size of the apparatus, and is about 98 per cent. pure. By special methods of remelting the purity can be increased to 99.9 per cent., though the yields of this very pure material are small. The main impurity of our beryllium is iron, which is introduced from the graphite crucible.

The recently developed double decomposition methods of the raw beryl for the formayion of the electrolyte salts, produce about 65 per cent. of beryllium, calculated as metal, so, that starting from the mineral the final yield of beryllium metal is about 60 per cent.

Illig(loc cit) states that "the raw beryl contains in all about 3 to 3.5 per( ) cent of beryllium, from which about 60 per cent can be actually recovered. Therefore, ~~x5000~~ 500 kg. of mineral will be required to produce one kg. of metal. However, as is often the case, the mineral costs $150 to $200 per metric ton, which makes one kg. of beryllium metal content cost $75 to $100.

The lowest bids for large amounts of mineral have been between $60 and $70 per ton, making the metal content cost $30 to $35 per kg. on the basis of the raw material. About 97 per cent. of the ore must be removed by various methods in order to prepare the salts required for the electrolyte. It may be noted that the electrolyzing costs are only one-third of the total cost of the beryllium metal produced, and that the present market price of the metal is almost entirely independent of the operating costs."

( ) The theoretically pure mineral contains 5 per cent beryllium.

"In about six months we will produce about 10 kg. of beryllium metal monthly, at a price of about $85.00 per kilogram. Buildings are in the process of construction to increase the output threefold, so it may be be concluded that far-reaching investigations both with alloys and with pure beryllium metal will be extensively made in the near future. In one or two years from now an estimate might be made of the size of the world market for beryllium metal, but not now."

UTILIZATION:- Beryllium has not yet been produced at low enough cost to permit its commercial use in any important quantity but much research has recently been directed toward more economical production of the metal and it is quite possible that eventually it may be produced at a cost to at least permit its use in alloys. There is no doubt that the metal possesses very valuable properties, viz. lightness, strength, hardness and resistance to heat and corrosion, which properties it also transmits to its alloys ~~of~~ in greater or less degree. Pure beryllium metal has found a limited use as a window for the rays in X-ray tubes. It is seventeen times as penetrable by X-rays as aluminum of the same thickness(Kurt Illig- Zeit. Angew. Chem, 40, 1160, 1927). It has been supposed that beryllium would prove to be particularly valuable in making light alloys with aluminium, magnesium, calcium and lithium, but apparently the recent investigations in this field have not been so encouraging as was hoped. Kurt Illig(loc. cit. Chem. and Met.) writes of the beryllium alloys as follows:

33-17

The most promising field which has so far been recorded in the literature is in the use of beryllium as a light metal. But the first studies of the metallographic division of Siemens-Halske have indicated that such a use is rather remote at present. Pure beryllium is an extremely hard and brittle metal, which scratches glass and can neither be rolled nor drawn because of its coarse crystal structure. Nevertheless plates of about 1 to 2 mm. by 10 to 20 mm. have been made from pure beryllium by special methods for use in X-ray work. But this is no application for which large amounts of metal need be produced.

Since beryllium has a specific gravity of 1.8 it has been considered advisable to try to alloy it with sufficient aluminum to make it workable. In this respect many interesting results may certainly be expected. It was not in the program of Siemens-Halske to make a systematic investigation in this direction, because the realization of our ambition to apply beryllium to arts and industry seemed only possible if beryllium alloys were developed which would compete with other alloys.

Americans have made valuable contributions to the study of beryllium-aluminum-lithium alloys, indicating that beryllium must not cost more than $20 per kilogram to make alloys of economic value. But this low figure is still of the distant future. Whereas the first grams of beryllium metal made by us cost $50 each, the price was soon reduced to $1.50 per gram in lots of 100 to 120 grams per day.

As soon as our proposed factory will produce 1 ton of beryllium per year, the price will be $75 to $90 per kilogram, and when the sale of this metal increases to 100 metric tons a year it may be found possible to sell it for $25 to $30 per kg. And if the cost of the raw beryl takes an unexpected drop or the methods of operation are considerably cheapened the metal will be still cheaper. In order to determine whether a large yearly production of beryllium at theeabove named price could be sold, the preliminary work of G. Massing and O.Dahl[2] on the promising alloys of beryllium with the heavy metals was extended in the laboratories of Siemens-Halske.

It had been shown that the addition of 2 to 2.5 percent. of beryllium to copper or nicel produced alloys possessing properties like those of the bronzes, a fact previously unknown. In the case of additions of beryllium to aluminum the alloy showed properties somewhat like those of duralumin

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2. Z.f. Metalkunde, 20 (1), 1924 (1928).

and silumin, though there is no advantage in favor of the beryllium-aluminum alloy. The more expensive beryllium cannot compete with silicon magnesium, and copper in making alloys with aluminum. The results of this work as well as of those of Kroll on beryllium-aluminum alloys work showed that there is a great affinity between the metals beryllium and aluminum.

Some important data on beryllium-copper and beryllium-nickel alloys might be noted. Alloys of cobalt with beryllium are very similar, but the silver-beryllium alloys have interesting properties which could not have been determined previously. In the study of beryllium-iron alloys the work has not progressed far enough to permit definite conclusions.

The most outstanding property of the beryllium alloys is in their improvement upon heat treatment. A copper-beryllium alloy containing 2.39 per cent. of beryllium, after ordinary quenching, has a Brinell hardness of 100 kg./sq. mm., but after heat treatment for 17 hours at 300°C. this rises to 440 kg./sq. mm., that is, to over 400 per cent. Some copper alloys containing over 6 per cent beryllium have a hardness of over 730 Brinell numbers. These alloys cannot be worked in the untreated condition. Bronze-like properties are developed in these copper alloys, which, in the untreated condition, can be rolled, drawn or worked to the desired shape and then by heat treatment can be hardened and roughened. It is possible to make thin elastic pieces. The following information on the strength of these alloys may be of interest.

In the untreated quenched state a copper alloy containing 2.5 per cent, of beryllium has a tensile strength of 48.9 keg./sq. mm., but after heat treatment it is 135 kg./sq. mm. The differences in the transverse bending strength are most astonishing; in the untreated condition, but quenched, it is 60.7 kg./sq. mm., but after heat treatment it rises to 216.7 kg./sq. mm. In the same alloys the yield point changes from 15.7 to 128 kg./sq. mm. on heat treatment, while the elastic limit in the first case is 5 kg./sq. mm., and in the second it is 45.9 kg./sq. mm.

As the beryllium content of these copper alloys is increased the final values for these mechanical properties in the treated condition are also increased. There is, however, a limit which is 6 to 7 per cent. Be in copper and nickel alloys. In general it may be said that the quenched alloys are very elastic and strong.

Heat treatment increases the elastic limit, and the yield point by about 800 per cent., while the tensile strength and the transverse bending strength increase about 3 to 4 fold. The ductility decreases proportionally with strength. This is not detrimental, since the shaping and working after quenching is done before it is given the heat treatment so that ductility requirements need not be considered after treatment. These alloys may be successfully rolled drawn, and pressed.

It is worth noting that the electrical conductivity of these alloys is lowered rather appreciably by the addition of beryllium. Alloys of 2.5 per cent. of beryllium, after quenching at 800°C., have an electric conductivity of 9.8recip. ohms/sq. mm. of cross section. Heat treatment changes this conductivity to 19 recip. ohms/sq. mm., and after annealing followed by a second hardening it reaches 21.5 recip. ohms/sq. mm. These alloys are more resistant to corrosion than the ordinary bronzes.

Beryllium has an interesting application as a deoxidizer in copper casting. It has been shown that the addition of 0.02 to 0.05 per cent. of beryllium to copper for casting changes the electrical conductivity of the casting from ~~fr~~ 35 to 50 recip. ohms/sq.mm. The various alloys and their applications have been protected by letter patent."

Beryllium nitrate is sometimes added in small amounts to the thorium nitrate solution used for impregnating incandescent gas mantles, to give strength to the oxide skeleton.

Beryllium oxide has been proposed as a refractory for crucibles as it melts at 2450°C. and is resistant to corrosion. It has also been proposed as an abrasive and for use in dental products and paint bases.

Investigations by the U. S. Bureau of Standards have shown that when beryl is substituted for felspar in the manufacture of porcelain in amounts varying from 25 to 45 per cent of the total mixtures, a product is obtained which possesses very high electrical resistance and low thermal expansion and which would therefore be very suitable for electrical uses.

Beryllium salts are used to a limited extent in pharmaceutical preparations and in organic syntheses.

Transparent beryl is utilized as a gem stone and the well coloured green and blue varieties, emerald and aquamarine, may be very valuable, when free from flaws. Yellow, pink, and colorless transparent beryls also occur and are used as gems but are much less valuable than good emeralds.

33-22

OCCURRENCE

Beryllium has been estimated to make up 0.001 per cent of the igneous rocks of the earth's crust. It is associated with granitic and aluminous rocks. However, it is perhaps more abundant in traces than is commonly supposed, as it is difficult to identify by chemical methods when present in minute amounts and is seldom determined in rock analyses, being weighed, if present, with the alumina. Recently, improved methods have been proposed for its detection. Beryllium has been detected in the spectrum of the sun and traces occur in some mineral waters. Beryllium occurs in a large number of pegmatite~~s~~ minerals of which the only one sufficiently common to be used as an ore is beryl,- beryllium aluminium silicate with theoretically 14 per cent BeO or 5 per cent Be. The fact that this mineral contains so little beryllium and the cost of extracting, separating and reducing the beryllium will probably always prevent the metal from being produced at a moderate price.

PRODUCTION

The U. S. Geological Survey estimates that the annual production of beryl in the United States while not accurately known probably does not exceed ten tons, this production being incidental to the mining of felspar or mica. No other figures are available.

PRICES

Recent offers for beryl have been at the rate of 4 to 5 cents per pound. Unless exceptionally rich deposits are discovered, this price will not likely be sufficient to induce anyone to mine for beryl alone and it will probably continue to be available only as a by-product~~s~~ of other mining operations.

Those interested in the production of beryllium metal naturally wish to obtain their raw beryl at the lowest possible price, since the beryl only contains 3 to 5 percent of beryllium metal and, the cost of the ore thus amounts to one dollar or more per pound of metal with beryl at 4 cents per pound. On the other hand it is doubtful [illegible] if even a price of 4 cents per pound will be sufficient inducement to the mining industry of Canada or United States to provide a supply of beryl adequate for the commercial production of beryllium in important quantity.

Remarkable deposits of beryl have recently been reported to occur in Namaqualand, Africa. These reports, if true, would indicate that probably beryl could be produced there in large quantities at low cost, and that this region may possibly provide the large supply of cheap beryl which the producers of metallic beryllium so much desire. (See under beryl).

BERYL- Beryllium- aluminium silicate. $3BeO.Al_2O_3.6SiO_2$ with sometime alkalis(Na_2O,Li_2OCs_2O) replacing beryllium to the extent of as much as 6 per cent. Analyses: BeO 11.3-14, Al_2O_3 17-19.6, SiO_2 62.4-67.8, Fe_2O_3 tr-2.2, CaO tr-0.9, Na_2O up to 1.8, Li_2O tr-1.17, Cs_2O tr-2.92, H_2O up to 2.7.

Form- Hexagonal- commonly in lonf. well-~~formm~~ formed prismatic crystals which may reach a weight of two tons or more.

Cleavage- c- imperfect and indistinct.

Fracture- Conchoidal to uneven. Brittle.

Lustre- vitreous, sometimes resinous.

Color- emerald-green pale green, light blue, yellow, rose, white to colorless, subtranslucent to transparent.

Streak- White

Hardness- 7.5-8. G 2.63-2.8, usually 2.69 to 2.70.

Pyrognostics, etc.- B.B. unchanged, or if clear becomes milky white. At high temperature fuses on edges. Fusibility less for alkali varieties. Insoluble in acids.

Optical Properties- Uniaxial negative- E- 1.564, W-1.568 for Na_2O=0.43 - E- 1.590, W-1.598 for mineral high in alkalis (Larsen). Somewhat pleochroic.

Varieties- Emerald- green, transparent. A very valuable gemstone when well coloured and free from flaws.

Aquamarine- bluish, transparent.

Morganite - pink or rose, transparent.

~~Helidorx~~Heliodor- yellow or golden, transparent.

Goshenite- Colourless, transparent.

The transparent coloured varieties of beryl other than emerald rank as semi-precious ~~xxxxx~~ gems when of suitable quality.

Alkali beryl- These are usually colorless or but faintly colored. The specific gravity is higher and fusibility greater than for the ordinary type. The alkali content may be as much as as: Na_2O 1.82, Li_2O 1.17, Cs_2O 2.92 (Caesium beryl from Hebron, Maine).

OCCURRENCE- Chiefly in granite pegmatites particularly in those containing albite and lithium minerals. Occasionally in schists, gneisses or limestone which have been intruded by granite or pegmatite, sometimes as microscopic crystals in granites. Beryl is widely distributed in pegmatites throughout the world. It is of common occurrence in the pegmatites of the New England States and many large crystals weighing up to 2-1/2 tons have been found. Also in important amounts in North Carolina and the Black Hills region of South Dakota. All varieties of beryl other than emerald occur almost exclusively in granite pegmatites. The best emeralds occur near Muzo, Columbia, in a limestone which has been acted on by ~~xxxxxxxxx~~ intrusions of pegmatites. They are also found in mica schists in the Urals and in the Tyrol. Some emeralds have been found in North Carolina. Aquamarine and other gem varieties of beryl are found on the Island of Elba, in Madagascar, in the Mourne Mountains of Ireland, the Ural Mountains, Maine, Connecticut, North Carolina, Colorado, California, Brazil, ~~and~~ Ceylon. and Africa.

In Canada- Beryl occurs in small quantities in a large number of pegmatites. In only one dike (lot 23, conc. XV, Lyndoch Tp., Renfrew county, Ontario) was it fairly abundant. A few years ago perhaps 3 or 4 tons of beryl were obtained from this pegmatite. Some faintly coloured bluish or greenish transparent fragments were obtained from the interior of crystals , which would have been suitable for gems if better coloured.

The discovery of remarkably rich deposits ~~og~~ of beryl in Namaqualand, S. Africa has recently been reported ( ) as follows:-

"Namaqualand, the home of the world's richest diamond deposits, is now known to contain the most remarkable occurrence of beryl ever discovered. About five years ago, Mr. A. Sleight, a prospector, while prospecting for mica at Jackhaal's Water, some 15 miles north of Steinkopp, found a very large beryl crystal. He retained a sample of the beryl and it remained among his effects until a few months ago. About the middle of February last, Mr. Sleight hear enquiries being made for beryllium ore and forwarded a sample to Mr. Ernest Sheppard of Johannesburg. The sample was analyzed and yielded 12 per cent of beryllium. A syndicate was formed in Johannesburg and prospecting work was started in the pegmatite where the crystal was found. From an excavation measuring 5 X 5 X 5 feet over ten tons of beryl were recovered in the course of a few days. Later assays indicate that this beryl carries over 15 per cent of beryllium which is priced at 12 10s. per lb. Towards the end of May an enormous "crystal" was excavated. Its dimensions were 5 feet by 8 ft. 6 inches and its weight is estimated at 16 tons. It is stated by interested parties

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( ) Mining Magazine, August, 1929, p. 95.

that wherever beryl has been discovered and a quantity excavated, the bottom of the excavation is seen to contain a strong continuance of the mineral. In one case, at least, large lumps of the blue variety, aquamarine, have been dug up, and there is the ~~possibilities~~ possibility of finding crystals of this latter variety of good quality, that is, semi-precious gems. There are indications of beryl on more than one line of pegmatites over a large area, and where these have been examined the mineral has been found not in ounces but in tons.

The beryl-emerald occurrence in the Murchison Range in Northern Transvaal, is said to have been traced for about 30 miles, but the mineral is found there in much smaller quantities than in Namaqualand. The material carrying the beryl crystals in the Murchison Range is a mica-schist of dark colour, composed chiefly of two varieties of mica- biotite and fuchsite. The main occurrence is a lenticular mass, approximately 500 ft. long by 200 ft. wide. The cleavage of the mica-schist is diagonally across the deposit, and there is considerably differentiation of the material in alternating zones running parallel to the lines of the cleavage. In a number of these zones of differentiation the mica flakes are of much larger size. Judging from the much greater abundance and larger size of the weathered and bleached crystals, occurring thickly in the larger-flake mica zones, the conditions prevailing in them seem to have been especially favourable to the crystallization of the beryl-emerald constituents."

Other minerals containing beryllium, but not found in sufficient quantities to be useful as a source of the metal, are:

Chrysoberyl:- Beryllium aluminate, $BeO.Al_2O_3$. Al_2O_3 80.2, BeO 19.8= 100.

Form- Orthorhombic- Crystals generally taken tabular || a. Often twinned. Both contact and penetration twins, often repeated forming pseudohexagonal crystals with or without re-entrant angles. Face a striated.

Cleavage- (011) distinct, (010) imperfect.

Fracture- Uneven to conchoidal. Brittle.

Lustre- Vitreous, silky in cymophane.

Color- Various shades of green, yellowish green, brown, yellow, greenish white. Sometimes red by transmitted light. Transparent to translucent.

Hardness- 8.5 S.G. 3.5- 3.84.

Optical Properties- Biaxial positive, α 1.747, β 1.748. γ 1.757. $2V=45^{\circ}$. Pleochroic.

PYROGNOSTICS, Etc.- Insoluble, infusible.

VARIETIES:-

Chrysolite- A name sometimes applied to the yellowish green gem variety of chrysoberyl, but more properly the name should be confined to olivine.

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Cat's Eye or cymophane- is a greenish, iridescent variety with a silkylustre, used as a gem.

Alexandrite- First discovered in the Ural mountains and named in honour of Czar Alexander II of Russia. A striking gemstone. By daylight it is emerald green, in artificial light columbine red. Strongly pleochroic, showing emerald green, columbine red and orange yellow.

OCCURRENCE- In pegmatites, granites, mica schists and gneiss. In alluvial deposits.

LOCALITIES- Brazil, the Urals, Ceylon, Tasmania, China, Connecticut, New York, Maine. In Canada, L 3 Conc. XVIII Raglan Tp Ont. Maskinonge Co, Quebec.

Trimerite- Silicate of beryllium, manganese and calcium.

Analysis $(MnCa)O.BeO.SiO_2$. SiO_2 39.77, BeO 17.08, MnO 26.86, FeO 3,87, CaO 12.44, MgO 0.61=100.63. (Wermland, Sweden).

Triclinic- pseudo-hexagonal. In thick tabular crystals hexagonal in form and angle.

Cleavage- basal, distinct,

Fracture- conchoidal, brittle.

Lustre- vitreous, brilliant.

Color- Salmon pink to nearly colourless.

Transparent to translucent.

Hardness 6.7, G. 3.47.

Biaxial negative α1.715, β 1.720, γ 1.725, 2V=83°. Basal section shows three radial segments.

PYROGNOSTICS, ETC.- Difficultly fusible to a black slag. Decomposed by strong acids with separation of flocculent silica.

OCCURRENCE- Minute crystals embedded in calcite, Wermland, Sweden, Rare.

Phenacite:- Beryllium silicate 2BeO.SiO_2. BeO 45.55, SiO_2 54.45=100.

Rhombohedral-Crystals commonly rhombohedral in habit, often lenticular, also prismatic. Penetration twins.

Cleavage- a distinct, r imperfect.

Fracture- Conchoidal, brittle.

Lustre- vitreous.

Color- Colorless, wine yellow, pale rose-red, brown.

Transparent to subtranslucent.

Hardness 7.5-8, G. 2.97-3.00.

Uniaxial positive E 1.670, W 1.654. Faintly pleochroic.

PYROGNOSTICS, ETC. B. B. remains unattacked. Insoluble in acids.

OCCURRENCES- In pegmatites with other Be minerals. In mica-schists with emerald.

LOCALITIES:- Ural Mountains, Brazil, Mexico, Maine and Colorado. In Canada with beryl, fluorite and molybdenite in pegmatite on the Height of Land Mining Company's claims on the Kewagama river, Timiskaming county, Quebec.

Leucophanite:- Fluosilicate of calcium, beryllium and sodium. BeO. CaO.2SiO_2.NaF. BeO 10.3, CaO 23.0, Na_2O 12.8, F 7‸9=103.4 deduct 3.4 (O=2F)=100.

Orthorhombic- Usually in tabular crystals often twinned. Penetration twins. Massive.

Cleavage- ~~b~~ c perfect, a O(201) distinct.

Fracture- conchoidal, very brittle.

Lustre- vitreous.

Color- whitish green, deep green, wine yellow, Transparent- colorless in thin fragments.

Hardness- 4, G. 2.96.

Biaxial negative, α 1.571, β 1.595, γ 1.598, 2V=39°.

Pyroelectric. Strongly phosphorescent with a bluish light when heated or struck.

PYROGNOSTICS, ETC.- B. B. phosphoresces and fuses with intumescence at 3 to a clear colorless glass. Insoluble in acids.

OCCURRENCE- In pegmatite with elaeolite, aegirite, mosanderite, at Langesund fiord in Norway.

Bromellite- Beryllium oxide BeO. Analysis: BeO 98.02, CaO 1.03, BaO 0.55, MgO 0.07, MnO tr, Sb_2O_5 0.29, Al_2O_3 0.14, ign. 0.85.

Chief Rare Element- BeO 98 per cent.

Form- Hexagonal, dihexagonal pyramidal class. Combination of prism and base, rarely with pyramid. Crystals pyroelectric.

Cleavage- Prismatic, distinct.

Color- White.

Hardness- 9 S. G. 3.017

Pyrognostics- Insoluble in acids, not attacked by alkali carbonate. Soluble by fusion in acid potassium sulfate.

Optical ~~Properties~~ Properties- Uniaxial positive ε = 1.733, ω = 1.719.

Associations, Localities- Occurs at Långban, Sweden associated Swedenborgite.

References- Zeits. Krist. 1925, 62, p. 113.

Am. Min. XI, p. 135.

Min. Mag. March, 1926, p. 5.

Bertrandite- beryllium silicate, $4BeO.2SiO_2.H_2O$. BeO 42.1, SiO_2 50.3, H_2O 7.6 =100.

Orthorhombic- Crystals often tabular $\|$ c. Heart-shaped twins, often hemimorphic.

Cleavage- m- perfect, also b and c.

Lustre- vitreous, pearly on c.

Colorless to slightly yellow.

Transparent.

Hardness 6-7. G. 2.6.

Biaxial negative α 1.591, β 1.605, γ 1.614, $2V=75^\circ$

PYROGNOSTICS, ETC.- Pyroelectric, B. B. infusible but becomes opaque. Insoluble in acids.

OCCURRENCE- Occurs implanted on quartz or felspar in cavities of pegmatite at Nantes, France. Also in pegmatites with beryl in Bohemia, Colorado, Maine and Virginia.

Bityite- Hydrous silicate of aluminium, calcium with BeO and Li_2O. $7(H_2\ Li_2\ Ca\ Be)O.\ 4Al_2O_3.5SiO_2$.

SiO_2 31.95, Al_2O_3 41.75, CaO 14.30, BeO 2.27, MgO 0.13, Li_2O 2.73, Na_2O 0.40, K_2O 0.16, H_2O 6.50, =100.19.

Pseudo-hexagonal- Occurs as minute hexagonal plates which in polarized light show division into six sectors and these show polysynthetic twinning. Crystals often in parallel growths with basal planes in common.

Cleavage-basal.

Lustre- Slightly pearly on base.

Color- Yellowish to white.

Hardness 5.5, G. 3.05.

Biaxial negative, $\alpha < 1.6$, β 1.63, $\gamma > 1.64$.

PYROGNOSTICS, ETC. Fusible, Insoluble in HCl.

OCCURRENCE - As crusts of minute crystals coating tourmaline, quartz, etc. in pegmatite at Mt. Bity, Maharitra, Madagascar.

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Meliphanite- Flucsilicate of beryllium, calcium and sodium near leucophanite. $2CaO.2BeO.3SiO_2.NaF$. CaO 29.1, BeO 13.1, Na_2O 8.1, SiO_2 46.9, F 5.0= 102.2, deduct 2.2(O=F).

Tetragonal- In obtuse octahedrons. Also massive, consisting sometimes of plates or lamellae.

Cleavage- c distinct, brittle.

Lustre- vitreous.

Color- Sulphur to honey yellow, flesh to brick red.

Transparent to translucent.

Hardness 5-5.5, G. 3.0.

Uniaxial negative, E 1.593, W 1.612. Anomalously biaxial negative. α1.593, β 1.613, γ 1.613. 2V small. Pleochroic.

PYROGNOSTICS, ETC- (B.B.) Fuses with intumescence to a white enamel, without phosphorescence. Insoluble in HCl.

OCCURRENCE - in pegmatites with elaeolite, aegirite, mosanderite, at Landesund fiord in Norway.

<u>Euclase</u> - Hydrous aluminium, beryllium/ silicate. SiO_2 41.3, Al_2O_3 35.2, BeO 17.3, H_2O 6.2=100.

Monoclinic- Only in crystals, habit prismatic with prisms vertically striated.

Cleavage- is highly perfect, a, c, rather difficult, fracture cohchoidal, brittle.

Lustre- vitreous, somewhat pearly on cleavage.

Colorless- pale green, blue and white.

Streak- uncolored.

Transparent to subtransparent.

Hardness 7.5, G. 3.1.

Biaxial positive, α 1.652, β 1.655, γ 1.671, $2V = 50^\circ$, Pleochroism distinct.

<u>PYROGNOSITCS, ETC.</u>- B. B. cracks and whitens, throws out points and fuses at 5.5 to a white enamel. Insoluble in acids. Electrified by friction.

<u>OCCURRENCE</u>- in mica schists, with topaz, corundum, rutile, cyanite.

<u>LOCALITY</u>- Brazil, Urals, Austrian Alps.

Eudidymite: Hydrous silicate of beryllium and sodium. $Na_2O.2BeO.6SiO_2.H_2O$.

SiO_2 73.4, BeO 10.2, Na_2O 12.7, H_2O 3.7 =100.

Monoclinic- Crystals always twins; habit tabular parallel to C. Also penetration twins. Faces c and pyramids often striated.

Cleavage- c perfect, t $(\bar{5}51)$ less perfect.

Lustre- Vitreous, pearly on c.

Color- white.

Transparent to translucent.

Hardness 6, G. 2.55.

Biaxial positive, α 1.545, β 1.546, γ 1.551, 2V = 30°.

PYROGNOSTICS, ETC.- Fuses easily to colorless glass, at ~~2.5~~ to 3. Incompletely soluble in acids.

OCCURRENCE- Very sparingly in zircon syenite in the Langesund fiord, Norway, with zeolites.

~~Epidydmx~~

Epididymite - Same composition as Eudidymite but different crystal form.

Orthorhombic- Crystals usually tabular parallel to C, and these faces striated. twinned.

Cleavage- b and c perfect.

Lustre- bitreous on b, pearly on c.

Colorless

Hardness 5.5. G. 3.548.

Biaxial negative- α 1.565, β 1.569, γ 1.569, 2V=31°.

PYROGNOSTICS, ETC.- Like eudidymite.

OCCURRENCE- At Narsarsuk, Greenland.

33-38

Danalite- Silicate and sulfide of iron, manganese, zinc and beryllium. Anal.: SiO_2 31.73, FeO 27.40, MnO 6.28, ZnO 17.51, BeO 13.83, S 5.48=102.23, deduct 2,74 for O = S = 99.49.

Isometric- In octahedrons, also with dodecahedral faces, striated longitudinally.

Cleavage- Not observed.

Fracture- Subconchoidal to uneven. Brittle.

Lustre- vitreo-resinous.

Color- Flesh-red to gray, streak similar but lighter.

Translucent.

Hardness 5.5-6, G. 3.43.

Iso~~metric~~tropic- n = 1.737.

PYROGNOSTICS, ETC.- Fuses readily at 3 to a black enamel. Decomposed by HCl with evolution of hydrogen sulfide and gelatinization of the silica.

OCCURRENCE- Associated with lithia mica in granite in Massachusetts, also in New Hampshire and Colorado.

Foresite- Hydrous silicate of aluminium, calcium and sodium chiefly, a zeolite related to stilbite/ which it resembles in form and habit.

Analysis: SiO_2 44.60, Al_2O_3 36.00, MnO 1.02, CaO 5.50, MgO 0.02, Na_2O 2.33, K_2O 0.72, BeO 0.71, H_2O 9.18 = 100.08.

OCCURRENCE- Found on the Island of Elba in cavities in granite, with stilbite and heulandite, tourmaline, lepidolite, quartz and felspar, as a coating on the stilbite and heulandite.

Gadolinite- Complex silicate of the rare earths, iron, and beryllium chiefly. SiO_2 22-24, Yt_2O_3 etc. 22-47, Ce_2O_3 etc. 5-32, FeO, Fe_2O_3 11-16, BeO 6-11, ThO- tr- 0.89, CaO tr-2, Na_2O tr-0.5, H_2O 0.3-3, MgO, PbO, MnO, Al_2O_3, K_2O- small amounts.

Monoclinic- Crystals rough and coarse, Masses, sometimes weighing as much as 60 lbs.

Cleavage- none.

Fracture- conchoidal or splintery, Brittle.

~~D~~

Lustre- Vitreous to greasy.

Color- Black, brown, in thin splinters greenish and nearly transparent.

Streak- greenish gray.

Hardness- 6.5-7, G. 4-4.5.

Usually isotropic and amorphous. n=1.70 to 1.78. Faintly Pleochroic.

PYROGNOSTICS, ETC.- B. B. glows, swells and cracks but does not fuse. Gelatinizes in acids.

OCCURRENCE- In pegmatites throughout the world.

LOCALITIES- Norway, Sweden, Hartz Mountains, Greenland, Llano county, Texas.

33-41

HERDERITE- Fluophosphate of calcium and beryllium. $CaO.2BeO.P_2O_5.Ca(F,OH)_2$. CaO 34.6, BeO 15.4, P_2O_5 43.8, F 5.9, H_2O 2.8 = 102.5, deduct 2.5 for O = 2F.

Orthorhombic- short pseudohexagonal prisms and pyramids.

Cleavage- poor.

Fracture- subconchoidal.

Lustre- vitreous to subresinous.

Color- yellowish and greenish white.

Translucent to transparent.

Hardness 5, G. 3.0.

Biaxial negative. α 1.592, β 1.612, γ 1.621, 2V=74°.

PYROGNOSTICS, ETC.- B.B. phosphoresces with an orange-yellow light, fuses with difficulty, becoming white and opaque. Soluble in acids.

OCCURRENCE- In a tin-bearing vein in Saxony. In pegmatites in Maine, where the crystals are implanted on quartz and muscovite crystals.

38-42

Helvite- Silicate and sulfide of manganese, iron and beryllium. Anal. Amelia County, Virginia. SiO_2 31.42, BeO 10.97, MnO 40.56, FeO 2.99, Mn 8.59, S 4.90, Al_2O_3 0.36 = 99.79.

Isometric- Commonly in tetrahedral crystals, rarely dodecahedral in habit.

Cleavage- Octahedral in traces.

Fracture- uneven to conchoidal, brittle.

Lustre- vitreous to resinous.

Color- honey-yellow, yellowish brown, reddish brown, green.

Streak-uncolored.

Subtransparent.

Hardness 6-6.5, G. 3.16-3.36.

Isotropic- n = 1.739.

PYROGNOSTICS, ETC.- Fuses at 3 with intumescence to a brown opaque bead. Decomposed by HCl with evolution of hydrogen sulfide and separation of gelatinous silica. Pyroelectric.

OCCURRENCE- In gneiss in Saxony. In pegmatite at Langesund fiord, Norway, with topaz, phenacite, monazite, etc. in pegmatite in the Ilmen Mts.,Russia, also in Finland, Hungary.

In cracks in spessartite, associated with monazite, microlite, etc. in the pegmatites near Amelia Court House, Virginia.

Sipylite- Complex columbate of the erbium earths, chiefly.
Analysis: Cb_2O_5 (incl. 2.00 Ta_2O_5) 48.66, WO_3 0.16, SnO_2 0.08, ZrO 2.09, Er_2O_3 27.94 (incl. 1 o/o Yt_2O_3), Ce_2O_3 1.37, La_2O_3 3.92, Di_2O_3 4.06, UO_2 3.47, FeO 2.04, BeO 0.62, MgO 0.05, CaO 2.61, Na_2O 0.16, K_2O 0.06, MnO, Li_2O, F, trace, H_2O 3.19, =100.48.

Tetragonal- Usually imperfectly crystalline or in irregular masses. Rarely in octahedral crystals.

Cleavage- p(111) distinct.

Fracture- Small conchoidal and uneven. Brittle.

Lustre- resinous and pseudometallic.

Color- Brownish black to brownish orange, in splinters red-brown.

Streak- light brown to pale gray.

Translucent.

Hardness 6, G. 4.89.

Isotropic- n 2.05 to 2.07.

PYROGNOSTICS, ETC.-B. B. decrepitates and glows brilliantly becoming pale yellow. Infusible. Decomposed slowly by boiling concentrated H_2SO_4.

OCCURRENCE- Occurs sparingly embedded in or adherent to masses of allanite and magnetite at Little Friar Mt., Amherst Co., Virginia.

Allanite-synonym Orthite: Complex silicate of the rare earths, aluminium, iron and calcium chiefly. SiO_2 29-34, Rare earths, chiefly Ce, La, Di 15-30, ThO_2 tr-3.5, Al_2O_3 6-22, FeO 1.2-18, MnO tr -2.5, CaO 1.4-17, MgO 0.1-2.7, K_2O tr.-0.8, Na_2O tr.-0.6, H_2O 1.3-14. Pb and U are present in variable small amounts. Be is sometimes present in amounts less than 1 per cent. CO_2,P_2O_5,SnO_2 and rare elements other than those mentioned may be present. TiO_2 is probably always present but was not determined in the older analyses.

The extreme variations in composition are in part due to alteration.

Allanite is related crystallographically to epidote.

Monoclinic- Often in crystals, also irregular or rounded grains and massive. Crystals often flattabular parallel to a, also long, flat prismatic. Crystals or masses may be several feet long and reach a weight of 100 lbs. or more.

Cleavage- traces.

Fracture- uneven, subconchoidal, brittle.

Lustre- submetallic, pitchy or resinous, sometimes vitreous.

Color- black when fresh to brown, reddish or yellowish brown when altered.

Streak- gray to greenish or brownish gray.

Subtranslucent to opaque.

Hardness 5.5-6, G. 3.5-4.2.

Optical properties- variable, isotropic or anisotropic, n 1.68-
1.74, May be pleochroic. Often contains inclusions of
other minerals.

PYROGNOSTICS, ETC.- B. B. fuses easily at 2.5-3 and swells, yielding a dark, porous, magnetic slag, easily decomposed by acids, with gelatinization of the silica.

OCCURRENCE- Common in pegmatites thruout the world, also often in granites and syenites less in more basic rocks. Common in pegmatites of the Canadian Precambrian shield, sometimes in very large crystals or masses weighing several hundred pounds, as at Hybla, Ont. (page)

Allanite is commonly surrounded by radiating fractures in the enclosing rock, and if in felspar, the part near the allanite is usually a deeper colour// than usual.

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<u>Hyalotekite</u>- complex boro-silicate of lead, barium, calcium, etc.
Anal.- SiO_2 39.47, B_2O_3 3.73, PbO 25.11, BaO 20.08, CaO 7.82, F 0.99, BeO 0.75, K_2O, Na_2O, Al_2O_3, Fe_2O_3, MgO, MnO, CuO, also present in small amounts.

Massive- coarsely crystalline.

Cleavage- easy in two directions at about 90°. Brittle.

Lustre- vitreous to greasy.

Color- white to pearly gray.

Transparent- in very thin plates.

Hardness 5-5.5, G. 3.81.

Biaxial positive- α 1.963, β 1.963, γ 1.966, 2V small.

<u>PYROGNOSTICS, ETC.</u>- B. B. fuses to a clear glass, in R. F. blackens with reduced lead. Insoluble in HCl.

<u>OCCURRENCE</u>- In a grayish white felspar at Langban, Sweden.

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Hambergite- Hydrous borate of beryllium. 4 $BeO.B_2O_3.H_2O$.

B_2O_3 37.1, BeO 53.3, H_2O 9.6=100.

Orthorhombic- In prismatic crystals, the a faces vertically striated.

Cleavage- b is perfect, a less so. Brittle.

Lustre- ~~xirx~~ vitreous.

Color- grayish white.

~~Transxxrxtx~~

Transparent to translucent.

Hardness- 7.5, G. 2.347.

Biaxial positive, α 1.560, β 1.591, γ 1.631, 2V= 88°.

PYROGNOSTICS, ETC.- B. B. decrepitates violently but does not fuse. Insoluble in acids except hydrofluoric in which it is completely soluble.

OCCURRENCE- In a small pegmatite with black mica, zircon, and fluorite at Langesund fiord, Norway, Also in Madagascar.

Beryllonite- Phosphate of beryllium and sodium. $Na_2O.2BeO.P_2O_5$.
P_2O_5 55.9, BeO 19.7, Na_2O 24.4= 100.

Orthorhombic- Crystals short prismatic to tabular, highly complex, with vertical striations. Twins, sometimes repeated.

Cleavage- c highly perfect, a less so, m and b faint.

Fracture- conchoidal, Brittle.

Lustre- vitreous, brilliant, sometimes pearly on c.

Colorless to white or pale yellowish.

Hardness 5.5-6, G. 2.845.

Biaxial negative, α 1.552, β 1.558, γ 1.561, $2V=68^{\circ}$.

PYROGNOSTICS, ETC.- Decrepitates somewhat and fuses at 3 to a slightly clouded glass. Slowly but compactly soluble in hot acids.

OCCURRENCE- Found loose amid disintegrated pegmatite material, with beryl, columbite, phenacite, herderite, smoky quartz, etc. at Stoneham, Maine. Rare.

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Cyrtolite-Alvite- Complex hydrous zirconium-hafnium silicate minerals related to zircon containing rare earths, thorium, uranium, calcium, etc. (Page) The alvite from XXB Alve near Arendal, Norway, contains 14.73 per cent. BeO.

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Muromontite- A mineral apparently related to allanite but containing little aluminium and much of the yttrium group earths with 5.52 per cent BeO.

OCCURRENCE- From Mauersberg in the Saxon Erzgebirge.

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Tengerite- Hydrous carbonate of yttrium and beryllium. A white fibrous powder occurring as thin coatings on gadolinite at Ytterby, Sweden and Llano Co. Texas. Biaxial positive, α 1.555, β 1.57, γ1.585,2V large (Larsen).

Arrhenite- A complex rare earth tantalo-columbate decomposition product resembling red felspar, occurring with fergusonite and cyrtolite at Ytterby, Sweden, contains 0.74 per cent BeO.

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CANADIAN CHEMISTRY AND METALLURGY. NOV. 1928.

The Production and Uses of Beryllium.

Metal Now Available in Semi-Commercial Quantities - Possibility of Developing Canadian Ores.

By Kurt Illig, Research Laboratories, Siemens-Halske, A.G.,
Berlin, Germany.

It is astonishing that so many attempts were made without sucess in an effort to deposit metallic beryllium from a fused electrolyte, during the very period that fused electrolyte processes were developed into commercial methods of production of the first rank. The methods of producing aluminum metal are well known; the world production to-day totalling hundreds of thousands of tons annually. Aluminum metal was isolated only a year before beryllium was isolated.

This year, 1928, marks the centennial of the first production of beryllium by the celebrated German investigator, Wohler. During these hundred years almost all of the alkali and alkaline earth metals such as Li, Na, K, Ca, Mg, Ba, and Sr, have been prepared from fused electrolytes in commercial quantities. In the case of beryllium alone did all of the investigators fail, until recently, to prepare this metal in such quantities as to permit a study of its properties and uses.

The difficulty which stands in the way of easy isolation of beryllium is its great affinity for oxygen. Before dealing with the modern methods of production, a brief resume of the history of this interesting metal may be worth while.

Beryllium was discovered in 1798 by Vauquelin in the mineral "beryl."

which had been known since antiquity. The word beryl is the root of the German word"Brille" (eye-glasses), for the reason that Nero possessed a kind of a monocle, made from a piece of polished optically clear beryl. The ordinary beryl, an aluminum-beryllium double silicate, having the empirical formula $3BeO, Al_2O_3, 6SiO_2$, has been comparatively unknown; the more valuable varieties of this mineral, the green emerald and the blue-green to pale bule or light rose coloured aquamarine were known in pre-biblical times. The colour of these precious stones is due to the admixture of small amounts of the oxides of chromium or of iron.

Other minerals are known to contain more or less beryllium, as for example, Chrysoberyl, also named alexandrite, $(AlO_2)_2Be$: phenacite Be_2SiO_4 which has a rather wide occurrence, and certain rare earth minerals, such as, euclase, gadolinite, helvinite, danalite, bertrandite, leucophane, melinophane - all of which are fundamentally silicates of beryllium, which differ from one another simply by the presence of silicates of other metal metals. A borate of beryllium, hambergite and two phosphates, beryllonite and herderite, might also be mentioned.

Naturally the first methods used in an effort to prepare beryllium metal were various reduction methods which were then known for the preparation of other similar metals. As the methods employed differ but slightly from one another, only the most important will be mentioned. In 1828 Wohler prepared metallic beryllium in small glistening masses by the action of potassium metal on beryllium chloride. Reynolds, Nilson, and Petterson tried this reduction with solid sodium metal. Kruss and Morath

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heated the double salt, potassium-beryllium-fluoride, with metallic magnesium, but since the results were negative they then tried the direct reduction of beryllium oxide with magnesium. This method produced small hexagonal crystals of metal of microscopic dimensions.

The alumino-thermic method of Goldschmidt offered a new means of producing metals, and was applied at once to beryllium. In this connection the work of Just and Meyer, of Vautin (of E.Merck, Darmstadt), and the extensive dissertation of Moormann and M.Engelhardt should be mentioned. However, no tangible results were obtained by the Goldschmidt method, because at the high temperatures which are reached in alumino-thermic reactions, the beryllium metal, if liberated, is vaporized or is reoxidized by the air.

Investigations of the reduction by carbon were unsuccessful, the result being beryllium carbide, due to the great affinity between carbon and beryllium. The experiments of Lebeau and of Liebmann were with carbon. The carefully conducted reduction investigations, carried out independently of each other by Warren and by Kroll, produced only microscopic glistening particles of metal embedded in a matrix of slag. Unfortunately the metal could not be melted together into a compact mass. Even to-day, so far as the literature is concerned, there is no pure thermic reduction method known which will produce compact metallic beryllium.

Gratzel was the first to attempt to isolate beryllium by the electrolysis of fused electrolytes, which methods attracted wide attention towards the end of the last century. His efforts proved to be as fruitless as those of Warren and of Borchers. During the years 1898-1899,

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Lebeau obtained metallic beryllium by very painstaking experimentation. The electrolyte he used was fused sodium fluoride plus beryllium fluoride; the former fuses at a relatively low temperature, and in it the latter seems to be slightly dissociated.

The melting point of beryllium metal is 1,285 deg. C., well above the temperature of the bath; consequently only exceedingly small particles of metal were found dispersed through the mass of material at the cathode. Lebeau used a nickel crucible as the cathode, with a rather large surface, and a graphite rod as the anode. The large cathode surface led to rapid cooling, which assisted in crystallizing the metal within the surrounding matrix.

As will be shown later,this never favors the formation of compact masses of beryllium. In order to obtain beryllium metal in masses sufficiently large to make possible a superficial examination of its properties, Fichter, in 1913, used an indirect method of attack. He carefully separated the crystals of beryllium metal from the surrounding matrix, pressed them together in a small cylindrical mold and melted the mass in an atmosphere of hydrogen. He obtained a regulus of metal weighing about 1 gram, which he kindly put at the disposal ofOsterheld, who determined the melting point as being 1,278 deg.C., within an error of ±5 deg.C.

The work which was decisive in the development ofberyllium manufacture was accomplished by the German investigators, Stock and Goldschmidt, with the co-operation of Preiss and Praetorius. They obtained metallic beryllium for the first time in the form of large regali, directly from a fused electrolyte. As mentioned before the earlier method failed because at the instant the metal was formed it was at once reoxidized or vaporized. The salt previously used as electrolyte was evaporated before the real reduction was started, or the viscosity of the fused salt was too high, or finally, the affinity between the anion and carion was too great to allow of a separation under the then existing conditions.

Accordingly, before starting their experiments Stock and Goldschmidt made an effort to find a method by which all of the above limiting conditions would be eliminated. They felt that the electrolytic separation of beryllium (melting at 1,285 deg. C.) from a fused salt mixture could only be possible if a salt be used, which at this temperature either did not evaporate at all, or at least did so only slightly. On the other hand, to avoid an unusually high potential drop between the electrodes, the salt must also possess at this temperature a very low viscosity; and furthermore the anions must be easily separated or removed from the electrolyte. It is only in this manner that the separated metal might be prevented from remaining in or being redistributed in the surrounding fused salt mass.

Investigations have shown that these conditions are fulfilled in general by the double fluorides of beryllium with sodium and barium. The barium-beryllium fluoride has an appreciable viscosity around 1,300 deg.C., but also has the advantage of being only slightly volatile at this temperature range; it has an appreciable dissociation within this range. The sodium-beryllium fluoride is strongly dissociated even at relatively low temperatures. This, therefore, offers a means of obtaining an electrolyte possessing a good conductivity. It has only one disadvantage, namely, that at very high temperatures the separated beryllium metal may be volatilized in appreciable quantities.

If the electrolysis is started with the sodium-beryllium fluoride and with rising temperatures some barium-beryllium fluoride is added in increasing amounts, there is obtained a useful mixture of the double salts for every temperature interval. When the final metal separating temperature of 1,300-1,350 deg.C. is reached, it is not difficult to continue the electrolysis for many hours, provided suitable additions of both double salts are made from time to time.

Stock and Goldschmidt protected this general method of procedure by letters patent in all large countries. They realized however, that much additional work was necessary, before all of the details for the continuous production of large quantities of beryllium would be established. In order to study the problems on thebroadest basis, the foremost German manufacturers organized a "Beryllium Research Institute" in 1923, under the chairmanship of the Siemens and Halske A. G., of Berlin. It was the aim of this institute to make a systematic study of the fundamental Stock-Goldschmidt method in all its details to determine whether or not it was possible to produce beryllium metal in commercial quantities from fused electrolytes. The numerous variables which had to be considered made the work tedious, especially so since the temperature range of 1,300-1,350 deg. C. had never been used previously in fused electrolytic work. Some of the details of these investigations of the institute to date are herewith recorded:

The question of crucible and of electrode materials had to be settled first. In the early experiments of Stock and Goldschmidt, a crucible made

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of graphite was used as the anode. Graphite containing as little iron as possible is the only material to use. Acheson graphite is the best. The difficulties encountered in mounting the electrodes of the crucible were soon overcome. Various metals were tried as cathode; the most satisfactory was a special iron, made up into a hollow water cooled electrode.

The electrolyzing current is sufficient to maintain the bath at the temperature required. At the start of the process the crucible is filled with pieces of carbon or graphite, iron carbide is pressed firmly against these pieces, and as soon as the proper temperature is reached the pieces are quickly dumped out of the crucible and a charge of low melting sodium-beryllium fluoride is immediately put in. Then barium-beryllium fluoride is added until the required temperature range is reached for the electrolysis to begin.

Only after a large number of experiments were made, was the best method for charging the crucible discovered, which method must be rigidly adhered to. Naturally there will be a relatively large burning loss of the graphite crucible, which, however, may be mininized by surrounding the crucible with another crucible packed with Kryptol, to prevent contact between the very hot external wall of the graphite crucible and the air. Another method is to coat the external wall of the graphite crucible with a fused mass of the electrolyte, making an impervious coating, which is in no way objectionable since no impurities will be introduced into the electrolyte.

At first, relatively small reguli, of several grams only, could be separated from a single charge, and it was an exciting moment when several reguli of about 20 grams each were obtained. These reguli were still contaminated with the melt, so were not fit for a scientific or technical investigation. Systematic and progressive development made it possible to obtain a single button of about 50 grams in weight, and at the same time containing only spots of very small amounts of impurities.

It was this material that the several laboratories connected with the Beryllium Institute, as well as others not so connected, investigated. They determined the physical properties of beryllium metal.

Hand in hand with the scientific incestigations on fused electrolytes went the determination of authentic methods of analysis. The previous methods recorded inthe literature were either too incomplete or entirely too circumstantial to be of undisputed value for rapid work. Hellmuth and Fischer[1.] stated these analytical investigations, and most of these have been published. Very good methods are now available for the rapid determination of beryllium in the presence of aluminum and other metals.

In 1926 the Institute felt convinced that in the Stock-Goldschmidt method there was a means by which a commercial production of beryllium metal might be expected. At the same time the commercial applications of this metal were studied.

On the grounds of the results of the investigations of the Institute during 1926, the Siemens-Halske A. G. decided to make a systematic study of the applications to a commercial scale. The previous work had shown that the best scientific and technical production of beryllium would be possible only if the salts used were cheaply prepared; especially if they

[1.] Wissenschaft Veroffent. Siemens-Konzern, 5, part 2, 99 (1926); Zeitsch. anal. Chem., 73, 54 (1928).

were not hygroscopic, such as the double fluorides. The preparing of the salt from the crude mineral beryl was next investigated, Both of these problems were solved in the past two years. Simply and cheaply prepared salts, such as the double fluorides, which also give good material yields, are being investigated now.

In the older methods the electrolyte became more and more enriched in barium fluoride, thus shortening the time of a single charge, but with the advent of the new salts it is now possible to make the process continuous and without interruption. Practically speaking, this continuous method is now limited only by the burning of the graphite crucible.

The fluoride which is liberated attacks the anode, forming carbon oxyfluoride; this by interaction with oxygen forms carbon monoxide in considerable amounts. It is hoped that by purely mechanical means a continuous method may be developed, such as is used for feeding electrodes into large ovens, so that the crucible question will no longer influence the duration of the electrolysis. Letters patent for the use of the new salts have been applied for in all the large countries, but since the patents have not yet been granted, details cannot be given here.

Special note should be made of the valuable sublimation products, which are inevitably formed during the electrolysis, and which come out of the crucible, and are recovered, reprecipitated and reused. At the same time the poisonous gases, fluorine and CO, are drawn off. With the salts used to-day it is possible to get a material yield of about 95 per ecnt and a current yield of about 80 per cent.

The beryllium metal is in convenient reguli of about 150 grams.

varying with the size of the apparatus, and is about 98 per cent. pure. By special methods of remelting the purity can be increased to 99.9 per cent., though the yields of this very pure material are small. The main impurity of our beryllium is iron, which is introduced from the graphite crucible.

The recently developed double decomposition methods of the raw beryl for the formayion of the electrolyte salts, produce about 65 per cent. of beryllium, calculated as metal, so, that starting from the mineral the final yield of beryllium metal is about 60 per cent.

OCCURRENCE OF BERYL.

While this work was going on, investigations were being made as to the location and size of the beryl deposits in the various parts of the world, and as to the prices at which the material was marketed. This analysis showed that as usual when the possibilities of a new use for a raw material bring it to the attention of the world, it is found in many places. Norway, Spain and especially Florida, Canada and Brazil, in the order of importance, have large deposits of beryl. There appear to be deposits larger than previously realized, in south Germany, and in the Ural mountains.

It may be safely predicted that in the near future many beryl deposits will be found because now for the first time mineralogists and geologists have a stimulus for looking for this mineral. The prices for the crude beryl are exceedingly high at present, probably because there is no direct market for the material, but more probably because the owner of a beryl mine has the false impression that he has a mineral classed as a semi-precious stone. The owner must be enlightened as to the actual facts.

The raw beryl contains in all about 3.5o 3.5 per cent. of beryllium, from which about 60 percent. can be actually recovered. Therefore, 500 kg. of mineral will be required to produce one kg. of metal. However, as is often the case, the mineral costs $150 to $200 per metric ton, which makes one kg. of beryllium metal content cost $75 to $100.

The lowest bids for large amounts of mineral have been between $60 and $70 per ton, making the metal content cost $30 to $35 per kg. on the basis of the raw material. About 97 per cent. of the ore must be removed by various methods in order to prepare the salts required for the electrolyte. It may be noted that the electrolyzing costs are only one-third of the total cost of the beryllium metal produced, and that the present market price of the metal is almost entirely independent of the operating costs.

BERYLLIUM ALLOYS.

The most promising field which has so far been recorded in the literature is in the use of beryllium as a light metal. But the first studies of the metallographic division of Siemens-Halske have indicated that such a use is rather remote at present. Pure beryllium is an extremely hard and brittle metal, which scratches glass and can neither be rolled nor drawn because of its coarse crystal structure. Nevertheless plates of about 1 to 2 mm. by 10 to 20 mm. have been made from pure beryllium by special methods for use in X-ray work. But this is no application for which large amounts of metal need be produced.

Since beryllium has a specific gravity of 1.8 it has been considered advisable to try to alloy it with sufficient aluminum to make it workable. In this respect many interesting results may certainly be expected. It was not in the program of Siemens-Halske to make a systematic investigation in this direction, because the realization of our ambition to apply beryllium to arts and industry seemed only possible if beryllium alloys were developed which would compete with other alloys.

Americans have made valuable contributions to the study of beryllium-aluminum-lithium alloys, indicating that beryllium must not cost more than $20 per kilogram to make alloys of economic value. But this low figure is still of the distant future. Whereas the first grams of beryllium metal made by us cost $50 each, the price was soon reduced to $1.50 per gram in lots of 100 to 120 grams per day.

As soon as our proposed factory will produce 1 ton of beryllium per year, the price will be $75 to $90 per kilogram, and when the sale of this metal increases to 100 metric tons a year it may be found possible to sell it for $25 to $30 per kg. And if the cost of the raw beryl takes an unexpected drop or the methods of operation are considerably cheapened the metal will be still cheaper. In order to determine whether a large yearly production of beryllium at theeabove named price could be sold, the preliminary work of G. Massing and O.Dahl[2] on the promising alloys of beryllium with the heavy metals was extended in the laboratories of Siemens-Halske.

It had been shown that the addition of 2 to 2.5 percent. of beryllium to copper or nicel produced alloys possessing properties like those of the bronzes, a fact previously unknown. In the case of additions of beryllium to aluminum the alloy showed properties somewhat like those of duralumin

[2] Z.f.Metalkunde, 20(1), 1924 (1928).

and silumin, though there is no advantage in favor of the beryllium-aluminum alloy. The more expensive beryllium cannot compete with silicon magnesium, and copper in making alloys with aluminum. The results of this work as well as of those of Kroll on beryllium-aluminum alloys work showed that there is a great affinity between the metals beryllium and aluminum.

Some important data on beryllium-copper and beryllium-nickel alloys might be noted. Alloys of cobalt with beryllium are very similar, but the silver-beryllium alloys have interesting properties which could not have been determined previously. In the study of beryllium-iron alloys the work has not progressed far enough to permit definite conclusions.

The most outstanding property of the beryllium alloys is in their improvement upon heat treatment. A copper-beryllium alloy containing 2.39 per cent. of beryllium, after ordinary quenching, has a Brinell hardness of 100 kg./sq. mm., but after heat treatment for 17 hours at 300°C. this rises to 440 kg./sq. mm., that is, to over 400 per cent. Some copper alloys containing over 6 per cent beryllium have a hardness of over 730 Brinell numbers. These alloys cannot be worked in the untreated condition. Bronze-like properties are developed in these copper alloys, which, in the untreated condition, can be rolled, drawn or worked to the desired shape and then by heat treatment can be hardened and roughened. It is possible to make thin elastic pieces. The following information on the strength of these alloys may be of interest.

In the untreated quenched state a copper alloy containing 2.5 per cent of beryllium has a tensile strength of 48.9 keg./sq. mm., but after heat treatment it is 135 kg./sq. mm. The differences in the transverse bending strength are most astonishing; in the untreated condition, but quenched, it is 60.7 kg./sq. mm., but after heat treatment it rises to 216.7 kg./sq. mm. In the same alloys the yield point changes from 15.7 to 128 kg./sq. mm. on heat treatment, while the elastic limit in the first case is 5 kg./sq. mm., and in the second it is 45.9 kg./sq. mm.

As the beryllium content of these copper alloys is increased the final values for these mechanical properties in the treated condition are also increased. There is, however, a limit which is 6 to 7 per cent. Be in copper and nickel alloys. In general it may be said that the quenched alloys are very elastic and strong.

Heat treatment increases the elastic limit, and the yield point by about 800 per cent., while the tensile strength and the transverse bending strength increase about 3 to 4 fold. The ductility decreases proportionally with strength. This is not detrimental, since the shaping and working after quenching is done before it is given the heat treatment so that ductility requirements need not be considered after treatment. These alloys may be successfully rolled drawn, and pressed.

It is worth noting that the electrical conductivity of these alloys is lowered rather appreciably by the addition of beryllium. Alloys of 2.5 per cent. of beryllium, after quenching at 800°C., have an electric conductivity of 9.8recip. ohms/sq. mm. of cross section. Heat treatment changes this conductivity to 19 recip. ohms/sq. mm., and after annealing followed by a second hardening it reached 21.5 recip. ohms/sq. mm. These alloys are more resistant to corrosion than the ordinary bronzes.

Beryllium has an interesting application as a deoxidizer in copper casting. It has been shown that the addition of 0.02 to 0.05 per cent. of beryllium to copper for casting changes the electrical conductivity of the casting from 35 to 50 recip. ohms/sq. mm. The various alloys and their applications have been protected by letters patent.

FUTURE PROSPECTS.

In about six months we will produce about 100 kg. of beryllium metal monthly, at a price of about $85.00 per kilogram. Buildings are in the process of construction to increase the output three fold, so it may be concluded that far-reaching investigations both with alloys and with pure beryllium metal will be extensively mage in the near future. In one or two years from now an estimate might be made of the size of the world market fo beryllium metal, but not now.

We hope that a large number of investigators will become interested in the valuable properties of beryllium and its alloys. New uses for the metal are opened up in consequence of the present comparatively low cost of the metal. Furthermore, a study of those alloys might be undertaken in which large percentages of beryllium are used, for example, the beryllium-aluminum alloys, in order that such alloys may be applied commercially without delay, as soon as the price of the metal takes another decided drop.

The time is now ripe for all scientists to interest themselves in developing new, even though at present commercially impossible, uses for beryllium metal.

CHAPTER IV

ZIRCONIUM AND HAFNIUM AND THEIR MINERALS

INTRODUCTION

Although the element zirconium was identified more than one hundred years ago (1789), it was not until 1923 that the element hafnium was recognized and found to be a constant and almost inseparable companion of zirconium. It is now known that even materials formerly supposed to be chemically pure zirconium compounds were really mixtures of zirconium with sometimes as much as 5 per cent hafnium. This discovery has necessitated a revision of the atomic weight of zirconium and new studies of the properties of the pure substance. Zirconium and hafnium are so much alike in their chemical properties that it is only by numerous fractional recrystallizations of certain salts that it is possible to separate them in approximately pure condition by making use of slight differences in the solubilities of their salts. Hafnium was identified as element of atomic number 72 by means of its X-ray spectrum, and approximate quantitative determinations of the amount of hafnium present with zirconium are made by comparing the intensit of the hafnium X-ray spectrum with that of the X-ray spectrum of known quantities of an element of neighbouring atomic number, i.e. ~~—~~ tantalum, element 73. Although zirconium and hafnium have similar chemical reactions they differ greatly in such fundamental properties as atomic weight, density, and atomic numbers. Some properties of the two elements are tabulated below:

	Zirconium	Hafnium
Atomic number	40	72
Atomic weight	91.22	178.6
Density of oxides (ZrO_2, HfO_2)	5.73	9.68
Isotopes	90,92,94,96(?)	

The close association and similar chemical properties of these two elements is paralleled by the case of tantalum and columbium, and by various members of the rare earth elements, which present more or less similar difficulties in separation.

ZIRCONIUM

CHEMICAL AND PHYSICAL PROPERTIES

Owing to the difficulty of preparing pure zirconium metal, there are considerable differences in the properties as reported by various workers. The specific gravity has been reported to be as low as 4.08 and as high as 6.4, the latter value being considered the best at present. Some samples of the metal have been reported to be brittle and hard enough to scratch quartz, others soft and ductile like copper. Melting points from 1,000 degrees to 2,800 degrees have been reported, 1,700 degrees C. being considered the best value at present. Other properties are similarly variable according to different investigators. It is stated to be only slightly attacked by ordinary acids. The metal has a strong affinity for oxygen and burns brilliantly when heated in air. It combines directly with nitrogen, hydrogen, carbon, silicon, and boron. It is rapidly attacked by aqua regia and hydrofluoric acid.

The impure metal has been obtained in powder form by heating potassium fluozirconate with sodium or potassium. Zirconium tetrachloride had been reduced by heating with sodium or zinc and sodium yielding products containing 96 to 99 per cent zirconium. A metal of 99.09 per cent purity was obtained by heating a mixture of zirconium oxide and calcium. The oxide or halide has been reduced by heating with magnesium or aluminium. The metal is also reported to have been obtained by electrolysis of a solution of zirconium tetrachloride mixed with a small proportion of ferric chloride. Ferrozirconium can be made in the electric furnace by reduction of zircon and iron ore, or by reduction of the mixed oxides with aluminium.

Zirconium metal 98 per cent grade is quoted as $15 per pound (October 1927).

UTILIZATION

Zirconium metal can scarcely be said to be in commercial use. Zirconium filaments were at one time used to some extent in electric lamps. The strong affinity which the metal has for oxygen has suggested its use as a reducing agent in preparing difficultly reducible metals. Ferrozirconium has been tried as a scavenger in steel-making but seems to have no advantage over ferrotitanium. As a steel alloying element zirconium in small amounts seems to have little effect on the properties of steel. Alloys of iron and zirconium with a little titanium have been proposed for spark points, lamps filaments, etc. Alloys of zirconium and nickel with zirconium up to 10 per cent have been proposed for use in high-speed machine tools. They are hard and require no tempering. The hardness is increased by increasing the proportion of zirconium, but the melting point and tensile strength are lowered. Alloys of zirconium with cobalt, aluminium, magnesium, and silver have been prepared. The metal apparently does not alloy with tin, lead, the alkali metals, or the metals of the alkaline earth group.

Zirconium oxide has very valuable properties as a refractory on account of its very high melting point, its resistance to corrosion, low coefficient of expansion, and low heat conductivity, but a very small amount of impurities in the oxide alter these properties materially. The oxide is used as a refractory in the form of brick, crucibles, muffles, laboratory utensils, etc., and is said to give particularly long service.

Up to 1 per cent of zirconia with some titanium is said to improve the properties of fused silica by giving greater tensile strength and reducing the tendency to devitrification.

Zirconia when heated to incandescence produced a brilliant light and is used, mixed with thorium and rare earth oxides, in the Nernst lamp.

Zirconia is used as an opacifier in ceramics, also as a constituent of toilet powder and polishing powders. The addition of 15 per cent ZrO_2 to porcelain is said to improve the strength, electrical resistance, and resistance to temperature changes.

Zirconium compounds make good white paint pigments, being chemically stable, non-poisonous, and possessing good covering powers.

Zirconium oxide and other compounds added to rubber are said to increase the strength and toughness.

Zirconium salts have been used to replace tin compounds in weighting silk, and their use as mordants in dyeing has been proposed.

The clear transparent varieties of zircon are used as gemstones and are next to the diamond in brilliancy and fire. They go under the names: hyacinth, jacinth, jargon, and Matara diamond. Colours are usually reddish, brownish, or yellow, but the colour can be completely discharged by heating. Decolourized zircons are sometimes coloured a beautiful blue by artificial means.

OCCURRENCE

Zirconium has been estimated to exist to the extent of 0.01 to 0.02 per cent of the earth's crust. Zirconium lines have been identified in the spectrum of the sun and stars. In the form of minute crystals of zircon, it is a common constituent of many rocks; particularly granites and syenites, and of sands resulting from the disintegration of igneous rocks. The so-called black sands are often particularly rich in minute zircon crystals. Zircon derived originally from eruptive rocks in many cases occurs in sedimentary rocks, as the mineral is hard and chemically resistant to weathering. Zircon is the most common zirconian mineral and it or cyrtolite commonly occurs in greater or less amount in Canadian Precambrian pegmatites, also in the pegmatitic apatite-phlogopite deposits of the Grenville areas in Ontario and Quebec. Zirconium occurs in small amounts in a great number of the rare minerals found in pegmatites. The only minerals important commercially as ores, however, are baddeleyite and zircon.

PRODUCTION

Zircon (ZrSiO) was the earliest source of zirconium for technical purposes and is still utilized to some extent. It is recovered mostly from more or less decomposed granites or pegmatites or from sands by simple tabling. North Carolina produced from 1 to 26 tons annually for a long period. During 1926 sands on the east coast of Florida were concentrated for zircon by means of Wilfley tables and magnetic separation.

Zircon was quoted at 3 cents per pound for 95 percent concentrate in 1927. It has been as high as 20 cents or more.

Brazil is the chief source of commercial zirconium ore, greatly overshadowing all other occurrences in available reserves and cheapness of exploitation. The Brazilian ore has been called brazilite and appears to be a more or less variable and complex mixture

mixture of baddeleyite (ZrO_2) with zirkelite $(Ce,Fe,Ca)O \cdot 2 (Zr,Ti,Th) O2)$, zircon, and orvillite $)8 ZrO_2 \cdot 6SiO_2 \cdot 5H_2O)$. The ore is said to occur in great masses weighing many tons, as a rock, and also asalluvial pebbles ("Favas") and large scattered boulders. The purified brazilian ore is marketed under the trade name "zirkite", which in 1927 sold for 3 cents per pound for the powdered material containing 80 per cent ZrO_2.

The Mining Industry for 1928 states that: "Some difficulty was reported during the past year in obtaining a sufficient quantity of zirconium ore, all supplies being insufficient to meet the demand and as a result prices increased over the preceding year. Zircon sand sold in carload lots for $95 per ton. Ore containing 75 per cent ZrO_2 ranged in price from $65 to $75 per ton in carload lots while the 65-70 per cent grade sold for $52 to $65. The pure oxide sold for 75 to 90 cents per pound."

The industrial use of zirconium oxide is steadily increasing in the manufacture of bricks, crucibles, and other refractory products such as high temperature cements. This is not rapid, however, due to the unwillingness of the producers to install additional and more suitable machinery for sorting and concentrating the ore.[1]

Imports into the United States of zirconium ore totalled 863,635 pounds valued at $9,788, and the imports of zirconium alloys such as ferrozirconium, zirconium, and zirconium ferrosilicon amounted

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[1] Eng. Min. Jour., Jan. 19, 1929.

to 941 pounds having a value of $829[1].

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[1] U.S.Dept. of Commerce.

HAFNIUM

Hafnium was first identified in 1923 by D. Coster and G von Hevesy and named from "Hafnia", an ancient name for Copenhagen. So far as known at present it occurs only with zirconium, which it always accompanies. In chemical properties hafnium resembles zirconium and to a less extent, thorium. Any reaction characteristic of zirconium is also characteristic of hafnium.

The metal has been prepared by methods similar to those used for the preparation of zirconium; by reducing a hydrofluohafniate with sodium, by reducing the tetrachloridewith sodium, and also by passing the vapour of the tetraiodide over a heated tungsten filament. The metal is said to have a specific gravity of 12.1 and a higher melting point than zirconium. The heated metal, like thorium, gives a high electron emission and its use in radio rubes has been patented. It appears from the latest reports, however, that hafnium is inferior to thorium as an electron emittor and as barium and strontium are superior to thorium it is not likely that hafnium will be used in this way. (<u>See under</u> Caesium and Thorium).

The amount of hafnium present in zirconium minerals varies from a few tenths of 1 per cent to as much as 10 or 15 per cent in certain alvites. In the case of zircons, cyrtolites, and alvites the amount of hafnium is roughly proportional to the radioactivity.

and to the amount of rare earth's present. Hafnium is said to be isomorphous with uranium and thorium, which may account for its occurrence with these elements in cyrtolite, though many rich uranium and thorium minerals contain no hafnium or zirconium whatever. Hafnium is detected and quantitatively determined by means of its X-ray spectrum. It is also possible to make approximate quantitative determinations by isolating the pure mixed oxides of zirconium and hafnium and determining the density. Neither of these methods is of the highest degree of precision, however. Although Hafnium is a quite rare element considered as a constituent of the earth's crust, of which it probably makes up not more than 1 part in 100,000, nevertheless should uses be found which would justify the cost of extraction it would be possible to obtain the element in considerable quantities, as hafnium is segregated in zirconium minerals and these are fairly abundant. The richest hafnium minerals cyrtolite and alvite, containing up to 15 per cent hafnium, are in some places obtained in quantities of hundreds of pounds or even s several tons in the course of mining pegmatites. Of the lower grade hafnium minerals, zircon, brazilite, and eudialyte could be obtained in large quantities.

In Canada cyrtolite of the type rich in hafnium occurs in fair abundance in the pegmatites of central Ontario, particularly in the neighbourhood of Hybla, Hastings county. Probably several hundred pounds could have been recovered from the MacDonald feldspar mine at Hybla.

ZIRCONIUM AND HAFNIUM-BEARING MINERALS

Zircon. Essentially a silicate of zirconium but with a variable amount of hafnium $((Zc,Hf)O_2 \cdot SiO_2)$. Analysis show from 61 per cent to 66.8 per cent zirconium oxide and hafnium oxide. The hafnium oxide content varies up to perhaps 4 per cent in true zircon and to 15 per cent in cyrtolite, alvite, etc., which though usually considered to be altered varieties of zircon, may be distinct minerals. Zircon occurs in square prisms and in irregular forms and grains. It is very hard, transparent to opaque, and colourless, yellowish, greyish or reddish brown. Flawless, transparent zircons are used as semi-precious gemstones under various names. Zircon is a common minor constituent of the more acid igneous rocks, particularly pegmatite, granite, and syenite, and in rocks which have been altered by granitic intrusions. Very large crystals weighing as much as 10 pounds have been obtained from contact rocks.

Zircon has been produced, in commercial quantities, from decomposed granite and pegmatite in Henderson county, North Carolina and from beach sands on the east coast of Florida. It has been f found in smaller quantities in numerous localities throughout the world.

Cyrtolite, Alvite, Etc. These minerals have been classed as varieties of zircon and often have been referred to as altered zircon. They resemble zircon in crystal habit but differ from it so much in composition that they might well be considered distinct mineral species. They are the richest known hafnium minerals, containing in some cases up to 17 per cent HfO_2.

Cyrtolite is a complex hydrous silicate of zirconium, hafnium, rare earths, thorium, uranium, calcium, etc. Due to the presence of uranium and thorium, the mineral is radioactive. It occurs massive and in radiating masses of crystals. It is found only in pegmatite. Alvite is somewhat similar to cyrtolite but is said to contain as muc as 14 per cent BeO.

Baddeleyite. Essentially zirconium dioxide (ZrO_2) with a small amount, not over 1 or 2 per cent of hafnium oxide. It is a hard, very heavy, yellowish, brown, black or colourless mineral. It is an important constituent of a decomposed magnetite-pyroxene rock in Brazil, the chief commercial ore of zirconium. It occurs in a similar rock in the nepheline syenite region of Ano, Sweden.

Zirkelite. A complex zirconate, titanite, and thorate of calcium, iron and rare earths. It is a black, nearly opaque mineral and has been found associated with baddeleyite in the decomposed magnetite-pyroxene rock of Jacupirango, Brazil.

Orvillite. Zirconium silicate ($8ZrO_2 \cdot 6SiO_2 \cdot 5H_2O$). This mineral occurs associated with zircon, baddeleyite, etc., in Brazel.

Eudialyte. A complex silicate and possibly zirconate, of sodium, calcium, iron, and rare earths, etc. It occurs associated with albite, sodalite, aegerite, etc., in nepheline syenites and pegmatites. It is of common occurrence in pegmatites and alakine syenites of the Julianehaab district, Greenland where, it is said, it could be obtained in considerable quantities, 55 tons having been at one time collected.

Catapleite. Hydrous silicate and zirconate of sodium and calcium. Found in nepheline syenite, pegmatite, etc., Greenland and Norway.

Lavenite. Complex silicate and zirconate of calcium, sodium, manganese, iron, etc. Found in nepheline syenite and pegmatite.

Rosenbuschite. Complex silicate, titanite, and zirconate of calcium, sodium, iron, and rare earths. Occurs in nepheline syenite and pegmatite, Norway.

Hiortdahlite. Silicate and zirconate of calcium, sodium, etc. Occurs in nepheline syenite, Norway.

Wohlerite. Silicate, zirconate, and columbate of calcium, sodium etc. Occurs in nepheline syenite and pegmatite, Norway.

Elpidite. Hydrous silicate and zirconate of sodium. Found in Greenland

Lorenzite. Silicate, titanite and zirconate of sodium. Occurs in pegmatite, Greenland.

Polymignite. Complex zirconate, titanite, and tantalo-columbate of rare earths, calcium, iron, etc. Found in nepheline syenites, etc.

Uhligite. Zirconate and titanate of calcium and aluminium. Occurs in a nepheline-bearing rock, lake Magad, East Africa.

Other Minerals. The following minerals among others, in some cases hold small amounts of zirconium: annerodite, arrhenite, astrophyllite beckelite, chalcolamprite, endeiolite, johnstrupite, koppite, leucosphenite, and mosandrite.

CHAPTER V

TANTALUM AND COLUMBIUM AND THEIR MINERALS

TANTALUM

CHEMICAL AND PHYSICAL PROPERTIES

Tantalum and columbium are metallic elements which like zirconium and hafnium always occur together in minerals and are so similar in their chemical reactions that it is very difficult to separate them, though much less so than in the case of zirconium and hafnium. Titanium, a rather common element with chemical reactions somewhat similar to those of tantalum and columbium, always accompanies the latter two elements in minerals, in varying amounts, but there are titanium minerals which contain no columbium or tantalum.

Tantalum is a light-coloured metal resembling steel or platinum in appearance. The pure metal is very tough, ductile, malleable and possesses great tensile strength. It may be drawn into wire and worked without annealing. On the other hand it may be made hard by introducing small amounts of other elements, even gases such as hydrogen or oxygen, which it absorbs when heated. The coefficient of expansion is slightly less than that of platinum, so that it may be sealed into glass. The electrical resistance is three times that of tungsten and eight times that of copper. When the metal is heated in air an iridescent film of oxide forms with colours varying according to the temperature, becoming blue at 400 degrees, black at

600 degrees, and at higher temperatures a layer of the white oxide Ta_2O_5 is formed. A thin wire will burn slowly at high temperatures. The powdered metal if heated red hot will decompose water. Tantalum wire heated in hydrogen absorbs large amounts of the latter, taking up as much as 740 volumes at a dull red heat. If the wire is then heated in a vacuum only three-fourths of the hydrogen is expelled, the remaining hydrogen apparently forming a stable metallic compound which is brittle and has high electrical resistance. All the hydrogen is expelled only at the fusion temperature. At high temperatures tantalum combines directly with carbon, nitrogen, and chlorine.

Tantalum is remarkably resistant to chemical reagents, resembling the noble metals in this respect. It is not attached by hydrochloric, nitric, or dilute sulphuric acid nor by aqua regia, either hot or cold. It is slowly attacked by boiling, concentrated sulphuric acid and more rapidly by hydrofluoric acid, though in the case of the very pure metal and very pure hydrofluoric acid the action is said to be very slow. It is readily dissolved by a miaxute of nitric and hydrofluoric acids. Solutions of caustic alkalis have but little effect when cold and dilute but much more when hot and concentrated. The metal is attacked by fused alkalis and alkali nitrates.

Tantalum alloys with iron, tungsten, molybdenum, and other metals.

Some of the more important properties of tantalum and columbium are given below.

	Tantalum	Columbium
Atomic weight	181.5	93.1
Atomic number	73	41
Density	16.6	8.4
Melting point	2850°	1950°
Linear coefficient of expansion per degree C	7.9×10^{-6}	

Impure tantalum has been prepared by reduction of the oxide with aluminium or misch metal (cerium group metal alloy); by reduction of the oxide with carbon in the electric furnace;and by moulding into rods with paraffin and heating in a vacuum by passing an alternating electric current. A patented process describes the production of pure tantalum by electrolysis of fused potassium fluotantalate using pure tantalum metal as cathode and impure metal as anode. During the last few years the ductile metal has been produced commercially with a purity of 99.5 per cent or better by heating potassium fluotantalate in a vacuum with metallic sodium or potassium. By this means the metal is obtained as a somewhat impure powder which is washed with mineral acids and water until free of salt, is compressed into bars, and heated to fusion in a vacuum furnace, the high temperature of fusion eliminating most of the remaining impurities.[1] The resulting metal is ductile and susceptible to mechanical working and during 1927 sold at around $200 per kilogram)between $6 and $7 per troy ounce or

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[1] Balke, C.W.: Chem. and Met. Eng.,1922, p. 1271.

one-third the value of gold).

Ferrotantalum can be made in the electric furnace by reduction of a mixture of tantalite and iron ore.

UTILIZATION

Tantalum was first used commercially in the filaments of incandescent electric lamps. It is said that 103,000,000 tantalum lamps were sold during the years 1905-11. Tantalum, however, has been entirely replaced by tungsten as a filament material in recent years. Tantalum has been used for dental and surgical tools, for pen points, chemical weights, etc., and as a substitute for platinum in laboratory utensils. It has been recommended as material for electrodes used in electrolytic processes and for spinnerets in the rayon industry.

A certain amount is said to be used for jewellery, advantage being taken of the fact that the metal may be superficially coloured by forming a film of oxide.

One of the most important uses for a time previous to the advent of the alternating current radio tube was in electrolytic alternating current rectifiers for radio sets, battery chargers, etc.; a strip of tantalum and one of lead form the electrodes, which are immersed in dilute sulphuric acid or other suitable electrolyte. By using two tantalum electrodes in a single cell it is possible to rectify both half waves of the alternating current, which by means of suitable condensers and inductances can be smoothed out to give practically a constant direct current. Such rectifiers are efficient, noiseless, practically never wear out or deteriorate, and require no care beyond the occasional addition of a little distilled water.[1]

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[1] Balke, C.W.: Loc.cit.

More recently an important use of tantalum is said to be in the manufacture of vacuum tubes for radio broadcasting and receiving, the metal being used as material for the plate and grid, particularly in power tubes. For this purpose tantalum is said to be superior to any other metal.

The commercial uses of tantalum are said to be rapidly expanding.

Alloys of tantalum with nickel, molybdenum, tungsten, iron, etc., have been prepared, and proposed for uses where resistance to corrosion is desired.

No compounds of tantalum are in commercial use so far as known. The white oxide Ta_2O_5 has been suggested as a refractory, but the cost would probably be too great except perhaps for laboratory ware.

COLUMBIUM

Columbium metal resembles tantalum in appearance and in general physical properties but is lighter, more easily fusible, softer and more readily oxidizable on heating. It also is malleable, ductile, and can be welded. Columbium is said to show the same resistance to chemical attack as tantalum. The metal is prepared by the same methods as used for tantalum.

So far as known, columbium has no commercial uses at present. That columbium has been neglected commercially is probably due to the difficulty of obtaining commercial quantities of suitable minerals rich in this element.

TANTALUM AND COLUMBIUM-BEARING MINERALS

Tantalum and columbium have been estimated to occur in the igneous rocks of the earth's crust to the extent of 0.000,00X or 0.000,000X per cent. These elements, with always more or less titanium, are found, usually along with uranium, thorium, rare earths, and common elements, in a great number of very complex rare minerals, which occur sporadically in granite pegmatites throughout the world.

The only mineral utilized commercially as a source of tantalum at the present time is tantalite. This mineral is theoretically a tantalate of iron and manganese (Fe Mn) Ta_2O_6, but actually columbium and a little titanium are always present and the mineral passes by insensible gradations to columbite, the corresponding columbate $(FeMn)Cb_2O_6$. In practice the mineral when high in tantalum is called tantalite and when high in columbium, columbite. High tantalum tantalite comes chiefly from Australia and sells (1927) around $13 per unit of Ta_2O_5, on a basis of 65 per cent

Ta_2O_5, i.e. a ton of 65 per cent ore would bring $845. The mineral (columbite-tantalite) rarely runs high in tantalum. It more often contains up to 40 per cent or more of columbium. Columbite-tantalite has been found in small quantities in a number of feldspar mines in Canada, and may be looked for in any pegmatites worked for feldspar or muscovite. In one instance a quantity of perhaps 200 pounds was seen in place. The Canadian columbites so far found, however, do not run high in tantalum and would not be particularly attractive as ore so long as higher-grade material is available. Columbium seems to be a much more abundant element than tantalum in the known pegmatites of the Precambrian shield.

Columbite-Tantalite. Columbate and tantalate of iron and manganese ($(Fe,Mn)O.(Cb,Ta)_2O_5$), showing all gradations from nearly pure columbite ($(Fe,Mn)O.Cb_2O_5$) to nearly pure tantalite ($(Fe,Mn)O.Ta_2O_5$). The iron and manganese also vary widely. Analyses show a range in the content of columbium oxide of from 3.5 per cent to 78 per cent, and of tantalium oxide of from 0.8 per cent to 82 per cent. The minerals occur in crystals and massive, are iron black or greyish black, have a submetallic lustre, are hard, brittle and heavy. Manganocolumbite and manganotantalite are varieties containin comparatively little iron.

Skogbölite. Nearly pure tantalate of iron ($FeO\ Ta_2O_5$). Occurs in pegmatites in Finland.

Tapiolite. Tantale and columbate of iron ($FeO(TaCb)_2O_5$). Occurs in pegmatites in Finland.

Ilmenorutile and Strüverite. Columbate, tantalate and titanite of iron. In ilmenorutile ($FeO\cdot(Cb,Ta)_2O\cdot5\ TiO$), columbite predominates, in strüverite ($FeO\cdot(Ta,Cb)_2O_5\cdot4TiO_2$) tantalum predominates. Occurs in pegmatites.

Stibiocolumbite and Stibiotantalite. Tantalate and columbate of antimony ($Sb_2O_3\cdot(Ta,Cb)_2O_5$). Has been found in pegmatite in California.

CHAPTER VI

THE RARE EARTHS

CHEMICAL AND PHYSICAL PROPERTIES

The rare earths are a group of elements so closely related chemically that they cannot be separated by ordinary chemical methods, and can be individually isolated in a pure state only by repeated fractional crystallizations. They were called earths because their oxides resemble lime and magnesia. In the early days of chemistry they were supposed to be very scarce but it has since been found that some of them are widely distributed and exist in greater quantities than was formerly supposed. The rare earths are a group of trivalent metals forming basic oxides and characterized by two diagnostic reactions by which they may be separated a s a group from most other elements, i.e., their oxalates and fluorides are insoluble in water or dilute acids. Thorium is related to the rare earths and its oxalate and fluoride are similarly insoluble, but it is not usually considered as a rare earth. The chief chemical differences of the individual rare earths are exhibited by the solubility of their salts and the degree of basicity of their oxides Cerium differs from the others in also forming a series of quadrivalent compounds.

The rare earths are usually considered to include the following elements:

Element	Symbol	Atomic number	Atomic weight
Scandium	Sc	21	45.10
Yttrium	Y or Yt	39	89.0
Lanthanum	La	57	138,91
Cerium	Ce	58	140.25
Praseodymium	Pr	59	140.92
Neodymium	Nd	60	144.27
Illinium[1]	Il	61	
Samarium	Sa	62	150.43
Europium	Eu	63	152.0
Gadolinium	Gd	64	157.26
Terbium	Tb	65	159.2
Dysprosium	Ds or Dy	66	162.52
Holmium	Ho	67	163.4
Erbium	Er	68	167.7
Thulium	Tm or Tu	69	169.4
Ytterbium	Yb	70	173.6
Lutecium	Lu	71	175.0

Some of the relative properties of the rare earths are shown in the following table:[2]

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[1] Identified in 1926 by B.S.Hopkins of the University of Illinois, by means of spectroscopic and X-ray spectroscopic evidence. The material containing illinium was isolated from 400 pounds of monazite residues. Illinium is very difficult to separate from neodymium.

[2] Hopkins: Chemistry of the Rarer Elements.

GENERAL COMPARISON OF RARE EARTH GROUP

Order of decreasing abundance	Ce, Nd, La, Y, Sa, Gd, Pr, Er, Yb, Lu, Dy, Ho, Tm, Tb, Eu
General order of increasing solubilities of salt	La, Ce, Pr, Nd, Sa, Eu, Gd, Tb, Dy, Ho, Y, Er, Tm, Yb, Lu
Decreasing basicity	La, Ce^{III}, Pr, Nd, Gd, Sa, Y, Tb, Dy, Ho, Er, Tm, Yb, Lu, Sc, Ce^{IV}
Decreasing heats of dissociation of anhydrous sulphates	La, Y, Lu, Yb, Er, Pr, Nd, Gd, Sa, Sc, Ce
Decreasing stability of nitrates	Y, Gd, Tb, Tm, Ho, Er, Yb, Sc
Increasing volatility of the chlorides	Yb, Lu, Sc, Th
Increasing Hardness	Pb, Sn, Ce, La, Zn, Nd, Pr, Sa

Coefficient of magnetization $X \times 10^{-6}$	Sc	Y	La	Sa	Nd	Eu	Yb	Gd	Er	Tb	Dy
	-0.05	-0.14	-0.18	+6.5	+33.5	+35.5	+33.6	+161	+189	+237	+290

The cerium group elements have been prepared and studied but many of the other rare earths have not yet been obtained in pure elementary condition. The cerium group elements resemble each other closely in physical and chemical properties, being white or slightly yellowish, moderately stable in dry air but tarnishing in a moist atmosphere. They decompose water with evolution of hydrogen, slowly in the cold, more rapidly with elevated temperatures, forming the hydroxides. They show great affinity for oyxgen, produce great heat on combustion, and are powerful reducing agents. Cerium ignites and burns when heated to 160 degrees in air, lanthanum at 445 degrees. They dissolve readily in dilute acids and unite directly with hydrogen, nitrogen, the halogens, sulphur, and phosphorus.Alloys are readily formed with iron, aluminium, zinc, magnesium, and many other metals. Pure cerium is nearly as soft and ductile as lead and may be easily cut by a knife,whereas samarium is brittle and nearly as hard as steel. The densities and melting point so far as known with any degree of certainty are as follows:

	Density	Melting point °C
Cerium	6.9	640
Lanthanum	6.1	826
Neodymium	6.9	840
Praseodymium	6.5	940
Samarium	7.7	>1,300
Scandium	2.5	1,200
Yttrium	5.5	1,490

Cerium is pyrophoric, emitting hot sparks when filed or struc with a hammer. The other members of the cerium group are probably not pyrophoric when individually pure, but alloys of cerium with other members retain their property. Such alloys are produced commercially in considerable quantities from monzaite under the name of mischmetal and usually contain about 45 per cent cerium, 25 per cent lanthanum, 15 per cent praseodymium and neodymium, 10 per cent samarium, 1 to 5 per cent iron, and small amounts of yttrium and other rare earths. Cerium or mischmetal forms alloys with iron which are more strongly pyrophoric than pure cerium and have the further advantage of being brittle so that they readily produce showers of sparks when filed. Auer-metal, containing 65 per cent mischmetal with 35 per cent iron, is particularly active in this respect. The sparks from Auer-metal are sufficiently hot to ignite volatile organic compounds such as gasoline, petroleum ether, benzene, etc., hence these iron alloys are much used in pocket lighters, gas lighters, etc.

Ferrocerium is a commercial product and was quoted at from \$5.75 to \$8.00 per pound in 1928.

Compounds. All the rare earths form strongly basic oxides of the type R_2O_3 under suitable conditions. With the exception of cerium, praseodymium, and terbium, the R_2O_3 oxide is obtained by ignition of the oxalates, hydroxides, carbonates, and nitrates in air. Cerium, however, yields CeO_2 on ignition in air and praseodymium and terbium give products of doubtful composition approximating R_4O_7 according to some authorities. The oxides of the rare earths are variously coloured. Some are white or yellowish white (CeO_2, La_2O_3, Sa_2O_3, Sc_2O_3, Yt_2O_3, Gd_2O_3, Tb_2O_3, Dy_2O_3, Yb_2O_3, Lu_2O_3). Pr_2O_3 is yellowish green, Pr_4O_7 black, Nd_2O_3 light blue, Eu_2O_3 rose coloured, Tb_4O_7 dark brown to black, Ho_2O_3 pale yellow, Eu_2O_3 rose-red, Tm_2O_3 greenish white. Salts of the rare earths are similarly variously coloured.

The hydroxides are precipitated by alkalis as a gelatinous mass difficult to filter and wash. They are insoluble in excess and dissolve readily in acids.

Chlorides, notrates, and sulphates are readily formed. These are all hydrated salts containing from 3 to 12 molecules of water and many are deliquescent. They are all soluble in water, the sulphates being more soluble the colder the water. The chlorides do not readily form double salts with other chlorides. Double alkali sulphates are formed and the differences in solubility of these is used to make an approximate separation of the cerium and yttrium-erbium groups in analysis. The separation is made by adding finely powdered potassium sulphate little by little to the solution of rare earth sulphates with stirring until no more potassium sulphate dissolves. The rare earths can be divided into three groups with respect to their solubility in saturated potassium sulphate solution.

(1) Soluble: yttrium, ytterbium, erbium, thulium, holmium, and dysprosium.

(2) Slightly soluble: gadolinium, terbium, and europium.

(3) Practically insoluble: thorium, cerium, lanthanum, neodymium, praseodymium, samarium, and scandium.

Double nitrates are formed with many elements, among which those of ammonium, magnesium, busmuth, nickel, and manganese have been used to separate the rare earths by fractional crystallization.

The prosphates are precipitated as a gelatinous mass soluble in strong acids.

It has already been mentioned that the oxalates and fluorides are practically insoluble in water or dilute acids and serve to separate the rare earths as a group, along with thorium , for most of the other elements.

In the search for improved methods of separation a great number of rare earth compounds have beenmade which are only of scientific interest.

Cerium differs from the other rare earths in forming two well-defined series of compounds, in which it is trivalent and quadrivalent respectively. The cerous salts are derivatives of the cerous oxide Ce_2O_3 and are colourless. Ceric salts derive from $Ce\ O_2$ and are yellow to red in colour and easily reduced to the cerous condition. They are less basic than the cerous salts and are readily hydrolyzed in solution. For this reason it is comparatively easy to separate cerium from the other rare earths.

EXTRACTION AND SEPARATION

The rare earths are obtained commercially as by-products of the extraction of thorium from monazite, which is described under thorium (page). To obtain the rare earths from minerals other than monazite the mineral must be brought into solution by treatment with acid or by fusion with a suitable flux. Phosphates and silicates, such as monazite and allanite may be decomposed and brought into solution by heating with sulphuric acid. Titano-tantalo-columbates are as a rule not readily decomposed by this treatment, but yield to hydrofluoric acid or to fusion withalkali bisulphates, hydroxides, peroxides, or acid fluorides. By these means the rare earths are either obtained in solution along with other elements or, if HF or fluoride have been used to open up the mineral, the rare earths are left as insoluble fluorides, whereas the other constituents dissolve. In any case the initial separation of the rare earths with thorium from otherelements is brought about by precipitation either as oxalates or as fluorides. These may then be transposed to sulphates by heating with sulphuric acid and the precipitation repeated. Lead is removed as sulphate, remaining traces by hydrogen sulphate, and the rare earths with thorium are finally obtained in practically pure condition as sulphates. Thorium may be separated comparatively easily by any one of several methods. In analytical work it is customary to separate and report the rare earths as two groups: the cerium group, and the yttrium-erbium group. The separation is made by dissolving the neutral rare earth sulphates in water and adding solid potassium sulphate powder until the solution is saturated. The double sulphates of cerium, lanthanum, neodymium, praseodymium, scandium, and samarium are insoluble and precipitate out along with some europium, gadolinium, and terbium and traces of the yttrium group. These comprise the cerium group as usually reported, and the remainder of the earths are reported as the yttrium-erbium group. Cerium because of its property of forming compounds of higher valency can be determined with fair accuracy by oxidation and reduction methods.

The separation in a pure state of the individual rare earths other than cerium can be achieved only by thousands of fractional crystallizations of suitable double salts, controlled by spectroscopic tests, determinations of the atomic weight, magnetic susceptibility, etc. In this work the most refined methods are necessary and even now it is doubtful whether certain of the elements have been obtained in an absolutely pure condition. As many as 15,000 recrystallizations have been made in the course of purifying some of these elements.

The rare earth metals have been obtained in impure form by heating the chlorides or fluorides with sodium, potassium, calcium, magnesium, or aluminium, and by heating the oxides with aluminium, magnesium, calcium, carbon, or silicon. These methods, however, produce alloys of the rare earth metals with the metal used for reduction. Cerium and mischmetal are produced commercially by electrolysis of the fused chloride contained in a graphite crucible using an iron cathode. They have also been produced in quantity by electrolysis of the fused fluoride and of the oxide dissolved in the fused fluoride. The product may be purified by heating with mercury and skimming the impurities from the molten mass of amalgam, after which the mercury is distilled off by heating to a higher temperature in a vacuum.

USES

Only the Cerium group of earths (comprising Ce, La, Pr, Nd, and Sa) are used commercially. Pyrophoric alloys of mischmetal with iron (Auer-metal) are used as flints in pocket lighters, gas lighters, etc., and were extensively used during the war in the making of tracer bullets and shells for night firing, the friction of the air causing the alloy to ignite, thus rendering visible the path of the projectile. Ferrocerium is said to be useful as a scavenger for removing oxygen from cast iron with beneficial results in increasing strength and machinability. Cerium has been used experimentally as a steel-alloying element, but so far it does not appear to be very favourably regarded for this purpose.[1] Mischmetal is a powerful reducing agent capable of reducing such refractory oxides as those of zirconium, tantalum, and columbium. It is used

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[1] Gillet and Mack: "Molybdenum, Cerium, and Related Alloy Steels."

to a limited extent as a component of flashlight powder and of the cored carbons of "flaming arc" lights. The addition of small amounts of mischmetal to aluminium as a purifying agent is said to be very beneficial in increasing the ductility of the metal. Misch-metal is also said to be used sometimes as a so-called "getter" to absorb the last traces of gas remaining in radio tubes after being exhausted. Calcium and magnesium are chiefly used, however, for this purpose. Incandescent gas mantles contain 1 per cent of cerium oxide the presence of which greatly increases the luminosity of the thorium oxide. Compounds of the cerium earths are used to a certain extent as colouring materials in the glass and ceramic industries. They have been proposed for use in the manufacture of dyes, in the dyeing of leather and textiles, and as catalysts or oxidizing agents in various chemical processes, also in photography and as antiseptics.

The most important use at the present time appears to be the utilization of the cerium group in the manufacture of pyrophoric alloys and cored carbons.

OCCURRENCE

The rare earths are widely distributed, but in minute quantitie Clarke and Washington estimate that the igneous rocks of the earth's crust contain on the average 0.02per cent of the oxides of the cerium and yttrium earths, which is more than the average content of copper, zinc, or lead, according to the same authors. The rare earths, however, are not concentrated in large deposits as are copper, zinc, and lead, but occur sparingly distributed in, chiefly, pegmatites and granitic rocks. The rare earths occur as constituents of some 150 or more minerals, nearly all of which are found in visible amounts only in pegmatites and to a less extent in granites. Minerals which contain rare earths almost invariably contain also thorium and uranium, and uranium and thorium minerals usually contain rare earths. This has led many to suspect that there may be some genetic connexion between uranium, thorium, and the rare earths, but nothing definite of this sort has been proved so far. The invariable association of thorium and rare earths with uranium in crystallized uraninite is a good example and might be considered good evidence of genetic relationships were it not for the fact that the amorphous pitchblende carries no thorium or rare earths. It may be that the constant association of these elements is due simply to isomorphous relationships and to the fact that all these elements tend to be concentrated under the same geological conditions. Rare earth minerals areusually complex, generally containing other elements, both rare and common. They form combinations as silicates, phosphates, titanates, and especially as titano-tantalo-columbates, also less frequently as zirconates, carbonates, fluorides sulphates, etc. The silicates are probably most abundant, the phosphates and titano-tantalo-columbates less so. Probably the commonest, most abundant, and widely distributed rare earth mineral is allanite or orthite. This is a silicate of rare earths, iron, alumina, and calcium chiefly, with minor amounts of thorium, uranium, and common elements. Allanite is a rather common mineral in pegmatites, pegmatitic granites, and coarse granite gneisses, and even occurs sometimes in more basic rocks. It is very frequently seen in granites and pegmatites of the Canadian Shield. Monazite, the phosphate of the rare earths and thorium, is also widely distributed, usually as relatively small crystals and grains in pegmatites and granites. Owing to the fact that it resists weathering sufficiently to accumulate in alluvial deposits it is the most readily available ore of thorium and the rare earths. Monazite is discussed in some detail under thorium (page). Apatite, particularly the brown-coloured varieties, appears to carry almost always a small content (up to 5 per cent) or rare earths, chiefly the cerium group. The titano-tantalo-columbates, represented by such minerals as euxenite, polycrase, fergusonite, etc., quite frequently occur in granite pegmatites throughout the world and are among the most frequently occurring rare minerals in the pegmatites of the Canadian Shield. Monazite appears so far to be much less abundant in Canada.

The commercial demand for the rare earths is comparatively small, probably not more than a few hundred tons a year, and is insufficient to use up the earths which are extracted as a by-produc from the recovery of thorium from monazite. There is thus no present demand for other minerals as ores of the rare earths. Many of the rare earth-bearing minerals, however, would be valuable for their content of uranium, thorium, tantalum, or columbium, if they could be produced in sufficient quantities.

Owing to the complexity of the rare earth minerals and the fact that many of them also contain one or more other rare elements such as uranium, thorium, tantalum, columbium, zirconium, beryllium, they are tabulated, in Chapter VIII, along with the uranium and thorium minerals.

CHAPTER VII

URANIUM AND THORIUM

URANIUM

CHEMICAL AND PHYSICAL PROPERTIES

Uranium is a lustrous, white metal which is malleable ductile, and capable of taking a high polish. Its hardness is less than that of glass and it is nearly as heavy as gold, the density being 18.7. Its melting point is about 1,850 degrees, which is about 100 degrees higher than that of platinum. The metal remains unchanged at ordinary temperature in dry air, but polished surfaces become considerably tarnished after a few days exposure to ordinary atmospheric conditions. It burns at 170 degrees C., forming uranous oxide. The metal is chemically very active. It reacts vigorously with fluorine, chlorine, bromine, and iodine. At 1,000 degrees C. it combines with nitrogen, producing a yellow nitride, and it also forms with carbon a well-defined crystalline carbide. Dilute hydrochloric and sulphuric acids dissolve the metal with vigorous evolution of hydrogen. Concentrated sulphuric acid in attacking the metal yields sulphur dioxide. Nitric acid forms the nitrate and evolves brown fumes of nitrogen oxides. Uranium displaces mercury, silver, copper, tin, platinum, and gold from solutions of their salts, in part even in the cold. The metal in powder form as obtained by certain methods of reduction is pyrophoric, taking fire spontaneously on exposure to air. Alloys of iron and uranium containing more than 20 per cent of the latter are also pyrophonic producing sparks when scratched or struck, the activity increasing with increase in the uranium content.

Uranium has the highest atomic weight (238.17) of all the elements and so far as known is the final element (92) in the classification according to atomic number. In chemical behaviour it is most nearly related to the chromium group of elements in the Periodic System. Three oxides are known: uranous oxide UO_2, urano-uranic oxide U_3O_8, and uranic oxide UO_3. A fourth oxide, U_2O_5, has been described, but has not been definitely proved to exist.

Uranous oxide is a brown to black, amorphous or crystalline power depending on the method of preparation. It is obtained by heating either of the higher oxides in hydrogen and by various other methods of reduction. It is the stable oxide under high temperature reducing conditions. The crystalline form has a density of 11.0 and is isomorphous with thorium and cerium dioxides. This oxide was for many years thought by the earlier chemists to be the element itself, as it cannot be further reduced by heating in hydrogen. It can be reduced, however, by heating with carbon at 1,500 degrees C. When heated in air or oxygen it is converted into U_3O_8, the action starting at anout 185 degrees C. It is only slowly attacked by hot, concentrated hydrochloric or sulphuric acids, but dissolves readily in even dilute nitric acid or aqua regia.

The U_3O_8 oxide is produced by heating the other oxides, ammonium uranate, or salts of uranium with volatile acids to 1,000 degrees C. in air. It is an amorphous powder varying in colour from green to black, according to the temperature at which it was heated, and with density 7.3. It is believed to be an association of UO_2 and UO_3 in the proportion of $UO_2.2UO_3$. It is also sometimes considered to be a uranate of uranyl -i.e. -- a compound in which uranium occurs as both base and acid since this element may act in either capacity. U_3O_8 is more soluble than UO_2, dissolving readily in dilute nitric acid and slowly in strong hydrochlorine or sulphuric acids. It is the form in which uranium is commonly weighed and reported in analytical work on minerals and ores.

Uranic oxide, UO_3, is obtained as an amorphous orange to red powder by taking ammonium uranate, uranyl nitrate, or similar compounds to a temperature 300 to 500 degrees C. It is reduced to U_3O_8 on further heating, the reduction being complete at 1,000 degrees C.

Uranium can act either as a base with strong acids or as an acid with strong bases. Thus salts such as uranous and uranyl chloride, sulphates, etc., are formed, and on the other hand uranates and peruranates of the alkalis and the more basic metals can be made.

Uranium salts seem to have the property of absorbing energy from light, which may later be given off in the form of fluorescence. Certain chemical compounds, e.g., oxalic acid, are decomposed by light when present in solution with uranium salts. Such actions are especially marked in the ultra violet part of the spectrum.

The most outstanding and remarkable property of uranium is that of radioactivity, which it shares to a comparable degree only with thorium. This subject is discussed in Chapter , page..

The chief value of uranium as it occurs in minerals is due to the fact that it is the parent of radium a very valuable element for which a demand exists, based chiefly on its use in the treatment of diseases.All geologically old uranium minerals contain radium in amount proportional to the uranium present, the ratio being 3.4×10^{-7} gram of radium per gram of uranium for the best preserved primary uranium minerals. Minerals that have been considerably altered may contain slightly more or less than this proportion of radium, due to enrichment or leaching away of the radium by secondary processes. Radium sells for from $50 to $70 per milligram of element and one milligram of radium is contained in about 6½ pounds of uranium element in minerals. The uranium after extraction of the radium is worth around $1 per pound.

PREPARATION

The U_3O_8 oxide may be reduced by heating with carbon or with magnesium, aluminium, or sodium. The anhydrous chloride may be reduced in the presence of sodium chloride by heating with sodium in a vacuum. By these methods the metal is obtained as a fine black powder which may be in a pyrophoric condition requiring careful subsequent treatment to prevent it from igniting when exposed to air. The metal has also been obtained by electrolysis of sodium uranium chloride using carbon electrodes in an atmosphere of hydrogen. See also, Electrolytic production of thorium and uranium, page....

Ferrouranium , an alloy of uranium and iron used in steel making, is said to be best made by reducing the oxides of uranium and iron with a good grade of coke, using fluorite as a flux in a tilting direct arc type of furnace with water cooled magnesite hearth and sides. In this way a product containing up to 70 per cent uranium can be made, the most useful grade being between 40 and 65 per cent uranium.

UTILIZATION

Uranium has but few commercial applications and probably large stocks, by-products of the radium industry, are in existence waiting a profitable outlet.

In ceramics the oxides and also sodium and ammonium uranate are used to impart yellow, orange, brown, dark green, or black colours to glazes. The oxides are also used in the manufacture of opalescent uranium glass some of which contains as much as 20 per cent of U_3O_8.

Uranium salts have been used as mordants in dyeing and calico printing. Salts of uranium are used to a certain extent in photography and in analytical chemistry. Uranium borate added to rubber is said to increase the tensile strength.

Uranium is used to a certain extent in steels and great virtues have been claimed for it as a steel alloying element in small amounts, not exceeding 0.6 per cent. It is said to be not only particularly effective as a scavenger in removing undesirable impurities, especially oxygen and nitrogen, from the steel, but also it is claimed to enter into combination with certain constituents of the steel either chemically as carbide or as an alloy resulting in increased strength, toughness, and resistance to fatigue, and an improvement in the hardening properties.[1] On the other hand it has been stated that although it increases strength and toughness it does nothing that cannot be as well done by less costly elements.[2] However, it is said to be regularly used in making certain high-speed tool steels, and such steels are said to show from 20 to 50 per cent higher general efficiency than other high-speed steels of the best grade.

Uranium and uranium carbide were found by Haber to be among the best catalysts for the manufacture of ammonia by direct combinations of nitrogen and hydrogen. They have the disadvantage of easily losing their catalytic activity unless very pure

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[1] "Uranium in Steel" ; Pub. by Standard Alloys Company, Pittsburgh.

[2] "Molybdenum, Cerium, and Related Alloy Steels": Gillet and Mack, Am. Chem. Soc. Monograph Series.

hydrogen is used.

OCCURRENCE

Owing to the radioactive properties of uranium and particularly of its associated disintegration product radium, very minute quantities can be detected and measured with fair accuracy by means of the electroscope. In the determination of minute amounts the uranium is calculated from the amount of radium found, which in turn is calculated from the amount of radium emanation produced by a given amount of the substance under test in a given time, the activity of the emanation being measured in a suitable electroscope in comparison with a known standard. By this method it has been found that all rocks contain uranium in minute quantities. It has been calculated that the igneous rocks of the earth's outer crust contain on the average 2×10^{-12} grams of radium per gram of rock and as 3.4×10^{-7} gram of radium is associated with 1 gram of geologically old uranium, therefore the average uranium content of the igneous rocks is 0.0006 per cent, which works out to about 5.4 grams uranium per metric ton of rock. Granites, however, on the average contain more than this proportion, basic rocks and sediments less, the average for granites being about 0.0009 per cent or about 8 grams uranium per ton of rock, and for sediments perhaps half the average for igneous rocks. Soils and meteorites also contain small amounts of uranium. The average content for stony meteorites is about one-quarter that for granite and for iron meteorites less than one-tenth that for the stony variety. Thus it appears that uranium occurs throughout the universe. Spring waters are sometimes quite radioactive and fresh and sea waters in general, as well as the atmosphere, show a slight radioactivity which in these cases, however, is mostly due to traces of radium emanation and its degradation products rather than to the presence of uranium itself. Emanation is constantly escaping in very minute amounts from the soil and from rocks which are undergoing weathering and is picked up by air and water.

Uranium in tangible amounts occurs in a great number and variety of rare minerals usually associated with thorium and the rare earth elements and often with titanium, tantalum, columbium, vanadium, zirconium, hafnium, etc., besides many of the common elements such as iron, manganese, aluminium, calcium, magnesium, sodium, and potassium, etc. All uranium minerals contain lead resulting from the atomic disintegration of the uranium.

The great majority of uranium-bearing minerals are found in pegmatites and more particularly in granite pegmatites. The chief exceptions are :

Pitchblende (page) occurs in mineralized veins related in origin to pegmatites, as in the cobalt-nickel-silver veins of Saxony and Bohemia ,the gold quartz veins of Gilpin county, Colorado the tin lodes of Cornwall, and the silver-bearing pitchblende veins of Great Bear lake in Canada.

Carnotite (page) and related vanadiferous minerals containing uranium are of secondary origin, occurring as impregnations in porous Triassic sandstones in Colorado and Utah. The uranium micas, autunite and torbenite, may also be secondary in sandstones or other rocks. Uranocircite, a secondary hydrous barium uranium phosphate, occurs in peaty muds in old lake bottoms in Madagascar and has been utilized as ore.

Kolm (page) a black carbonaceous rock occurring interbedded with Cambrian slates in Sweden, contains up to per cent uranium. It resembles cannel coal in appearance and to a certain extent in properties containing a considerable amount of hydrocarbons which burn with a luminous flame. Both the slates and the kolm itself contain Cambrian fossils, chiefly fragments of trilobites. Other black carbonaceous slates have been found to contain minute amounts of uranium, which is sometimes accompanied by a little vanadium.

Asphaltic petroleum and black petroleum residues resulting from the natural evaporation or distillation of such petroleum sometimes contain a very little uranium with usually much more vanadium.

In general it may be stated that uranium is concentrated in acid igneous rocks. In sediments it (and vanadium) tends to be associated with carbon and hydrocarbons. Thus even in the case of the carnotite sandstones the richest ore is often found associated with carbonized woody matter.

Uranium is obtained as a by-product of the radium industry. Any mineral containing a considerable percentage of uranium might be workable on account of the radium content, if available in sufficient quantities to warrant commercial operations. Practically, only pitchblende and carnotite have been used to any important degree as ores. Radium and uranium were first obtained from the pitchblende oc occurring in the cobalt-nickel-silver veins of Saxony and Bohemia. Then the carnotite deposits of Colorado and Utah came into prominence and for many years constituted practically the only important source of these elements. About 1923 extensive and very rich deposits of pitchblende and its alteration products in the Belgian Congo were brought into production and resulted in the speedy decline of the American carnotite industry, which with ores averaging only 1 to 5 per cent U_3O_8 could not compete with the rich Belgian ores running 50 per cent U_3O_8 or better.

Other uranium minerals that have been mined for ore in a small way, the total amounts aggregating from less than 100 to a few thousand tons, are Betafite and euxenite from Madagascar; mud containing autunite and uranocircite from a Tertiary lake bed in Madagascar; tyuyamunite, a calcium carnotite from the Tyuya Muyun mountains of Ferghana, Russian Turkestan; davidite, uranium-bearing ilmenite, and complex uranium-acid earth minerals from Olary and Mount Painter, South Australia. Rocks impregnated with autunite and torbernite have been mined in Portugal and Cornwall.

THORIUM

CHEMICAL AND PHYSICAL PROPERTIES

Thorium is a strongly radioactive element like uranium giving rise to a more or less similar series of radio-elements, one of which, mesothorium, is commercially extracted.

Thorium element is a metal resembling platinum in appearance, hardness, and ductility. It has atomic number 90, atomic weight 232.15, density 11.2, and melting point 1,845 degrees C. The metal probably has not yet been obtained in an absolutely pure state. It is ordinarily obtained by reduction methods as a dark grey powder that can be hammered or rolled into a coherent mass. The powder ignites when rubbed or crushed in air and the metal in ribbon form burns brilliantly when heated just below redness, giving off a shower of sparks and forming the white oxide. At 450 degrees it burns brilliantly in chlorine, bromine, iodine, and sulphur; at about 650 degrees it combines directly with hydrogen and nitrogen. The metal is dissolved readily by concentrated hydrochloric acid or aqua regia, but it is only slowly attacked by sulphuric, hydrofluoric, and dilute hydrochloric acids. Nitric acid attacks it vigorously at first, but the metal becomes passive and the action stops. It is not attacked by alkalis. In its chemical reactions thorium resembles zirconium and cerium. The oxide ThO_2 is a white powder obtained by igniting the hydroxide or a salt of an oxy-acid, and is difficultly soluble in acids. Thorium oxide containing 1 per cent cerium oxide forms a mixture which emits a very brilliant light when heated to incandescence and is the basis of the incandescent gas mantle. Pure thorium oxide is much less efficient. The hydroxide is precipitated by ammonia or alkali hydroxides and is insoluble in excess of the reagent, but readily soluble in acids. The fluoride and oxalate are very insoluble and are used for the analytical separation of the element along with the rare earths. From a neutral solution of thorium nitrate hydrogen peroxide precipitates the bulky, gelatinous, thorium, peroxynitrate, an important analytical reaction. The hydroxide and carbonate are soluble in alkali carbonates. Thorium salts and the oxide are colourless or white when pure. The nitrate is the most important salt, being used in the preparation of incandescent gas mantles. Thorium, like uranium, is strongly radioactive.

PREPARATION

The separation and preparation on a commercial scale of pure thorium compounds is effected by various complicated methods [1], the details of which are kept secret. There are many methods available and costs no doubt are the determining factor in commercial practice.

The minerals used as ores, i.e. — monazite, thorite, or thorianite — are soluble in hot concentrated sulphuric acid. On dilution silica and insoluble matter can be filtered off and the thorium

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[1] A good account of such methods is given in Mellors "Comprehensive Treatise on Inorganic and Theoretical Chemistry"; vol.V11,p.178, et.seq.

precipitated by oxalic acid along with rare earths. In the working up of monazite, the ground ore is digested with twice its weight of hot concentrated sulphuric acid, until all the monazite has been decomposed. The pasty mass is then poured slowly into cold water and insoluble mineral particles are filtered off. The thorium and rare earths are now in soluting along with phosphoric acid. By graduated neutralization of the solution with a bas thorium phosphate is precipitated along with some rare earths, while the greater part of the rare earths remain in solution. The thorium-rare earth phosphate precipitate may be dissolved in acid and precipitated as oxalates. The thorium oxalate may then be separated from the rare earth oxalates by treating with ammonium oxalate in which the thorium oxalate is soluble, the rare earth oxalates much less soluble. Or the oxalates may be digested with sodium carbonate in which the thorium is soluble, the rare earths less soluble, the thorium being precipitated by sodium hydroxide.By such methods as these the thorium may be concentrated and gradually separated from the rare earths, the final product being usually thorium nitrate of a high degree of purity. It would evidently be a simple matter to recover the mesothorium present by adding a little barium salt to the original sulphate solution by which the barium and mesothorium sulphate precipitate would be filtered off along with the insoluble material.

An electrolytic method of producing metallic thorium and uranium has recently been devised[1] and it is said that by this method ... "up to the present time the total production of uranium has not exceeded three pounds... The price of the metal depends largely upon the shape and sizes desired, but a basic price of about $75 per pound for the sintered metal is a fair estimate.... In as much as the raw materials, uranium nitrate and thorium nitrate, used in the production of these metals, are readily available ~~in~~ large amounts, the prices mentioned would diminish with increased production."

UTILIZATION

An alloy of tungsten with a little thorium is said to be used in the filaments of incandescent lamps, the function of the thorium being to reduce the tendency of the pure tungsten to crystallize and become brittle with use, at high temperature.

Tungsten wire containing thorium oxide is used as the filament in radio tubes. Such thoriated filaments give an electron emission at a low red heat which is greater than that given by pure tungsten filaments at a much higher temperature, hence these tubes are much more efficient for a given filament current consumption. However, the latest tubes using alternating current to heat the filament, as well as the B series tubes for direct current, utilize a nickel-iron alloy filament coated with a mixture of barium and strontium oxides and have

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[1] "Electrolytic production of thorium and uranium" by F.H. Driggs, Engineering and Mining World, Sept., 1930, pp. 477-478

approximately double the electron emission of the thoriated filament from the same current consumption.

Thorium salts have bacterecidal and antiseptic properties. The oxide has been used as a catalyst in the synthesis of organic chemical compounds. Various thorium salts have been used as constituents of flashlight powders.

The most important use of thorium has been and perhaps still is in the manufacture of incandescent gas mantles. These consist of thorium oxide containing 1 per cent cerium oxide with sometimes trace of beryllium and magnesium oxides. Pure thorium oxide itself is not particularly efficient as a light emitter, but in 1890 A von Welsbach discovered that the luminosity is greatly increased by the addition of 1 per cent cerium oxide and it is said though much research has since been expended in efforts to improve the efficiency of the mantle, no better material has yet been found and even the proportion of thoria and ceria have remained unchanged. Mantles are made by a soaking woven cotton or artificial silk fabrics with a solution containing thorium and cerium nitrates in the proper proportions along with a little beryllium nitrate and magnesium nitrates. The purpose of the beryllium and magnesium is to strengthen the delicate oxide skeleton. The impregnated mantle is dried, and the organic matter burned away while the nitrates are transformed with tenfold increase in volume into light, porous oxides which remain as a coherent skeleton having the same form as the original cotton or silk fabric. The oxide skeleton is then dipped in collodion and dried. The collodion gives sufficient strength to permit handling and shipment of the otherwise very fragile oxide skeleton and is burnt off after the mantle is placed in position for use.

Although it might be thought that the electric lamp had now completely driven out the incandescent gas mantle, there appears to be still a considerable consumption of thorium salts. In 1926 the United States imported 21,390 pounds of thorium nitrate valued at $1.31 per pound, 13 pounds of thorium oxide valued at $1.54 per pound, and 669,760 pounds of monazite valued at $0.036 per pound. Nevertheless, the consumption has greatly decreased and no new uses of importance have so far appeared. As a source of mesothorium, thorium has probably no great commercial interest now that radium is being produced at much reduced prices from the rich Congo ore, though no doubt mesothorium is recovered in working up monazite for thorium. Mesothorium should be present in the ratio of 3 to 5 X 10^{-10} parts to one part thorium, in old unaltered thorium minerals.

OCCURRENCE

Thorium, like uranium, is widely distributed in minute amounts. In general it resembles uranium in distribution, being chiefly concentrated in the acid rocks, particularly granites and pegmatites. It has been estimated that thorium occurs to the extent of 15 X 10^{-6} grams per gram in average igneous rocks, and 20 X 10^{-6} grams per gram in average granite, which is about two and one half times the average uranium content for the same rocks. Thorium or thorium emanation has also been detected in the air, water, spring water, and soils. Thorium occurs in a great number of the rarer pegmatite minerals, particularly with uranium, rare earths, titaniu tantalum, columbium, and zirconium. Most, if not all, minerals which contain uranium also contain thorium in greater or less amount and vice versa. The richest thorium minerals are the oxide thorianite, and the silicate thorite. These are very valuable ores, but only a few tons of these minerals have been produced, chiefly from river sands in Ceylon. Monazite is the chief ore of thorium. It is essentially a phosphate of cerium and yttrium earths containing thorium equivalent to from 1 to 14 per cent thorium oxide. The monazite of commerce is recovered from river and sea beach sands in which the monazite grains originally derived from the weathering of granites and pegmatites have been more or less concentrated by the sorting action of water. Monazite sands have been worked chiefly in Indian, Ceylon, Brazil, North Carolina, and recently in Florida. Average commercial monazite concentrates yield from 6 to 10 per cent ThO_2. The Carolina sands averaged about 4 to 4.5 per cent ThO_2, the Brazilian about 6, and the Indian and Ceylon sands from 8 to 10 per cent or better. The sands are usually concentrated by Wilfley tables or by dry blowing with a final separation of the more magnetic minerals by means of electro-magnetic separators. Sometimes a little gold is recovered as a by-product in the non-magnetic residue. Monazite concentrate minimum 6 per cent ThO_2 was quoted at $120 per ton in 1927. The consumption of monazite has decreased as the electric lamp has displaced the gas mantle, so that in recent years only a few hundred tons have been produced annually.

WORLD'S PRODUCTION OF MONAZITE SAND[1]

(In Metric Tons)

[1] The Mineral Industry, For 1928

	Brazil (a)	United States	Travancore	Ceylon
1912	3,344	9.6	1,135	....
1913	1,415	Nil	1,234	....
1914	599	Nil	1,185	....
1915	439	16.1	1,108	....
1916	Nil	16.5	1,292	....
1917	1,156	34.7	1,940	....
1918	499	(b)	2,117	20
1919	146	(b)	2,057	40
1920	1,153	(b)	1,667	73
1921	335	(b)	1,280	76
1922	115	(b)	127	102
1923	Nil	(b)	251	(c)
1924	Nil	(b)	633	25
1925	20	(b)	0 .05	(c)
1926	200	....	65	(c)
1927	203	(c)	285	(c)

(a) Exports. (b) Less than three producers, no statistics published.
(c) Statistics not available.

CHAPTER VIII

MINERALS CONTAINING URANIUM, THORIUM, AND THE RARE EARTHS

The minerals which contain uranium, thorium, and rare earths are for the most part extremely complex and variable in composition so much so that the chemical constitution of but few of them is known with any degree of certainty. In many, the role of certain of the various oxides present, which may function either as acids or bases, is doubtful. Further difficulties arise from the fact that the uranium and thorium minerals have been subjected to the action of radioactive disintegration and autoxidation so that their composition and presumably their molecular structure is very different now from what it was when they first crystallized from igneous rocks, some millions or hundreds of millions of years ago. Uranium and thorium in time change to lead and helium, so that all primary minerals containing these two elements should also contain lead in proportion to the amount of uranium and thorium originally present and the age of the mineral. This proportion may be more or less altered by natural alteration, leaching, or enrichment. Secondary uranium and thorium minerals derived from the alteration of the primary minerals, may, of course, contain abnormal proportions of lead. The more complex primary minerals of this group offer almost unlimited possibilities for isomorphous replacement of both acidic and basic elements. Thus, for example, different specimens of a mineral species containing titanium, tantalum, and columbium a acids may vary widely in the proportion of these elements present, whereas at the same time the relative amounts of the various associated basic elements may present equally great variations. Often two or more minerals more or less similar in composition, or crystal form, are intergrown in such a way that it is difficult or impossible to obtain either constituent in a pure state.

For all these reasons, and in addition the difficulty particularly in the past of making accurate chemical analyses of these complex minerals, the matter of their exact mineralogical classification, definition of species, nomenclature, etc., is in a more or less uncertain state. In the following list, the minerals have been placed for convenience in alphabetical order in groups according to their chief acid radiale. For more detaild descriptions and analyses, Dana "System of Mineralogy" and Appendices, Hintze "Handbuch der Mineralogie", and the "Handbuch der Mineralchemie" by Doelter and others should be consulted. The two latter works are particularly complete and comprehensive.

All minerals containing uranium and thorium are radioactive so that the presence of these elements may be detected by means of the electroscope, the scintilloscope, or by their action on photographic plates. Electroscopic tests for radioactivity are made on minerals of Canadian origin free of charge by the Geological Survey.

Fluorides.

Fluocerite. Fluoride of the cerium earths ($((Ce, La, Di)F_3])$) Occurs in pegmatite, Sweden.

Yttrocerite. Fluoride of calcium, yttrium, and cerium earths.

Yttrofluorite. Fluoride of calcium, yttrium earths, etc. Occurs in a Norwegian pegmatite.

Oxides, Hydroxides.

Becquerelite. Hydrous uranic oxide ($UO_3 \cdot 2H_2O$) with some lead oxide An alteration product of pitchblende. Lambertite is a mineral said to be uranium oxide (UO_3).

Ianthinite. Contains water, uranium and iron. Occurs with becquerelite in veins in pitchblende and, apparently, alters to becquerelite.

Fourmarierite. Hydrous oxide of uranium and lead, or hydrous uranate of lead. An alteration product of pitchblende.

Pitchblende. Probably in most cases essentially uranium oxide (U_3O_8) with small amounts of iron, manganese, aluminium, calcium, magnesium, silica, etc., and more or less lead and helium derived from uranium by radioactive disintegration. Uranium constitutes from 40 to 76 per cent of the mineral. Pitchblende never occurs in crystals, it is always massive, typically black with a pitch-like lustre. It is very heavy and rather hard. Pitchblende occurs in veins mineralized with gold, silver, cassiterite, cobalt-nickel arsenides, various sulphides, etc.

Schoepite. Hydrous oxide of, chiefly, uranium .An alteration product of pitchblende.

Thorianite. Essentially an oxide of thorium and uranium ($(Th, U)O_2$). Occurs in pegmatites in Ceylon.

Thorotungstite. Hydrous oxide of, chiefly, tungsten and thorium. Results from the decomposition of scheelite or wolframite and some rare earth mineral.

Uraninite. Believed to consist, essentially, at the time of formation of uranium oxide (UO_2) with some thorium oxide (ThO_2) and rare earth oxides. A little UO_3 may have been initially present By radioactive disintegration uranium and thorium change in part to lead an helium and due to radioactive autoxidation and material alteration part of the UO_2 becomes oxidized to UO_3. The uranium content ranges from 54 per cent to 75 per cent. Occurs usually in crystals or in forms showing indications of crystallization. Least altered specimens are iron grey, brooming black by alteration. As a result of more pronounced alteration, the mineral is coated with decomposition products that are scarlet, orange, yellow, greenish, greyish or brownish. The mineral is rather hard, very heavy. When fresh it has almost a metallic lustre, when altered the lustre tends to be pitch-like or dull. Has been found in pegmatites.

Carbon Compounds.

Ancylite. Hydrous carbonate of cerium and strontium ($2CeO_3\cdot3\ SrO\cdot7\ CO_2\cdot5\ H_2O$). Has been found in pegmatite.

Bastnaesite. Fluocarbonate of the cerium earths.

Cordylite. Fluocarbonate of the cerium earths and barium. Found i pegmatites.

Kischtimite. Hydrous fluocarbonate of the cerium earths.

Lanthanite. Hydrous carbonate of lanthanum ($La_2O_3\cdot CO_2\cdot 9H_2O$).

Liebigite. Hydrous carbonate of uranium and calcium.

Parisite. Fluocarbonate of the cerium earths and calcium. Found in pegmatites.

Rutherfordine. Uranium carbonate. An alteration product of uraninite.

Schroeckingerite. Hydrous uranium carbonate. An alteration product of uraninite.

Tengerite. Carbonate of yttrium and beryllium (possibly a mixtu Has been found coating gadolinite.

Thucholite. Chemical composition unknown. Contains carbon, hydrogen, oxygen, water, thorium, uranium, caesium, the ytterbium-erbiu group earths, vanadium phosphorus, calcium, silicon and other common elements.

Uranothallite. Hydrous carbonate of uranium and calcium. Occurs encrusting uraninite.

Voglite. Hydrous carbonate of uranium, calcium and copper. Occurs

Silicates.

Alvite, Cyrtolite, Zircon, Etc., See Chapter IV, zirconium and hafnium-bearing minerals.

Allanite or Orthite. Complex silicate of ceasium, yttrium, iron, aluminium, and lime with minor amounts of other elements. Common in pegmatites and granites.

Bazzite. Silicate of scandium and other rare earths with some iron and sodium.

Beckelite. Silicate of, chiefly, cerium group earths and calcium, some yttrium and zirconium. Known to occur in a nepheline rock, U.S.S.R.

Bodenbenderite. Complex silicate and titanite of, chiefly, manganese, yttrium, earths and aluminium. Found in veins of albite and fluorite.

Buszite. Supposed to be a silicate of the rare earths. Found, in one instance, intergrown with beryl.

Cappelenite. Borosilicate of, chiefly, yttrium and barium. Found in a vein in nepheline syenite.

Caryocerite. Complex fluosilicate of thorium, caesium, yttrium, calcium, etc. Occurs in pegmatite dykes in nepheline syenite, Norway.

Cenosite. Hydrous silicate of, chiefly, yttrium and calcium ($2\ CaO\ (Yt,Er)_2O_3 \cdot CO_2 \cdot 4SiO_2 \cdot 2H_2O$).

Cerite. Hydrous silicate of the cerium group with a little iron, calcium and aluminium.

Eucolite and Eudialyte. Silicate, zirconate, and chloride of sodium, potassium, calcium, cerium, iron, etc. See Chapter IV, zirconium and hafnium-bearing minerals.

Ferrothorite, (variety of thorite). Hydrous silicate of thorium, iron, and uranium.

Gadolinite. Silicate of, chiefly, yttrium, beryllium and iron ($2\ BeO \cdot FeO \cdot 2\ Yt_2O_3 \cdot 2SiO_2$). Occurs in granite pegmatites and is one of the most abundant of the rare minerals. It has been found in masses weighing as much as 60 pounds.

Garnet. Essentially silicate of calcium, magnesium, iron, manganese, aluminium, chromium and titanium. Some garnets contain small amounts of rare earths, uranium and thorium; it is not certain whether these elements are constituents of the garnet or of other minerals included in the garnet.

Hainite. Silicate of sodium, calcium ceasium, zirconium, titanium, etc.

Hellandite. Hydrous silicate of the rare earths, calcium, aluminium, iron, and manganese. Occurs in pegmatites, Norway.

Hydrothorite. Hydrous silicate of, chiefly, thorium. An alteration product of mackintoshite.

Johnstrupite. Fluosilicate and titanite of, chiefly, caesium, calcium and sodium.

Kasolite. Hydrous silicate of uranium and lead.

Keilhautite. Titano-silicate of calcium, aluminum, iron, and rare earths.

Lessingite. A silicate of, chiefly, the cerium earths and calcium.

Mackintoshite. A hydrous silicate of, chiefly, thorium and uranium. Mackintoshite is possibly merely uranothorite less altered than usual. Occurs in a pegmatite, Texas.

Melanocerite. S complex fluosilicate, borate, and tantalate of, chiefly, rare earths and calcium. Occurs in southern Norway.

Mosandrite Hydrous titano-silicate of cerium and calcium, chiefly ,- near johnstrupite. Occurs in Norway.

Naegite Chiefly zirconium silicate. Probably related to cyrtolite. Found in Japan in placer tin deposits.

Pilbarite. Hydrous silicate of thorium, uranium, and lead. ($ThO_2 \cdot UO_3 PbO \cdot 2 SiO_2 \cdot 4 H_2O$). An alteration product of a primary pegmatitic mineral. Occurs in a pegmatite worked for tantalite in Australia. The pegmatite is about 30 feet wide bordered on each side by 4 or 5 feet of coarse albite with a little quartz and black mica in which tantalite and radioactive minerals occur.

Rinkite. Fluosilicate and titanate of cerium earths, calcium and sodium. Near johnstrupite and mosandrite. Occurs in Greenland.

Rosenbuschite, Silicate, titanite, and zirconite of, chiefly, calcium and sodium. Occurs sparingly in southern Norway.

Rowlandite. Fluosilicate of yttrium and cerium earths, chiefly. Occurs in a pegmatite in Texas, as rather large lumps with glassy interior externally altered to a waxy, brick-red substance, chiefly a carbonate of the rare earths and lime.

Sklodowskite Hydrous silicate of uranium and magnesium. Chinkolobwite previously described is identical with Shlodowskite (Min. Mag., Sept. 1826, p.115). Occurs in Belgian Congo.

Soddite. Hydrous silicate of uranium. Formula, perhaps, 5 $UO_3 \cdot 2SiO_2$ $6H_2O$. Occurs in Belgian Congo.

Rare Earth-Bearing Kaolin (Takizolite). Hydrous silicate of alumina. ($2Al_2O_3 \cdot 7\ SiO_2 \cdot 7\ H_2O$). Soft. From an altered granite, Japan.

Thalenite Hydrous yttrium silicate. Related to yttrialite and rowlandite. Occurs in Sweden.

Thorite. Hydrous silicate of thorium, chiefly, with usually considerable uranium and iron. Occurs in pegmatites.

Variety - **Uranothorite**, has high uranium
Calciothorite, has high calcium
Ferrothorite, had high iron

Thortveitite Silicate of scandium and yttrium earths. Formula essentially $(ScYt)_2O_3 \cdot 2\ SiO_2$. Befanamite is the nearly pure scandium end member from Madagascar. Occurs in pegmatites.

Titanite (Syn. Sphene). Essentially a titanosilicate of calcium with some iron and manganese. Formula $CaO \cdot TiO_2 \cdot SiO_2$. In some cases contains small amounts of rare earths up to 5 per cent. Rare earth bearing varieties have been called grothite, alskedite, and eucolite-titanite. Common in acidic rocks and pegmatites. Small amounts of rare earths have been found in several Canadian examples. Very large titanate crystals occurring in Ontario contain about ½ per cent of rare earths.

Toernebohmite. Hydrous silicate of cerium group earths and aluminium. Occurs in Sweden. The deposit is believed to be a contact metamorphic replacement of limestone.

Tritomite. Hydrous fluo- and boro-silicate of rare earths, thorium and calcium, chiefly. Occurs in nepheline syenite pegmatites in Norway.

Tscheffkinite. Titanosilicate of chiefly, cerium earths and iron.

Uranophane (Syn. Uranotil) Hydrous silicate of uranium and calcium. Soft, yellow. Occurs as an alteration produce of gummite with uraninite.

Yttrialite. Silicate of yttrium earths and thorium. Occurs in masses up to 10 pounds in weight associated with gadolinite in pegmatite in Texas.

TITANATES, TANTALATES, COLUMBATES

Aeschynite or Eschynite. Titanate and columbate of cerium and thorium chiefly, with some calcium and iron. Occurs in pegmatites.

Ampangabeite Columbate, tantalate, and titanate of uranium, thorium, rare earths, iron. etc. Occurs often in parallel growths with columbite. In pegmatites, Madagascar.

Betafite. Columbate and titanate of, chiefly, uranium. Common in the pegmatites of Madagascar.

Blomstrandite. Hydrous titano-tantalo-columbate of, chiefly, uranium, calcium, and iron. Occurs in pegmatites.

Brannerite. Titanate of, chiefly, uranium, thorium, and rare earths. Occurs as small pebbles and rough crystals from a placer gold deposit in Idaho. Derived from pegmatites in the vicinity.

Chalcolamprite Columbate, silicate, and fluoride of, chiefly, calcium, cerium, and sodium. Related to pyrochlore. Occurs sparingly in southern Greenland.

Delorenzite. Essentially a titanate of rare earths, uranium, iron and tin. Probably the titanium end of the euxenite group. Occurs in pegmatites in Italy.

Dysanalite. Titanate, columbate, and tantalate of calcium chiefly. Related to perovskite and pyrochlore. Occurs in granular limestone in Baden; in Arkansas.

Ellsworthite Hydrous titano-tantalo-columbate of, chiefly, uranium, lime, and iron. Occurs with cyrtolite in salmon-coloured calcite and smoky quartz in pegmatite at Hybla, Ont. As crystals in red calcite with apatite, biotite, magnetite, pyroxene, etc., in Haliburton, Ont.

Eschwegite. Hydrous titano-tantalo-columbate of yttrium earths, chiefly. Formula: $5\ (YtEr)_2O_3\cdot 6\ (Ta\ Cb)_2O_5\cdot 10\ TiO_2\cdot 7\ H_2O$.
It is found as pebbles in Brazil. Resembles rutile.

Euxenite group. Essentially titano-tantalo-columbates of rare earths, uranium, thorium, iron, and calcium. An isomorphous series in which the percentages of both acid and basic elements may vary widely.

Priorite and Blomstrandine are similar in chemical composition but are believed by W.C.Brogger to differ from euxenite-polycrase in their crystallographic constants.

Lyndochite is the low uranium end of the euxenite group containing less than one per cent uranium as U_3O_8.

Tanteuxenite is the high tantalum member.
Delorenzite may be the high titanium member.

Euxenite has $Cb_2O_5+Ta_2O_5 : TiO_2 = 1: 3$ or less.[1]

Polycrase has $Cb_2O_5+Ta_2O_5 : TiO_2 = 1: 4$ or more.[1]

Occur in granite pegmatites; perhaps the most frequently occurring uranium minerals of pegmatites. Colour is black to brownish black.

Fergusonite. Columbate and tantalate of rare earths, thorium, uranium, iron, and calcium. Occurs in pegmatites.

Hatchettolite Tantola-columbate of, chiefly, uranium, calcium, and iron. Pyrochlore group. Occurs in muscovite-bearing pegmatites with samarksite.

Hielmite. Stanno-tantalate and columbate of uranium, rare earths, iron, manganese, and cerium. Occurs in pegmatite in Sweden.

Ishikawaite Columbate and tantalate of, chiefly, uranium, iron and rare earths. Occurs with samarskite in Japan.

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[1] Brogger, W.C.: Videnskabs - Selskabet Skrifter, No. 6, 1906; p.92.

Kalkowskite Chiefly a titanate of iron. A sample analysed carried some mica and monazite. Occurs as platy grains in a schistose mass of fine flaky muscovite, associated with zircon and monazite, in Brazil.

Knopite. Titanate of calcium, chiefly, with some rare earths, iron, etc. Related to perooskite. Occurs in crystalline limestone in Sweden; with magnetite in pegmatites associated with nepheline rock in British Columbia. It is black.

Koppite. Columbate of cerium earths, calcium, sodium, and potassium It is of brown colour and occurs with apatite in a granular limestone in Baden.

Loparite. Titanate of cerium earths, calcium and sodium. Related to perooskite-knopite group. Occurs in nepheline sysnite in Russia.

Microlite. Chiefly tantalate of calcium. Occurs in pegmatites. In Virginia it occurs in crystals up to 4 pounds in weight with monazite, fluorite, beryl, columbite and spessartite.

Polymignite. Columbate, titanate, and zirconate of cerium earths, iron, and calcium. Black and hard. Occurs in Norway and reported from a few other places.

Pyrochlore. Titano-columbate of, chiefly, calcium, rare earths, and thorium. Occurs in nepheline syenite and pegmatite.

Risorite. Columbate, tantalate, and titanate of the yttrium earths chiefly. Occurs in pegmatite in southern Norway.

Samarskite. Tantalo-columbate of, chiefly, uranium, cerium, and yttrium earths and iron. Occurs in pegmatites. Calciosamarskite, a variety with much lime, occurs in Ontario.

Sameresite. Hydrous columbate, titanate, and tantalate of uranium chiefly. Occurs in beryl-bearing pegmatites in Madagascar, intimately associated with brown zircon crystals, native bismuth, and altered biotite. Galena altered to pyromorphite also occurs in the same pegmatites, which may account for the samiresite being unusually rich in lead.

Sipylite. Columbate of erbium, lanthanum, didymium, uranium, iron, lime, etc. Hard. Occurs sparingly embedded in or adhering to masses of allanite and magnetite, in Virginia.

Tanteuxenite. Titano-columbo-tantalate of chiefly yttrium and cerium earths. Occurs as worn pebbles in stream tin deposits in Pilbara district, western Australia, and in pegmatites at Woodstock western Australia.

Toddite. Tantalo-columbate of, chiefly, iron, uranium, rare earths manganese and calcium. Hard and pitch black. Occurs with columbite in pegmatite at Sudbury, Ont.

Wiikite . Hydrous complex titano-tantalo-columbate of yttrium, and cerium earths, uranium, iron, etc., isomorphous with samarskite. Occurs in pegmatites consisting of quartz, potash feldspar, and biotite with monazite, allanite, and nuolaite, in Finland.

Yttrocrasite Hydrous titanate of, chiefly, yttrium earths and thorium. Found in Texas. Black.

Yttrotantalite. Hydrous tantalate and columbate of, chiefly, yttrium earths, iron, and calcium. Occurs in pegmatites.

Zirkelite. Zirconate and titanateof iron, calcium, thorium, rare earths, etc. Occurs with baddeleyite, perovskite, etc., in the decomposed magnetite-pyroxenite in Brazil. Also from the gem gravels of Ceylon.

PHOSPHATES

Apatite. Essentially calcium, fluophosphate and chlorophosphate. Both fluorine and chlorine may be present. Rare earths are sometimes present in amounts up to 5 per cent. Common in contact metamorphic rocks, basic rocks, and calcite-fluorite-apatite-fledspar pegmatites. Sometimes occurs in granite pegmatites. Brownish and reddish apatites from Ontario localities have been found to contain small amounts of rare earths.

Auerlite. Hydrous silicophosphate of thorium. Soft. Associated with zircon, sometimes in parallel growths in decomposed granite, in North Carolina.

Autunite. Uranium,calcium, phosphate. $CaO.2UO_3.P_2O_5.8H_2O$. Soft and yellow. Occurs in pegmatites and pegmatitic veins with uraninite, pitchblende, cassiterite, silver ores, etc.

Bassetite Hydrous phosphate of uranium and calcium. $CaO.2UO_3.P_2O_5.8H_2O$. Occurs in Cornwall.

Churchite. Hydrous phosphate of calcium and cerium. $3\ CaO \cdot 5\ Ce_2O_3 \cdot 6\ P_2O_5 \cdot 24\ H_2O$. Occurs as a thin coating in quartz in a copper lode Cornwall, England.

Dewindtite (Sym.Stasite) Hydrous phosphate of uranium and lead. Formula: $3\ PbO \cdot 5UO_3 \cdot 2\ P_2O_5 \cdot 12\ H_2O$. Dewindtite and stasite, originally described as different minerals, are now considered by their describer, A. Schoep, to be varieties of the same compound. Canary yellow colour. Occurs impregnating torbernite in Belgian Congo.

Dumontite. Hydrous phosphate of lead and uranium. Formula: $2\ PbO \cdot 3UO_3 \cdot P_2O_5 \cdot 5\ H_2O$. Found in pockets in torbernite in Belgian Congo.

Florencite. Hydrous phosphate of aluminium and cerium earths. Occurs as a rare constituent of cinnabar-bearing sands in Brazil.

Fritzscheite. Hydrous phosphate of uranium, manganese, and vanadium — resembles autunite. Soft. Occurs with autunite and torbenite, Bohemia.

Georceixite Hydrous phosphate of aluminium, barium, calcium, and cerium. $(BaCaCe)\ O \cdot 2Al_2O_3 \cdot P_2O_5 \cdot 5\ H_2O$. Hard. Occurs in rolled pebbes in diamond sands, Brazil.

Monazite. Phosphate chiefly of the cerium earths with some thorium and yttrium earths. Occurs in crystals in pegmatites and as small grains in acid igneous rocks; as rolled grains in place and beach sand deposits derived direct from igneous rocks. Commercial production chiefly from beach sand or placer deposits in India and Brazil. In Canada occasional crystals in pegmatites. Has been found in small amounts in many pegmatites throughout the world.

Parsonite. Hydrous phosphate of, chiefly lead and uranium. Hard. Occurs in Belgian Congo.

Phosphuranylite. Hydrous uranium phosphate. Deep lemon-yellow colour. Occurs as a pulverulent incrustation with other uranium minerals in North Carolina.

Renardite. Hydrous phosphate of uranium and lead. Yellow. Found as minute crystals with quartz, trobernite, and clay in Belgian Congo. Resembles dewindlite and dumontite.

Rhabdophanite. Hydrous phosphate of lanthanum, didymium, ytterbium, erbium. Rather soft. Occurs very sparingly on limonite and pyrolusite in Cornwall.

Torbernite. Hydrous phosphate of uranium and copper. Soft. Micaceous cleavage.

Uranocircite. Hydrous phosphate of uranium and barium. Has a yellow-green colour and is soft. Occurs in quartz veins, Saxon Voigtland.

Uranospathite. Hydrous phosphate of uranium and calcium. Like bassetite. Soft.

Weinschenkite. Hydrous phosphate of the yttrium erbium earths. Formula: $(Yt\ Er)(PO_4)(H_2O)_2$ with $Yt:Er = 5:1$. Colour is white.

Occurs as a coating on limonite iron ores in Bavaria.

Xenotime. Phosphate of the yttrium earths, chiefly. Occurs in pegmatites.

ARSENATES

Retzian. Hydrous arsenate of manganese, rare earths, and calcium. Rather soft. Occurs sparingly with jacobsite in small drusy cavities in the manganiferous limestone of Moss mine, Sweden.

Troegerite. Hydrous arsenate of uranium. Lemon yellow colour, and soft. Occurs with walpurgite and other uranium minerals in Saxony; also with uraninite in South Dakota.

Uranospinite. Hydrous arsenate of uranium and calcium. Soft. Occurs with uraninite and various secondary uranium minerals in Saxony.

Walpurgite. Hydrous arsenate of bismuth and uranium. Wax yellow colour. Rather soft. Occurs with troegerite and other secondary uranium minerals in Saxony.

Zeunerite. Hydrous arsenate if uranium and copper. Soft. Occurs with other uranium minerals in various areas.

URANATES, VANADATES

Carnotite. Hydrous vanadate of, chiefly, uranium and potassium with also calcium and barium. $K_2O \cdot 2UO_3 \cdot V_2O_5 . 8 \pm H_2O$. The Colorado varieties contain up to 0.90 P_2O_5 and 1.03 Ba O.

See also tyuyamunite which is calcium carnotite $CaO2UO_3 \cdot V_2O_5 \cdot 8 \pm H_2O$.

Soft and of yellow colour. Occurs as a powdery impregnation in

Triassic and Jurassic sandstone in Colorado and Utah. As powdery encrustations in joints and cavities of a lode composed chiefly of quartz, magnetite, and black mica with some tscheffkinite at Olary, South Australia; also in small amounts in coarse-grained conglomerate of the Pottsville formation(Pennsylvania) at Mauch Chunk, Pa. Oreof radium, uranium, and vanadium.

Curite. Hydrous uranate of lead. Formula: $2\ PbO \cdot 5UO_3 \cdot 4H_2O$ .Occurs with torbernite and other minerals in Belgian Congo.

Gummite. Hydrous silico-uranate of lead, calcium, etc., of indefinite composition. Soft. Alteration produce of uraninite, often associated with the latter, wherever found.

Rauvite. Hydrous calcium uranium vanadate. Formula:$CaO \cdot 2UO_3 \cdot 6V_2O_5 \cdot 20\ H_2O$. Fills spaces between grains of sand, in asphaltic sandstone at Temple mountain, Utah.

Tyuyamunite. Hydrous vanadate of uranium and calcium,-calcium carnotite. $CaO \cdot 2UO_3 \cdot V_2O_5 \cdot 8 \pm H_2O$. Yellow and soft.

Uranosphaerite. Hydrous uranate of bismuth, $Bi_2O_3 \cdot 2UO_3 \cdot 3\ H_2O$. Soft. Occurs with other uranium minerals in Saxony.

Uvanite. Hydrous vanadate of uranium. $2\ UO_3 \cdot 3\ V_2O_5 \cdot 15\ H_2O$. Disseminated in rock near Greenriver, Utah.

SULPHATES

Gilpinite. Hydrous sulphate of, chiefly, uranium, copper, iron, and sodium.$(Cu,Fe,Na_2)O \cdot UO_3 \cdot SO_3 \cdot 4\ H_2O$ .Soft. Occurs as coatings on green copper ore and pitchblende and associated with gypsum.

Resembles johannite and uranopilite.

Johannite. Hydrous sulphate of uranium and copper. Soft and emerald green. A secondary mineral from pitchblende, in Bohemia.

Uraconite. Hydrous sulphate of uranium, copper, and calcium. Lemon-yellow and soft. From the alteration of uraninite, Bohemia.

Uranochalcite. Hydrous sulphate of uranium, copper, and calcium. Green and soft. From the alteration of uraninite, Bohemia.

Uranopilite. Hydrous sulphate of uranium and calcium. $CaO \cdot 8UO_3 \cdot 2 SO_3 \cdot 25 H_2O$. Lemon yellow powder. Occurs as encrustations on uraninite and mica schist in Bohemia.

Zippeite. Hydrous sulphate of uranium. Formula probably. $2UO_3 \cdot SO_3 \cdot 4H_2O$. From the alteration of uraninite, Bohemia.

CHAPTER IX

RADIOACTIVITY AND THE RADIO-ELEMENTS

RADIOACTIVITY

INTRODUCTION

Radioactivity is a term applied to the property possessed only by a few elements of spontaneously giving off radiation of an extraordinary character. It has nothing to do with the science of wireless communication —"radio" so-called, — with which it is sometimes popularly supposed to be connected in some mysterious way. The rays comprising radioactive radiation are in part entirely different from others common to human experience such as light, heat, wireless or radiowaves, etc. One or more of three distinct kinds of rays are emitted by radioactive substances; the alpha, beta, and gamma rays. The alpha rays are nuclei of atoms of the gas helium each carrying two unit charges of positive electricity, and travelling at an initial velocity of about 10,000 miles per second. When these positively charged nuclei are neutralized by electrons they become atoms of ordinary helium. The beta rays consist of electrons that are nothing more than minute unit particles of negative electricity ejected at a velocity approaching that of light — i.e., 186,000 miles per second. Thus the alpha rays consist of minute, positively electrified particles comprising the major part of the atoms of an actual material substance the gas helium which has weight and is identical with ordinary helium gas obtained in other ways, whereas the beta rays are identical with the electrons emitted by the red-hot filament of a radio vacuum tube except that in the latter case the electrons are thrown off from the red hot metal at a much lower velocity. The initial velocity of alpha and beta rays varies considerably with different radioactive substances, the figures cited being approximate maxima. The gamma rays are ether vibrations of the same nature as light, wireless waves, and ordinary X-rays, but of much shorter wave length than even X-rays. It has been estimated that it would be necessary to use 2,000,000 volts on a X-ray tube in order to produce X-rays as short as gamma rays.

The three types of rays differing so fundamentally in character, naturally possess very different properties and each produces distinct effects. The alpha rays consisting of comparatively large and heavy nuclei of atoms of helium and travelling at a much lower velocity than the beta and gamma rays, have the least penetrating power and are stopped even by a sheet of paper or tinfoil. The beta rays composed of the much more minute electrons which have a mass of about $\frac{1}{1,834}$ of that of the hydrogen atom or about $\frac{1}{7,000}$ of that of the helium atom and travelling nearly as fast as light are, therefore, more penetrati and can pass through as much as 3 millimetres thickness of aluminium Both alpha and beta particles thus have size and weight and are actually minute fragments of the original parent atom thrown off like projectiles at tremendous velocity by the radioactive substances.

As the alpha and beta particles are electrically charged, they are deflected in electric or magnetic fields. On the other hand the gamma rays are not material and carry no electrical charge, being no more than an electro-magnetic wave motion of very short wave length propagated through the ether at the speed of light. The penetrating power of such rays is the greater the shorter their wave length, hence gamma rays have very great power of penetration, exceeding ordinary X-rays in this respect. It has been found that the gamma rays will penetrate a foot of iron. The penetration is less the greater the density of the substance bombarded, hence lead being a cheap element of high density is commonly used as a protective material to shield workers from X-rays and radioactive radiations.

The range of the various rays in air, as might be expected, corresponds to their penetrating power. Alpha rays travel not more than about 8 centimetres, being soon stopped by collisions with the oxygen and nitrogen atoms of the air. Electrons of the beta rays may travel as much as 250 cm. in air, whereas gamma rays from radium are only half absorbed after passing through 115 metres of air and their intensity is reduced to $\frac{1}{100}$ only after traversing 760 metres.

All three rays have the power of affecting a photographic plate, the beta rays being much more active than the alpha or gamma rays in this respect. They excite luminescence in various chemicals and minerals, hence radioactive substances are mixed with a specially prepared impure zinc sulphide, for example, to make luminous paint. The alpha particles are chiefly concerned in producing luminescence, the action of the beta and gamma rays being relatively feeble. The luminescence of a zinc sulphide screen acted on by alpha particles appears to the unaided eye as a steady glow, but if observed under the microscope it is seen to consist of countless individual flashes each caused by the impact of a single alpha particle. By a suitable arrangement it is possible in this way to county the number of alpha particles thrown off by a known weight of substance in a given time and thus determine the rate of disintegration of the substance. Highly active substances such as salts of radium and mesothorium themselves glow in the dark though this effect is said to be due to traces of impurities and they excite luminescence in the glass containers.

THERMOLUMINESCENCE OF COMMON MINERALS ASSOCIATED WITH RADIOACTIVE MINERALS IN PEGMATITES

It has been found that feldspar, mica, and calcite that have been in the neighbourhood of radioactive minerals in pegmatite possess the property of glowing strongly in the dark when heated. This thermoluminescence may last for several minutes, but finally ceases and cannot be re-excited by cooling and heating nor by exposure to sunlight. This peculiarity of feldspars and micas that have been subjected to radioactive radiations for millions of years apparently is not generally known, as it does not seem to be mentioned in the literature, though thermoluminescent calcite has been described. This discovery was made accidently and independently by two parties of prospectors searching for radioactive minerals in different parts of Ontario and came about as a result of placing mineral specimens on a hot camp stove at night.

It is well known that certain minerals become thermoluminescent after artificial exposure to strong radium radiations so there can be little doubt that the natural thermoluminescence is produced in the same way by weaker radiations acting over tremendously long time periods.

COLOUR CHANGES DUE TO RADIATIONS

The radiations produce markedcolour changes in glasses and gem minerals, and may either decolorize, cause a colour to appear in a previously colourless substance, or change the colour of a naturally coloured material. One of the most interesting natural examples of such coloration is the occurrence of pleochoric haloes in the micas of igneous rocks. These haloes are seen occasionally in thin rock sections under the microscope as darker-coloured circular areas or rings surrounding minute inclusions, most often in mica but sometimes in other minerals, and represent a cross-section of a spherical mass of the mica which has been coloured by the action of alpha radiation from radioactive substances contained in the inclusion. The dark "smoky" quartz which is often found associated with radioactive minerals in pegmatites is believed to owe its colour to the action of radiation from radioactive substances, whereas pink or red feldspar in contact with radioactive minerals is usually a darker red colour than it is elsewhere. The dark purple fluorite sometimes found in pegmatites and veins of igneous origin also probably owes its colour to radioactive radiations. Lind states that the colour of materials such as glass and minerals which have been artificially coloured by exposure to radium radiation, can be discharged by heating to a fairly high temperature. This is also true of the naturally coloured minerals just mentioned. Smoky quartz and purple fluorite heated to about 500 degrees C. become colourless whereas the dark red feldspar loses the greater part, if not quite all, of its colour by similar treatment.

IONIZING EFFECTS

All the radiations have the power of ionizing gases, that is, they cause gases to become conductors of electricity, the alpha rays being much more effective than the others in producing this effect. Hence all three rays will discharge an electroscope, by rendering the surrounding air conductive and thus enabling the charge to leak away. This property constitutes an extremely sensitive method of detecting even the most minute quantities of radioactive matter and is much used for the detection and quantitative estimation of such substances.

CHEMICAL EFFECTS

Marked chemical effects are produced by all three rays, but particularly by the alpha and beta rays. Only a few examples need be mentioned in this field, to which a whole volume[1] has been devoted recently. In general the radiations may be said to exert chiefly disintegrative and oxidizing effect on substances exposed to their action. Thus water is broken up into hydrogen, oxygen, and hydrogen peroxide; carbon monoxide and dioxide are decomposed into their constituent elements; ammonia is decomposed into nitrogen and hydrogen; organic compounds are decomposed into their gaseous elements. On the other hand the radiations may initiate or accelerate certain chemical reactions of combination.Alpha rays are very effective in producing ozone in passing through the air and probably for this reason rapidly oxidize metals exposed to their action

The internal bombardment of radioactive substances by their own radiations, especially by the alpha particles which possess great energy, must be at least partly responsible for the continuous generation of heat by these elements. One gram of radium element continuously produces about 130 calories per hour, which is enough heat to melt one and one-half times its own weight

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[1] Lind, S.C.: "The Chemical Effects of Alpha Particles and Electrons Pub. by the Chemical Catalog.Co.Inc.,One Madison Ave.,New York, U.S.A., Price $3.65

of ice every hour.

PHYSIOLOGICAL EFFECTS

The radiations from appreciable amounts of very active substances such as radium, mesothorium, and their emanations will cause severe burns or even kill living tissue. Certain types of cells appear to be more affected than others. Thus radium is much used in the treatment of cancer and other abnormal tissue growths, also in certain skin diseases. Water containing minute traces of radioactive substances is supposed to be beneficial when used for drinking and bathing. The gamma rays more particularly are utilized for therapeutic purposes, the active preparation being usually contained in metal applicators sufficiently thick to stop all alpha rays and much of the beta radiation.

RECOIL ATOMS

When alpha or beta particles are ejected the parent atoms tend to recoil just as a gun does when it is fired, following the law that action and reaction are equal and opposite. Under suitable experimental conditions not only can the phenomena of recoil be demonstrated but such "recoil atoms" can even be collected for study. Atoms which in this way lose alpha or beta particles change into new elements. The loss of an alpha particle diminishes the atomic weight by 4 (the atomic weight of the helium atom) and even the loss of the minute beta particle alters the properties of the parent atom, though the atomic weight remains practically the same.

DISINTEGRATION AND TRANSMUTATION OF INACTIVE ELEMENTS BY THE ACTION OF ALPHA PARTICLES

The ancient alchemists were much concerned with attempts to change one element into another, preferably lead to gold, but always without success. Within recent years Rutherford and other by utilising for this purpose the tremendous concentrated energy of alpha particles have been able to change exceedingly minute quantities of certain elements into other elements of lower atomic weight. Thus, when nitrog and several other elements of low atomic weight were bombarded by alpha particles occasional atoms of hydrogen could be detected, the conditions being such that the hydrogen could have resulted only from the disruption of the nitrogen or other atoms acted on by the alpha particles. Experimental evidence has been recently obtained indicating that sometimes the alpha particle when it collides with the nucleus of another atom such as nitrogen not only displaces a hydrogen atom but combines with the remaining nucleus. Thus from nitrogen atomic weight 14, losing 1 (H=1) and gaining 4 (He=4) the new element with atomic weight 17 would be formed, which would be an isotope of oxygen. This then is a case of true synthesis of an element.

COMPOSITION AND STRUCTURE OF ATOMS

From the facts that radioactive elements change into other elements by losing helium atoms and electrons, that alpha particles which are nuclei of helium atoms moving at high velocity can dislodge hydrogen atoms from other elements, and finally that the atomic weights of elements differ by four (the atomic weight of helium) or one (atomic weight of hydrogen) or some multiple of one or both, it appears that the atoms of which all matter is composed are made up of electrons or minute unit particles of negative electricity, together with hydrogen or helium, or both, which are charged with positive electricity, the total quantities of negative and positive electricity in the atom being normally equal.

Thus an atom of any element according to one conception is believed to consist of a central nucleus around which revolves one or more electrons, the whole contained within a spherical space of radius 10^{-8} centimetres. The nucleus is very small compared with the atomic space, being only about 10^{-15} centimetres in diameter, so that the atom resembles in structure our planetary system, except that the distance from the atomic nucleus to the outer electrons is relatively very much greater than the distance from the sun to the earth. The number of outer electrons is characteristic for each element and is the same as the atomic number. Thus hydrogen has one, helium two, copper 29, uranium 92 of these orbital electrons. The nucleus of the hydrogen atom is ca called a proton and consists of one unit of positive electricity corresponding to the negative unit, the electron. The proton although smaller in diameter than the electron contributes all but about $\frac{1}{1,834}$ of the mass of the hydrogen atom. The helium nucleus is built up of four hydrogen nuclei and the atomic nuclei of all other elements consist of numbers of hydrogen and helium nuclei characteristic for each element except that in the case of elements with atomic weight about 40 there are also electrons associated with the nucleus besides those revolving in outer orbits.

DETECTION AND DETERMINATION OF RADIOACTIVITY

Tests for Radioactive Minerals

Because of the unique property possessed by the radioelements of giving off alpha, beta, and gamma radiation, the presence of these elements in minerals or other substances is easily detected by radio-activity tests even when the amounts present are so small as to be far beyond the possibility of exact chemical determination. Radioactive radiations are detected and measured chiefly by three general methods:

(1) By their action in discharging an electroscope.

(2) By the luminescent effects produced by impacts of alpha particles on a zinc sulphide screen, i.e., the scintilloscope.

(2) By their effect on photographic places.

(1) Electroscopic Methods. Methods involving the use of the electr -scope are those most commonly used, being simple, convenient, and and equally useful for either qualitative or quantitative

observations. The common form of electroscope consists essentially of a small strip of extremely thin aluminium or gold leaf attached by its upper end to an upright metal support which is insulated from the ground. When the leaf and its support are charged by touching with an ebonite rod which has been rubbed on the coat sleeve (wool) or silk, the leaf diverges from its support, because both are charged with the same kind of electricity and hence repel one another. If a substance emitting radioactive radiations is brought near, the air is ionized, that is, it is rendered capable of conducting electricity so that the charge gradually leaks away and the leaf falls at a rate depending on the strength of the radiation. Electroscopes designed for quantitative work are enclosed in metal cases with windows and are provided with a small microscope containing a scale by means of which the rate of fall of the leaf can be accurately measured. Electroscopes of different types can be used to measure alpha, beta, or gamma activity.

Alpha ray electroscopes of the United States Bureau of Mines type are most used for testing minerals. They consist (See Figure1 and Plate I) of three main parts: the head A containing the electroscope proper, a metalionization chamber B in which the mineral can be placed, and a microscope with eye-piece scale for reading the leaf. The head, or brass, with mica and wire gauze windows contains the lead and its metallic support, which is insulated from the rest of the instrument by sulphur, amber, or bakelite. A charging switch S can be turned to touch either the leaf system or to engage a catch on the outer case which is grounded. The chamber projecting from the head on the lower right of Plate I is intended to hold a small glass vial containing chemical for drying the air in the head. This chamber was not on the standard instruments but was added by the writer. The ionization chamber is a brass vessel with which the head engages by a threaded connexion. A door permits the insertion of solid mineral specimens or brass plates containing mineral powders. The brass plate P makes metallic contact with the leaf support and exposes a large surface from which the charge can leak away. The whole instrument with the exception of the leaf system is connected to the ground. The head is interchangeable with different ionization chambers so that chambers suitable for determining emanations may be used.

(Insert Figure 1)

To detect radioactivity in a mineral the leaf is charged and after waiting 5 or 10 minutes the natural leak is determined by noting how many divisions the leaf falls in a given time. The natural leak is the rate of fall of the leaf at any particular time due to the natural ionization or conductivity of the air and is usually very small, but it varies from time to time. Radioactive emanations or radiation from the earth and from surrounding objects, as well as dust, smoke, or fumes, light and particularly ultra violet light, flames, thunderstorms, and moisture in the air influence the natural leak. The mineral is then inserted in the ionization chamber taking care not to touch plate P, and the rate of fall of the leaf is again determined. If the leaf falls at a greater rate when the mineral is in the chamber the mineral is radioactive. An approximate quantitative determination of the radioactivity of the specimens can be made as follows. The mineral is reduced to fine powder and a weighed amount, usually 1 to 5 gram is placed in the brass plate container. There should be enough powder to cover the depression uniformly with a smooth layer of powder. The rate of leak is then determined and compared with the rate for the same weight of a similar mineral of known uranium and thorium content with an equal surface area in the same or similar containers. It is not possible in this way to distinguish between activity due to the uranium series and that due to the thorium series, but when both are present the result may be expressed as uranium equivalent. The uranium activity equivalent of any amount of thorium is 0.3 of the thorium (more precisely 0.28). This value is deduced from the count made by Rutherford and Geiger of the number of alpha particles ejected by uranium and thorium and their products. Values for the radioactive constants as found by different investigators vary somewhat. Thus if the standard is known by chemical analysis to contain 8 per cent U and 3 per cent Th, the total activity should be the same as if 8 + (3 X 0.3) = 8.9 per cent of U were present. The natural leak might be found to be at the rate of 0.2 scale divisions per minute, the leak for the unknown 15 divisions per minute, and for the standard 30 divisions per minute. The unknown, therefore, contains $\frac{15-0.2}{30-0.2}$ X 8.9 =4.4 U equivalent.

This method is not absolutely accurate because the result is influenced by such factors as the fineness, the rate of loss of emanation, and the density, of the two powders. Nevertheless it is rapid and very useful for approximate determinations.

The so-called alpha-ray type of electroscope measures chiefly the ionization produced by alpha particles, but it is also affected to a minor degree by the beta and gamma rays.

Electroscopes can be designed to measure the beta radiation by having a window of thin metal, exposed to to the radiation, and sufficiently thick to stop the alpha rays but permit the beta rays to pass through. In this case also the gamma rays have some effect.

Gamma-ray electroscopes are used to measure the radium content of very active preparations such as radium salts, by comparing with pure radium standards. These instruments are encased in thick lead which stops both alpha and beta rays and permits only gamma rays to penetrate to the electroscope. Commercial radium salts are sold on the basis of radium element content as determined by the gamma-ray electroscope.

The emanation type electroscope is used for the accurate determination of small amounts of radium and mesothorium by measuring the activity of the gaseous emanations radon and thoron which they produce. This type may consist of the same interchangeable head as shown in the figure of the United States Bureau of Mine type alpha -ray electroscope but with a gas-tight emanation chamber into which the emanation is introduced. With this instrument it is possible to measure very minute amounts of radium and mesothorium such as are present in ordinary rocks, as the gaseous emanations can be collected from a comparatively large sample of material, if necessary. The emanations may be obtained from off rock samples or other materials by fusion with a suitable flux, by solution, or by a combination of both fusion and solution. The emanation present in the original sample is thus driven off and may be measured immediately or the sample free of emanation may be set away in a suitable sealed vessel for a known length of time, after which the emanation which has grown in the meantime is collected in the evacuated emanation chamber and its activity measured, and compared under similar conditions with the activity of the emanation from a known standard.

(2) Scintilloscope Methods. Certain specimens of zinc sulphide have the property of becoming momentarily luminescent when struck by alpha particles. It is said that very pure zinc sulphide does not luminesce, the effect being due to the presence of small amounts of certain other elements which render thezinc sulphide

thus sensitive.

If a glass plate coated with a thin film of the sensitive zinc sulphide is held with the coated side near a not too strong source of alpha rays and viewed in the dark with a low power microscope (ten power is sufficient) each individual flash caused by an alpha particle striking the screen can be easily seen. If a more active material such as a radium preparation is used so many alpha particles are continually striking the screen that it luminesces over its whole surface, due to the impact of thousands of alpha particles. Thus zinc sulphide mixed with a small amount of radium salt and a suitable binder is used as luminescent paint for the figures on the dials of watches, compasses, etc., for use in the dark.

This arrangement of a zinc sulphide screen with a simple microscope which can be focused on the coated side of the screen is called a scintilloscope. Various types are made but the principle is the same in all. Instruments of this sort[1] can be obtained for as little as $5 or $10, and when correctly used are very sensitive detectors of radioactivity. They have the DISADVANTAGE that they must be used in the dark, and the eyes must first be rendered sensitive by remaining in the dark for some time. The screen should not be exposed to light as after such exposure the zinc sulphide will glow strongly for some time and

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[1] From Gallenkamp and Co., London, Eng., or Bausch and Lomb, Optical Co., Rochester, N.Y., U.S.A.

alpha-ray flashes cannot be distinguished on the screen until luminescence due to light has subsided. For best results scintilloscope observations should be carried on in as nearly as possible complete darkness. Further, great care must be taken that the screen does not become contaminated by particles of radioactive material. If the screen alone shows flashes of light it is contaminated and must be discarded. With proper conditions, however, very weak radioactivity may be detected. In such cases only one flash may occur in several minutes.

Suitable refinements of the scintilloscope principle have enabled investigators to count the alpha particles thrown off by known quantities of radioactibe substances and thus determine the disintegration constant or rate of decay. Rough quantitative estimates of radioactivity can be made with the small instruments commonly sold by counting the number of flashes in a given time, compared with a standard. If the flashes come too abundantly to be easily counted their number can be reduced to about one or two per second by measured dilution of the powdered test material with ground sand, both being well mixed by grinding together in a small mortar.

(3) Photographic Methods. A very simple and easy way to detect radioactivity is to expose a plate wrapped in light-proof paper to the action of the radiations. Upon developing the plate in the usual way it will be found to be darkened just as if it had been

exposed to light. The length of exposure necessary for good results may vary from a day or two to weeks or months. In using this method to detect radio-activity in minerals it is well to interpose some metal object such as a small coin between mineral and plate. The metal is not penetrated by beta rays, with the result that the plate is not so much darkened where it has been thus protected. The mineral to be tested may be powdered and placed in a small container such as the top of a small cardboard or metal can. Coins can be placed on top of the powder nearly up to the level of the edges of the container and the plate (wrapped in paper or contained in a plate holder) lain on top with emulsion side down but not touching the coin. Small fragments of a mineral may be laid on top of the plate wrapped in paper, or plate holder but it is better not to put large rough specimens directly on the plate as effects due merely to pressure may be obtained. In the case of large rocky specimens, the covered plate can usually be arranged to lie on top of or alongside the suspected mineral in the specimen and preferably separated from it.

FIELD INDICATIONS OF RADIOACTIVE MINERALS

Radioactive minerals in pegmatite may be recognized, after some experience, with almost absolute certainty by the fact that they give rise to fractures in the rock which radiate out in all directions from the radioactive mineral. The common inactive minerals found in pegmatites such as black tourmaline, garnet, pyroxene, magnetite, ilmenite, etc., do not produce this effect, which appears to be confined entirely to radioactive minerals. Zircon produces the same fracturing and might be cited as an exception to this rule, but as a matter of fact it usually contains small amounts of uranium and thorium. Columbite-tantalite does not give rise to fractures unless it contains appreciable U and Th.

The feldspar surrounding radioactive minerals is usually a deeper red than elsewhere-another good indication, but as feldspar is sometimes superficially reddened by iron rust from oxidizing pyrit or other sources of iron, care should be taken in applying this observation.

Uraninite that is considerably altered may give rise to stains of canary yellow or bright orange but certain iron stains may be easily mistaken for these uranium decomposition products.

Tests for radioactivity are made on Canadian minerals free of charge by the Geological Survey. Mineral samples up to 12 ounces in weight addressed to the Director, Geological Survey, Ottawa, may be sent post free, and should be marked "Mineral Samples" O.H.M.S. As nearly as possible the exact locality from which the samples are obtained should be indicated in the letter accompanying samples.

THERMAL EFFECTS OF RADIOACTIVE DISINTEGRATION AS A SOURCE OF THE EARTH'S INTERNAL HEAT

A large part of the energy of disruption of radio-active substances appears locally as heat in the substances themselves. T The alpha particles being swift but comparatively large and heavy, have little power of penetration and can escape only from a few layers of atoms on the surface. Those in the interior must expend their energy largely as heat. Beta rays are more penetrating but are stopped by a millimetre of heavy elements. Some energy escapes in the form of gamma rays. The recoil of the parent atom in transformation must also be converted chiefly into heat. The amount of heat which can be thus produced is of considerable magnitude.For instance many actual experimental determinations of the amount of heat evolved by one gram of radium have been made with results varying from 100 to 134.4 calories per hour. This is an amount of heat sufficient to melt about one and one-half grams of ice every hour or to raise the temperature of over 1 gram of water from freezing point to boiling point every hour. It would appear, therefore, that in the case of radioactive substances contained in the rocks of the earth's crust, the radiations must be almost completely absorbed and converted into heat.

It has long been suspected that heat thus generated by radioactive substances contained in the rocks might account for the earth's internal temperature. It has been found that in deep mines and bore-holes the temperature increases on the average at the rat of 0.00032 degrees C. per centimetre or about 1 degree per 100 feet in depth, and the existence of active volcanoes at the presen time shows that temperatures at least sufficient to melt rock (1,000-1,300 degrees C.) are reached at greater depths. Much attention has been devoted to this subject, particularly by Joly and Holmes. The amount of heat lost by radiation from the earth can be calculated and it has been found that if uranium, thorium, and potassium were present throughout the total mass of the earth in the same proportion in which they occur in the superficial igneous rocks the heat generated by radioactive disintegration would be very much greater than is necessary to replace that lost by radiation. Hence it follows that the greater proportion of these radioactive elements must be concentrated in a comparatively thin outer layer of the earth's crust. Holmes[1] has recently shown that taking into account the heat-producing effect of the beta-ray activity of potassium, which is an important constituent of igneous rocks, occurring to the amount of as much as 3 to 5 per cent in granites, the heat lost by the earth could be supplied by a thickness of 20 kilometres (12.4 miles) of average igneous rock, or by 15 km. (9.3 miles) of average granite. Apparently, therefore, the granitic rocks of the earth's surface cannot be more than 12 miles thick. Holmes[2] figures are as follows:

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[1] "The radioactivity of Potassium and its Geological Significance"; Phil. Mag. Dec., 1926, p. 1225
"Contributions to the Theory of Magmatic Cycles"; Geol. Mag., July, 1926.

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[2]

	ELEMENT	URANIUM	THORIUM	POTASSIUM	RUBIDIUM
	Energy liberated per gram per year nE(4.19 X 10^7) cal.	$7900X10^{-4}$)	($2300X10^{-4}$)	$1.24X10^{-4}$	$2.38X10^{-4}$
Average igneous rock	Contents in grams per gram of average igneous rock[1]	$6X10^{-6}$	$15X10^{-6}$	$26000X10^{-6}$	$mX10^{-6}$
	Heat generated in cals. per gram of average igneous rock per year	$4.74\ X10^{-6}$	$3.45X10^{-6}$	$3.22X10^{-6}$	$2.38mX10^{-10}$
Average granite	Content in gm.per gram of average granite [1]	$9X10^{-6}$	$20X10^{-6}$	$34,000X10^{-6}$	n.d.
	Heat generated in cals.per gram of aver.granite per yr.	$7.1X10^{-6}$	$4.6X10^{-6}$	$4.2X10^{-6}$	n.d.
Average plateau-basalt	Contents in gm. per gram of average plateau-basalt [1]	$2.2X10^{-6}$	$5X10^{-6}$	$8000X10^{-6}$	n.d.
	Heat generated in cals.per gm. of aver.plateau-basalt per year	$1.7X10^{-6}$	$1.2X10^{-6}$	$1.0\ X10^{-6}$	n.d.

Total heat in calories per year generated in :

Average igneous rocks (density=2.75)=$11.4X10^{-6}$per gm.=$31.4\ X10^{-6}$ per c.c

Average granite (density=2.65)=$15.9X10^{-6}$per gm. =$42.2X10^{-6}$ per c.c.

Average plateau-basalt (density=3)= $3.9X10^{-6}$ per gm.=$11.7X10^{-6}$per c.c.
=$13.3X10^{-6}$per c.c. o
eclogite (density = 3.4)

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[1] For the data of radium and thorium, See Joly, J.: Phil.Mag.(6)xlviii, p.819 (1924); and for radium alone, Holmes, A.: Geol. Mag., lxii, p.509 (1925). The figures for potassium are based on thousands of analyses of rocks from all parts of the world.

THEORY ASCRIBING GEOLOGICAL REVOLUTIONS TO THE RADIOACTIVITY OF THE CRUSTAL ROCKS

It has long been known that geological history comprises a series of periods of igneous activity and mountain building during which the continental areas tended to be elevated, alternating with periods of comparative quiescence during which the continental areas were slowly worn down by erosion, sediments accumulated on the continental shelves, and the edges of continents tended to sink slowly below the sea. Joly has proposed a theory, recently elaborated by Holmes (Loc.cit.), to account for such geological cycles or revolutions, based on the heat generated by radio-active elements in the rocks in conjunction with isostasy. The theory of isostasy supposes that granite rocks, being lighter than basic rocks, exist only as a thin layer no more than 12 miles thick on the surface of the continents whereas under these granitic rocks and under the oceans the rocks are heavy basic types such as basalt,eclogite, and peridotite. The granitic rocks have a density of about 2.7 and the basaltic substratum has probably on the average the density (3.4) of eclogite or peridotite. Owing to the plasticity of the deeper rocks at a depth of 50 to 60 miles, the lighter continental granitic crust acts as though it were floating on the basaltic layer in the same way as a light solid would float on a heavy liquid and the whole system tends to adjust itself to hydrostatic (or isostatic equilibrium, which means that if such a condition were completely attained a vertical column of given cross-section and 60 miles or more deep taken anywhere through continents or oceans would in every case have exactly the same mass. Gravity determinations indicate that most large land areas are in fact in nearly complete isostatic equilibrium but local areas may be less completely adjusted, and such regions are subject to faulting with accompanying earthquakes. During a period of geological quiet the underlying basaltic layer is in general at a temperature below its melting point except for comparatively small areas where local volcanic activity exists. This condition apparently exists at present as determinations of the speed of earthquake shocks indicate that the underlying rocks act as though they were solid. Gradually, however, heat accumulates in the rock as a result of the disintegration of uranium, thorium, and potassium and concurrently with the increase in temperature the volume of the rock increases and the earth as a whole becomes slightly larger in circumference. The oceans are good condustors of heat and contain but little radioactive matter whereas the basaltic layer under the continents is blanketed by a layer of granitic rocks with a higher radioactive element content than the basalt itself. Consequently, the continental basaltic layer accumulates heat at a greater rate than the suboceanic basalt and melts at an earlier stage than the latte As the continental basalt melts it becomes less dense, also the lower part of the floating granite crust melts more or less and hence the continental granite layer tends to sink relatively to the oceans. Meanwhile breaks in the crust will be filled by liquid rock from below. Finally as a result of isostatic readjustment, tidal, and other effects, more or less circulation of the liquid basalt occurs by which the hotter continental basalt loses its heat to the oceans. It may also break out and form sheets over great continental areas. In time so much heat is lost that resolidification occurs, with resulting general contraction and the outer crust accommodates itself to the smaller circumference by folding along its lines of weakness, thus producing mountain chains and tending to uplift the continents. A period of comparative quiet ensues during which heat again accumulates until the whole cycle is repeated. There is geological evidence that twenty or more such revolutions have occurred, of which at least four have been of major importance. The duration of such a cycle has been estimated to be from 50 to 60 million years.

HIGHLY PENETRATING TERRESTRIAL RADIATIONS AND THEIR POSSIBLE USE IN PROSPECTING FOR RADIUM AND PETROLEUM

Milliken and others have recently shown that the earth is being constantly and uniformly bombarded over its whole surface by highly penetrating radiations (i.e. of extremely short wave length compared even with gamma rays from radioelements) which must come fro space outside the earth. That these are of extra-terrestrial origin is proved by the fact that they are stronger the higher up in the atmosphere the measurements are made, as on high mountains, the atmosphere absorbing them somewhat at lower levels, and they are weaker beneath the waters of lakes. These cosmic radiations have been named the "Milliken rays" in honour of Prof. Milliken.

Highly penetrating radiations from the earth itself have also been studied and recently L.N.Bogoiavlensky, A.A.Lomakin, and A.Cheropenikov[1] of the Russian Institute of Applied Geophysics have completed a five year study of such highly penetrating terrestrial radiations in relation to the geology of known oil fields. A preliminary study of the short-wave radiations was made in the neighbourhood of Leningrad ~~and~~ and at Pyatygorsk in the Caucasus, a region where radium is deposited in travertines and breccia. A sensitive electrometer was used which could be heavily screened from above and from the side by one or all of four lead hoods, each 2 cm. in thickness, and from below by one or more of four lead plates of the same thickness. The total weight of the lead screening was 1,056 pounds and a small crane was necessary to handle the hoods. When all the hoods and plates were used the instrument was completely screened in all directions by 8 cm. of lea Thus the effect of both the Milliken rays and the terrestrial short-wave radiations could be studied by varying the thickness of the hood and plate screens. A special apparatus was also devised to

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[1] Translated in Information Circular No. 6072, No.6072, June, 1928, Dept. of Commerce, U.S.Bureau of Mines, Washington, D.C.(Free)

measure accurately the amount of emanation in the air. The results of these investigations are summarized by the authors as follows:

"From this table it is seen that at point 6 radiations were encountered whose wave length was 0.00165 A.U., which is 12 times harder than the gamma rays of radium C (0.02A.U.) and only 4 times softer than those observed by Milliken at Mura lake in California. It may be supposed that with a greater thickness of lead it would be possible to investigate radiation of even shorter wave lengths."

"Investigations of the type described above indicating the existence of strong penetrating earth's radiations were made in other places. It was always possible to observe the constancy of the intensity. For instance, in the garden of Pavlovsk Geophysical Observatory(near Leningrad) on various days, the following values were obtained for q_{max}[1]: 8.45,8.67,8.57,8.48, and 8.45 ions. A table is now given which represents the general summary of all the observations carried out with the same apparatus. Here the values of q_{max}, that is, with the apparatus unshielfed by lead, are recorded in Table II, as follows:"

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[1] q max represents the intensity of the radiation in terms of ions produced per cubic centimetre per second with the apparatus unshielded.

TABLE 11

Caucasus. Region of travertines with deposits of radium.	11.2-22.7
Caucasus. Summit of Mashuska. Senon limestone	11.2
Kuban region. Clays	11.7-13.5
Leningrad. Main building of Weights and Measures ,in building	9.4
Pavlovsk. Garden of the Geophysical Observatory	8.5
Leningrad. On the ice of the River Neva	7.4
Leningrad. The Institute of Applied Geophysics	7.9
Leningrad. In private house. Before leaving for Caucasus	7.4
Leningrad. In private house. Upon returning from Caucasus	7.6

"In the Institute of Applied Geophysics there were observed radiations which were much harder than γ rays of radium C, according to the following:

$\mu_1 = 0.24$ $\lambda_1 = 0.0070$

$\mu_2 = 0.12$ $\lambda_2 = 0.0034$

$\mu_3 = 0.15$ $\lambda_3 = 0.0045$

These experiments were carried out with hoods and filters up to thicknesses of 8 cm., and the absorption of the hoods was not noticed, but the coefficient of absorption of the bottom filters corresponding to the wave lengths was recorded."

"From all these figures it can be seen that the intensity of the penetrating radiations close to the earth's surface varies within wide limits and apparently depends directly upon the concentration of radioactive elements in a given place. It is supposed that the harder rays were encountered in consequence of considerable masses of radioactive material. Under these conditions the relative amount of hard rays increases because with increase in hardness the active volume has also increased. The experiments described above are not exhaustive, and it is desired to carry out some more having for their aim a more complete investigation. The work has been carries out by the help of the Institute of Applied Geophysics, with close participation of the Main Chamber of Weights and Measures, whose co-operation is appreciated."

"1. Measurements of penetrating radiations from the earth made at Pyatygorsk (in the Caucasus) by means of a portable electrometer covered with lead 1 cm. in thickness have shown that although the same apparatus had been used the intensity fluctuated greatly, depending upon the observation stations where the measurements were made. The fluctuations of intensity were specially marked in places rich in radium, where divergances of no less than 100 per cent were observed between stations separated by only a few metres."

"2. Measurements made at the same observation stations during a period of three years have shown the intensity to be constant and to be independent of meteorological conditions and fluctuations of emanations in the atmosphere, in the limits of sensitiveness of the apparatus."

"3 . Measurements of the radioactive elements in the upper layers of the soil have shown their constancy, which permits the supposition that the fluctuations are probably due to deeper strata only. "

"4. The use of four hoods fitting each other, 2 cm. thick and covering the apparatus from above and laterally, and of four flat lead screens protecting it from beneath has shown the influence of the hoods to be very slight and that of the screens very important, thus testifying to the electrometer being acted upon chiefly from below."

"5. The thickness of lead protecting the apparatus from above, fro the sides, and from below having been varied from 0 to 8 cm., computation of the coefficients of absorption was rendered possible. As it appeared, the coefficients of absorption by screens varied from 0.45 to 0.06 for 1 cm. Values approaching the lower limit were frequently noted at different stations. In most cases the height of the coefficient of absorption diminished as the thickness of the lead screens increased; that is, a complex of radiations was here dealt with, some of them possessing a much greater radiating capacity than the γ rays of radium C. The radiations are directed from below and their source may be understood to lie in radioactive elements diffused in the upper strata of the soil."

Similar measurements of the penetrating terrestrial radiations were then made over the known oil deposits of the Maikopsky field with the result that the radiations were found to be stronger directly over the oil deposits than elsewhere. From the numerous observations maps were prepared showing radiometric contours corresponding to the distribution of the oil.

The results of this investigation are summarized by the authors as follows:

"The intensity of penetrating radiations originating in the earth depends mainly on the degree of concentration of radioactive elements in the core of the earth. Our latest experiments in the study of emanations of the earth lead to the supposition that the radium dispersed in the core of the earth yields a certain amount of emanations of much shorter waves than those previously admitted. The slightest change of radium content in ores must, therefore, be reflected in the intensity of penetrating radiation."

"The radioactivity of an oil bed must differ from that of the strata inclosing it on the following ground: "

"1. Oil, being an organic compound, possesses an immense power of absorbing radioactive emanations."

"2. The layers underlying the oil bed, having been developed from repositories of sea-ooze, are richer in radium because of the greater power of absorption peculiar to colloids."

"The oil bed must, therefore, be richer in radioactive element than the embedding clay layer."

"The experiments of the Radiometric Subsection of the Institute of Practical Geophysics with the oil deposits of the Maikovsky district, in the Kuban government, have shown that penetrating radiations increase above oil lenses of light naptha as well as above strata of heavy oil. "

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If the results obtained by the authors are found to apply generally it would appear that another very valuable geophysical aid to prospecting, particularly for radium and for petroleum, has been discovered.

THE RADIOACTIVE ELEMENTS

Introduction

Radioactivity is a property which appears to be definitely connected with high atomic weight. There are some forty radio-elements having atomic weights between 206 and 238.17 and all elements with atomic weight greater than 209 are radioactive. Of the elements having atomic weights less than 206 only potassium and rubidium are definitely known to be radioactive, and these only to a very slight degree, their activity, which is confined to the emission of beta rays, being not more than $\frac{1}{1,000}$ that of the beta-ray activity of uranium.

All the radioelements, with the exception of potassium and rubidium, are found only in minerals containing uranium and thorium. Uranium has the highest atomic weight (238.17) of all known elements thorium the next highest (232.15), and these two elements are the parents of all other radioelements, except potassium and rubidium. The way in which uranium and thorium break down to form other elements was explained by Rutherford and Soddy in 1903 and is one of the most fundamental and far-reaching discoveries of all time, since it led to entirely new conceptions of the constitution and properties of matter and formed the foundation for many of the great advances in pure and applied science which have been so noteworthy in recent years.

Rutherford and Soddy showed that radioactivity is due to spontaneous violent explosions or disruptions of the atoms, accompanied by the expulsion at tremendous velocities of actual fragments of the atom -- the alpha and beta particles. In any radioactive substance on the average only a certain fraction of the total number of atoms explode ina given interval of time, this fraction being characteristic and unalterable for that particular element. In other words, nothing within human power can cause a greater or less percentage of the atoms to explode. What causes the atoms to explode or why some explode sooner than others is unknown. After an atom has exploded it has lost some of its former constituent parts i.e., an alpha or beta particle or both, as the case may be, and consequently it becomes an atom of a totally different substance with a lower atomic weight and different chemical properties. The element thus formed may itself be radioactive, in which case its atoms also will explode and form atoms of another different element and so on until the stepping down process is finally brought to an end by the formation of an element-lead -- which does not undergo further transformation. Thus uranium atoms explore -- on the average about one in every 10^{18} (See footnote) per second -- and expel an alpha particle, a helium atom of atomic weight 4. What is left of the original uranium atom now has in round numbers an atomic weight 238 − 4 = 234, and is a new element known as uranium X_1, with totally different properties from the original uranium atom. Of the uranium X_1 atoms present one in 10^7 explodes per second and expels a beta particle only. As the beta particle is of such small mass as to be inappreciable the atomic weight of the remainder of the atom, now called uranium X_2, remains 234 the same as its parent, but nevertheless the loss of the beta particle has changed the electrical constitution of the remainder of the atom, so that it is definitely a new element with different properties from either its parent or grandparent. Uranium X_2 also emits a beta particle and becomes uranium II, a new element with atomic weight still 234, but strange to say, having chemical properties identical with the original uranium. Gamma rays accompany the expulsion of beta particles but have no part in the production of new atoms, being probably merely a secondary effect somewhat analogous to the ripple wave motion produced by dropping a stone into still water. Continuing with the uranium

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10^{18} means 1,000,000,000,000,000,000. It is convenient to express such large numbers as powers of ten. Thus $10^1 = 10$, $10^2 = 10 \times 10 = 100$, $10^3 = 10 \times 10 \times 10 = 1,000$. Similarly $10^{-3} = \frac{1}{10^3} = \frac{1}{1,000}$ and so on. Hence $3.4 \times 10^{10} = 34,000,000,000$ and $3.4 \times 10^{-7} = \frac{3.4}{10,000,000}$ or 3.4 parts in 10,000,000.

disintegration series, uranium II loses an alpha particle and becomes in part ionium with atomic weight 234-4 =230. Ionium expels alpha particles and becomes radium with atomic weight 230-4=226. Radium expels both alpha and beta particles and becomes a highly radioactive but chemically inert gas known as radium emanation or radon with atomic weight 222. This in turn loses an alpha particle and changes to a solid element radium A of atomic weight 218. Disintegration continues in successive steps until finally inactive uranium lead, atomic weight 206, is produced.

Going back again to uranium II, it was mentioned that this element changes in part to ionium and so on, down through the radium series. As a matter of fact, it is believed that only 97 per cent of uranium II changes to ionium, the remaining 3 per cent changing to uranium Y or protactinium which like ionium is the paren of another series of radioactive disintegration elements, called the actinium series, having atomic weights the same as the corresponding members of the radium series but with differing rates of disintegration. In the actinium series, actinium corresponds to radium and actinium emanation to radium emanation, the final product being actinium lead. The actinium series[1] represents the most important example of what is called "branching" - i.e. one radio element changing into two new ones -- in the uranium series, but

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[1] The actinium series is now (1932) believed to derive from an isoto of uranium named by Rutherford actino-uranium, and actinium lead is suspected to have an atomic weight of 207.

other minor branchings occur in both the main uranium or radium series and the thorium series as well as in the actinium series itself, which are indicated in the tables (pages).

Thorium goes through a somewhat similar but slower series of changes, one stage being a highly active product, mesothorium, corresponding to radium and another stage is a highly radioactive but chemically inert gas, thorium emanation or thoron, corresponding to radium emanation. The final end product of thorium is also inactive lead but with atomic weight 208, instead of 206 as for uranium lead. Uranium lead, actinium lead, thorium lead, and ordinary lead are identical in all chemical respects. The only properties in which they differ are atomic weight, density, and solubility. Thus thorium lead is slightly heavier than common lead, which in turn is heavier than uranium lead, and saturated solutions of salts of heavier lead contain more grams per litre of the heavier lead salt than do saturated solutions of a lighter lead salt, at the same temperature. The three leads once mixed cannot be separated. Elements such as these three leads having identical chemical properties but slightly different atomic weights are said to be isotopes and such substances are absolutely inseparable by chemical methods. It is now known that the greater number of so-called elements, formerly supposed to consist of one substance only, are really mixtures of isotopes, the atomic weights of which are apparently almost always whole numbers but which may differ by several units. Thus the elements composed of mixed isotopes come to have atomic weights, or better, chemical reacting weights, which are not whole numbers. The proportion of the various isotopes prese in such mixed elements is, so far as known at present, constant for each such element, but is very different for different mixed element Some mixed elements, e.g., cadmium, tin, xenon, contain as many as from six to nine isotopes. On the other hand there are some element e.g., oxygen, hydrogen, nitrogen, helium, carbon, etc., which consist of only one isotope, and the atomic weights of such elements as actually experimentally determined are very nearly whole numbers. Any slight deviations from whole numbers in such cases are accounted for by differences in the internal energy of the atom, as the mass of a body appears to be greater as its energy content increases.

About forty radio elements deriving from uranium and thorium have been identified and if it were not for the principle of isotopy it would be impossible to place them in the Periodic classification of the elements. But as many of these elements are chemically inseparable from one another they can all be arranged in ten groups of isotopes occupying definite places in the Periodic Table as isotopes of thallium, lead, bismuth, polonium, radon, radium, actinium, thorium, protactinium, and uranium.

DISINTEGRATION CONSTANT, HALF VALUE PERIODS AND RADIOACTIVE EQUILIBRIUM

The number of atoms of any radioelement which disintegrate at any instant is proportional to the number of atoms of the element present, and this ratio is called the disintegration or transformation constant commonly designated by the Greekletter lambda. . It has been found to be impossible to increase or decrease the rate of disintegration by any known means. Thus the same proportion of the atoms of any radioelement disintegrates at any time under any conditions whatsoever, whether the radioelement is in the form of element, or combined with other elements, and regardless of different temperatures, pressures, or electric or magnetic influences to which it has so far been possible to subjec it.

The decay of a radioelement follows an exponential law. If, starting with a given amount of a radioelement, one-half of this a amount is transformed in a given time then in twice the time, one-quarter of the original amount will be left, in thrice the time onl one-eighth of the original quantity will remain, and so on. For this reason theoretically there might always be a little left, as even one atom might exist forever without disintegrating, so that the possible absolute life period of any radioelement is infinity. For this reason use is made of the "Half value period" and the "Period of Average Life". The half-value period is the time during which one-half of any original amount of a radioelement decays. The period of average life=1.443 times the half value period$=\frac{1}{\lambda}$.

It can be shown mathematically, and has been found by experiment to be true that in any series of radioelements, the various elements present after the lapse of a sufficient time interval, will thereafter remain in a constant relationship to one another, that is, they will all be present in certain proportions which will not vary so long as the system remains undisturbed. This means that at any instant the number of daughter atoms which disintegrate is exactly the same as the number of daughter atoms being formed from the parent, for each element concerned. Under these conditions the elements are said to be in radioactive equilibrium. This, of course, does not apply to the three radio-leads, uranium lead (radium G), actinium lead (actinium D), and thorium lead (thorium D) nor to helium; all these, being inactive, accumulate in increasing quantities with increasing age. A simple actual example of a case of radio-active equilibrium cited by Hevesy and Paneth[1] shows clearly how this condition is attained.

Suppose we have 10^{15} uranium atoms free of uranium X at first. In five days about 1,000 atoms or the $10^{12\text{th}}$ part of the total will disintegrate. In the next five days another $10^{12\text{th}}$ part of the remaining atoms, i.e. $(10^{-15}-1000)$, will disintegrate, and so on. The number of atoms disintegrating is so small in relation to the total number that the number disintegrating (1,000) per 5-day period remains practically constant for many thousands of years. Each 1,000 disintegrated atoms have changed to UX_1 atoms, but these in turn disintegrate and at a relatively much faster rate, so that in the first 5 days 15 per cent or 150 decay and 850 remains, in the second 5 days 15 per cent or 850 or 127 decay and so on. The number 127 is appreciably different from 150, whereas 1,000 new UX_1 atoms are being produced in each 5 day period, so that for a certain time UX_1 atoms accumulate until the total number present is such that 15 per cent of the number or 1,000 disintegrate per 5-day period.

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[1] Hevesy, George, and Paneth, Fritz: "A Manual of Radio-activity"; translated by Robert W. Lawson, Oxford University Press.

When equilibrium is attained the amounts of the radio-elements present are directly proportional to their half-value periods and hence can be easily calculated. Thus for example to calculate the amount of radium in equilibrium with 1 kilogram (1,000 GRAMS) of uranium, we have: taking the half-value period of uranium as 5×10^{9} years and that of radium as 1,700 years, the radium constant $= \frac{1700}{5 \times 10^{9}}$ of 1,000 $= 0.34$ milligrams. It may be noted this result thus calculated from the half-value periods of uranium and radium is based on the actual experimental determination of the disintegration constant by counting the particles given off, since the half-value period is the reciprocal of the disintegration constant. The amount of radium contained in the least altered old primary uranium minerals has also been determined directly and found to agree well with the above result. The table shows that after fifty 5-day periods the number of UX_1 atoms produced is the same as the number decaying, for the 5-day interval and that U and UX_1 are then in radioactive equilibrium.

TABLE XVI[1] (Radioactivity, Hevesy and Paneth , page 87)

Number time intervals of 5 days	Number of UX atoms produced in the interval by the decay of U atoms	Number of UX atoms available from the previous time interval	Sum of the two numbers	Number of UX atoms decaying in the interval of time	Number of UX atoms remaining at the end of the time-interval
1	1,000	---	1,000	150	850
2	1,000	850	1,850	277	1,573
3	1,000	1,573	2,573	386	2,187
4	1,000	2,187	3,187	478	2,709
5	1,000	2,709	3,709	556	3,153
6	1,000	3,153	4,153	623	3,530
7	1,000	3,530	4,530	680	3,850
8	1,000	3,850	4,850	728	4,122
9	1,000	4,122	5,122	768	4,354
10	1,000	4,354	5,354	803	4,551
••	•••	•••	•••	•••	•••
••	•••	•••	•••	•••	•••
••	•••	•••	•••	•••	•••
50	1,000	5,667	6,667	1,000	5,667
51	1,000	5,667	6,667	1,000	5,667
52	1,000	5,667	6,667	1,000	5,667
53	1,000	5,667	6,667	1,000	5,667

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[1] The numbers in the table are not strictly correct, for during the time-unit of 5 days, which has been chosen on the ground of clearness, the decay does not take place uniformly. A correct treatment presupposes that the time-unit can be neglected in comparison with the half-value period. The formulae of infinitesimal calculus operate with indefinitely small times, within which the decay is strictly constant.

FINAL QUANTITATIVE RESULTS OF THE TRANSFORMATIONS

The final result of all the changes of uranium and thorium is that:

One atom of uranium changes to one atom of uranium lead and eight atoms of helium .

One atom of thorium changes to one atom of thorium lead and six atoms of helium.

Consequently, 238.17 grams of uranium if completely disintegra'ed would produce 206 grams of uranium lead and 32 grams of helium; and 232.15 grams of thorium similarly would yield 208 grams of thorium lead and 24 grams of helium. Three per cent of the uranium lead is supposedly derived from the actinium branch series.

The rate at which the various radioelements disintegrate has been determined, so that the rate at which lead and helium are produced from uranium and thorium is known and consequently if the amount of uranium, thorium, and lead contained in a primary unaltered radioactive mineral is known the age of the mineral can be calculated. The exact calculation of the age is somewhat complicated but approximate results are obtained by substituting the percentages of lead, uranium, and thorium in the formula:

$$\frac{Pb}{U + 0.36\ Th} \times 7600 = \text{the age of mineral in millions of years.}$$

In this way the age of the Precambrian granites intruding the Grenville series of Ontario and Quebec has been found to be about 1,100 million years.

The helium content of a mineral could be used in a similar way in conjunction with the uranium and thorium content, to determine the age if it were not for the fact that much of the helium escapes, so that low results are obtained by this method.

As all the other radioelements (Except rubidium and potassium as previously mentioned) result from the disintegration of uranium and thorium and as millions of years are required for the accumulation of appreciable quantities of the disintegration products, these can be obtained only from uranium and thorium minerals. Of the various disintegration products radium and mesothorium are the only ones extracted commercially at present.

RADIUM AND MESOTHORIUM

Radium and mesothorium though differing in origin, in atomic weight, and rate of radioactive disintegration are nevertheless isotopes. That is, they have absolutely identical chemical properties and cannot be separated by any chemical means. Hence, so far as chemical properties are concerned, the following description of radium applies also to mesothorium.

Radium element has been prepared in small quantities by the electrolysis of radium chloride using a mercury cathode. It is a brilliant white metal which melts at 700 degrees and blackens immediately on exposure to the air, possibly owing to the formation of the nitride. Like calcium, strontium, and barium, to which family radium belongs, the metal decomposes water and its oxide or hydroxide is more or less soluble. The specific gravity is about 6. The atomic weight of radium as determined by Honegschmidt is 225.97 ± 0.012. The atomic weight of mesothorium should be about 228 -- i.e., 4 units less than that of its parent thorium 232.12.

Radium resembles barium in its chemical reactions. Thus the chlorides, bromides, and nitrates of both are soluble, the carbonates and sulphates are insoluble. The radium salts, however, are less soluble than the corresponding barium salts. Radium sulphate is the most insoluble sulphate known, its solubility in water at 25 degrees being only about one one-hundredth that of barium sulphate. Though the presence of 50 per cent sulphuric acid has no appreciable effect on the solubility, at higher acid concentration the solubility increases rapidly. Commercial processses for the recovery of the minute amounts of radium and mesothorium in ores are all based essentially on the insolubility of the sulphates of radium, mesothorium, and barium.

RADIOACTIVE PRODUCTS

The relation of radium and mesothorium and their products to the disintegration products of uranium and thorium are shown in Table page . Perhaps the most remarkable disintegration products of these two elements are the gaseous so-called emanations radon and thoron. These are chemically inert gases resembling helium, argon, krypton, xenon, in that they will not enter into chemical combination with other elements. The radium atom of atomic weight 226 expels an alpha particle or charged helium nucleus and becomes an atom of the gas radon with atomic weight 222. Mesothorium, atomic weight, 228, goes through a series of changes by which two alpha particles are lost giving the atomic weight 220 for thoron. The actinium branch of the uranium family also produces an inert gas actinium emanation or actinium with atomic weight 218 and half-value period of only 3 or 4 seconds. The final stable end products of the three series are radium G(uranium lead), actinium D(actinium lead), and thorium D (thorium lead) all of which are isotopes of common lead.

RECOVERY FROM ORES

The principle of all commercial processes for the extraction of radium is first to separate the radium as insoluble sulphate in conjunction with barium sulphate, from the other constituents of the ore. This may be done by treating the ore with an acid such as nitric by which the constituents of the ore are obtained in solution. The acid is then diluted or partly neutralized and a little soluble barium salt solution is added, followed by sulphuric acid or a soluble sulphate. The barium and radium precipitate together as insoluble sulphates, the barium sulphate furnishing enough bulk to permit handling without much mechanical loss. Pitchblende ore has been treated directly with sulphuric acid mixed with a little nitric, barium salt being added to collect the radium sulphate residue. The sulphate precipitation separates radium, mesothorium, barium, and lead from uranium, thorium, rare earths, vanadium, and other elements present.

Lead can be separated by precipitation as sulphide without causing much loss of radium. Barium and radium sulphates are isomorphous, that is they can grow together as constituent molecules of a single crystal so that the precipitate is not merely a mixture of crystals, some of which are pure barium sulphate and some pure radium sulphate, but each individual crystal consists chiefly of barium sulphate in which part of the barium is replaced by radium. This is the reason that the barium sulphate precipitation is so effective in recovering the radium.

The barium-radium sulphate precipitate is next converted to carbonate or sulphide and then to chloride or bromide. The mixed barium and radium chlorides or bromides are separated by numerous fractional crystallizations. The radium salt being less soluble than the barium salt, tends to crystallize out first and thus becomes concentrated in the first fractions. By recrystallizing these fractions many times the radium salts may be eventually obtained free from barium.

The most desirable ores for radium extraction are those, such as pitchblende and carnotite, which are readily soluble in acids. The complex radioactive minerals containing titanium, tantalum, and columbium are insoluble in ordinary acids (except HF) and their treatment would probably be much more complicated and expensive than is the case with pitchblende or carnotite. Pitchblende or uraninite is the ideal ore mineral, being very rich in uranium (up to 80 per cent U_3O_8) and readily soluble in nitric acid, chlorinated hydrochloric acid, or a mixture of sulphuric and nitric acids. The American carnotite ore though usually low grade (½ per cent U_3O_8) had in its favour the fact that it is soluble in acid and that it contains enough vanadium to contribute considerably toward paying the cost of treatment. In fact some of these ores, it is said, could perhaps be profitably treated for their vanadium content alone. Vanadium is a steel-alloying element for which a constant demand exists, but the consumption of uranium is small and recovery of this element cannot at present be expected to assist to any considerable extent in paying the cost of the radium extraction.

Uranium minerals and their occurrence are discussed under Uranium (page).

Mesothorium is identical with radium in its chemical properties; hence both are unavoidable obtained as a chemically inseparable mixture when minerals containing both uranium and thorium are treated. Mesothorium, however, has a much shorter life than radium;half of any given quantity will decay in 6 or 7 years, whereas half of any amount of radium is transformed in 1,690 years. For this reason mesothorium is much less valuable than radium.

The amount of radium relative to uranium contained in old, unaltered minerals is a constant and is in the ratio of $3.4X\ 10^{-7}$to 1 which is about 3.4 parts of radium element by weight in 10,000,000 parts of uranium element, or about one part radium to 3,000,000 of uranium.Thus, one gram of radium is associated with about 6,484 pounds of uranium element or 7,645 pounds of U_3O_8 contained in minerals. In commercial practice the value of radium ores is based on the U_3O_8 content as determined by chemical analysis.

The amount of mesothorium relative to thorium contained in old, unaltered thorium minerals is also believed to be constant, and is in the proportion of from 3 to 5 $X10^{-10}$ grams mesothorium to one gram thorium element, the value obtained depending on which particular figures for the half-value period are used in the calculation. The half-value period for mesothorium is generally given as 6.7 years, for thorium variously as 1.8, or 2.2×10^{10} years.

USES

Radium is in demand chiefly by hospitals and the medical profession. Minor quantities are used for scientific experimental purposes and for making luminous paint. During the world war, however, this last was an important use, the British government having bought 18 grams for this purpose. Radium is marketed in the form of chloride, bromide, or sulphate. The chief therapeutic application of radium is in the treatment of cancer and skin diseases. For this purpose it is the gamma radiation which is utilized, the radium salt or emanation being contained in hollow metal (platinum, gold, or monel metal)needles, tubes, or flat applicators called placques. Strong gamma radiation acting for some time produced burns on living healthy tissue, similar to X-ray burns. The therapeutic value of radium is believed to be due chiefly to the fact that the gamma radiation is capable of stopping the growth of dividing cells and that abnormal or diseased cells are more susceptible to radiation than normal cells of healthy tissue. The adjustment of dosage is thus of supreme importance in order that the abnormal cells may be killed without unduly injuring the healthy tissue. It is in the matter of control of dosage that radium is superior to hard X-rays which have similar effects but often cannot be applied without also penetrating and injuring healthy tissue. It is stated that the practice of administrating the maximum or lethal dose in the shortest possible time by the use of a comparatively large single quantity of radium is now being superseded by the application of a smaller quantity more evenly distributed by means of a number of containers for long periods of time. Thus the needles most used at the present time contain only 1 to 2 milligrams of radium.[1]

In hospitals possessing relatively large amounts of radium the radium itself is sometimes not used directly but is stored in a safe connected by a tube to a complicated glass apparatus by means of which the highly active gaseous emanation(radon) can be collected purified, and compressed into hollow glass needles or tubes. The emanation thus produces the effects of radium in concentrated form and there is no danger of losing the radium itself. The equilibrium amount of radon is generated every 30 days, but the radon itself decays quickly (half-value period 3.8 days)which is a disadvantage, so that there is a tendency, especially now that radium is less expensive than it was, to use the radium directly in needles containing 1 to 2 mg. of radium in the form of sulphate. It is said that the use of radium in hospitals is increasing and that one hospital which already had 4 grams recently bought 4 grams more. In recent years many alleged radium remedies for various diseases, devices for rendering drinking water radioactive, cosmetic

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[1] "Radium, Its Production and Therapeutic Application";published by Radium Belge, 10 Montagne du Parc, Brussels.

etc. have been put on the market in various forms and sold at high prices. Most of these contain only minute traces of radium, if any, and even in the case of those that do contain appreciable quantities the prices charged are equally exorbitant. The therapeutic value attributed to radium in such preparations is very doubtful, to say the least, and in any case radium treatment of any sort should only be administered by those competent to do so.

Luminous paints consisting of zinc sulphide along with a little radium and a suitable binder are used on watches, compasses, electric push button switches, gun sights, etc. Inferior grades may be made with mesothorium which has a much shorter life. It is said, however, that even when radium is used the zinc sulphide gradually becomes insensitive, i.e., loses its property of luminescing under the impacts of alpha particles and that the active life of mesothorium is sufficient to last during the period of sensitiveness of the zinc sulphide.

Radium is said to be used in a Russian rubber factory to prevent the accumulation of large charges of static electricity generated by the friction of moving rubber materials. Such static electricity may give rise to spark discharges which are dangerous when explosive vapour or dust is present. A small amount of radium placed at suitable points makes the air so good a conductor of electricity that the static charges leak harmlessly away to the nearest grounded metal.

Many industrial operations produce dusts that are potentially dangerous explosives when mixed with air and it is possible radium may find application in preventing static discharges from moving belts, etc., in such cases.

PRODUCTION

The estimated total world's production of radium up to 1926 was according to "The Mineral Industry", 507 grams, distributed as follows:

	Grams
United States	250
Belgian Congo	180
Czechoslovakia	42
Portugal	15
Madagascar	8
Russia (Ferghana)	6
Cornwall	5
South Australia	1
Total	507

In 1927 Radium Belge marketed 28 grammes and in 1928, 40 grammes. Other sources, chiefly Czechoslovakia, during the same years probably produced about 6 grammes.

This is about 20 ounces worth at present prices about $40,000,000, of which nearly one-half was produced by the United States from carnotite ores before the opening up of the pitchblende deposits of the Belgian Congo.

Apparently no data are available regarding the production of mesothorium, but it is probable that this element is recovered in the treatment of monazite and perhaps finds its chief outlet in the form of luminous paint.

PRICES

Previous to the opening of the Belgian Congo deposits radium sold for well over $100,000 per gram of element. Since then the retail price has dropped to about $70,000 per gram with some sales of large lots at $50,000 to $60,000 per gram. Mesothorium preparations are usually sold on the basis of their gamma-ray activity equivalent to radium and are said to sell at from 40 to 60 per cent of the value of radium for an equivalent gamma radiation. Mesothorium should be very much more active than radium (in the proportion of their half-value periods- i.e.) about 250 to 1), but pure mesothorium cannot be obtained in appreciable quantities from minerals, as some radium is always mixed with it. It is said that most commercial mesothorium preparations probably consist of 99 per cent radium, though the activity during the first few years is chiefly due to the relatively small amount of mesothorium present.

LITERATURE

The literature of radioactivity is very extensive and widely scattered. Only a few of the more accessible and generally interesting works need be listed here.

Russell, A.S.: "An Introduction to the Chemistry of Radioactive Substances"; London, John Murray, Albermarle St., W (about $1.50).

Hevesy, George, and Paneth Fritz; "A Manual of Radioactivity"; translated by Robert W. Lawson Oxford University Press. (About $3.80)

Fajans,K.: "Radioactivity"; translated by T.S.Wheeler and W.G.King, Methuen and Co. Ltd., 36 Essex St.,W.C.,London, (About $1.60).

United States Bureau of Mines Bulletins 70, 103, 104.

"The Mineral Industry"; McGraw-Hill Book Co. (Production and Commercial Aspects).

CHAPTER X

RADIOACTIVE MINERALS AS GEOLOGICAL AGE INDICATORS

The Lead Ratio Method

The use of uranium- and thorium-bearing minerals in the estimation of the age of rocks is based on a number of assumptions:

(I) That uranium and thorium change quantitatively to lead and helium as final stable end-products.

(II) That the rate of transformation to lead has been uniformly the same as at present throughout geological time.

(III) That no lead or short-lived radioactive substances capable of quickly producing lead entered into the original composition of the radioactive mineral when formed.

(IV) That the relative proportions of uranium, thorium, and their lead end-products as formed by disintegration have not been changed by such natural processes as alteration, replacement, or leaching.

If the above conditions were fulfilled and the rate of production of lead from uranium and thorium were accurately known, it would be possible to calculate the age of the minerals with great exactness from the present content of lead, uranium, and thorium.

The first and most fundamental assumption quantitatively stated, is that uranium and thorium change spontaneously, through a series of intermediate radio-elements, to stable uranium lead and thorium lead respectively, and helium in accordance with the equations:

$$U\ (238.14) \rightarrow Pb_U (206.04) + 8\ He\ (4.00)$$

$$Th\ (232.12) \rightarrow Pb_{Th} (208.0) + 6\ He\ (4.00)$$

The slight loss of mass which apparently occurs in the process is no doubt represented in part at least by the tremendous energy set free in the form of heat and radiation during disintegration.[1]

[1] Rutherford states (Radiations from Radioactive Substances p. 531) That : "In the transformation of uranium to lead, eight particles and six particles are liberated with a total emission of energy per atom of 45 million volts. The total mass of eight free helium nuclei and six electrons corresponds to 32.012, while the pass equivalent to an emission of energy of 45 million volts is 0.048. Consequently the theoretical difference of mass to be expected between uranium and uranium lead should be 32.060, and the departure of the atomic mass of uranium from a whole number should be 0.060 greater than for uranium lead.

That this fundamental assumption is in all probability at least approximately correct is indicated by the constant presence in all uranium and thorium minerals, of lead that which differs in atomic weight from ordinary lead (207.20). Uranium-lead from the purest uranium minerals (i.e., those containing least thorium) has an atomic weight close to 206.00 (e.g., leads from various pitchblendes and uraninites containing little or no thorium have given the results 206.05, 206.06, 206.08, 206.12 according to various determinations by Honigschmidt or Richards) whereas lead from the purest thorium minerals has an atomic weight close to 208 (e.g., 207.90 for thorite containing 30.1 per cent. Th and 0.45 per cent U). As there is almost invariably some uranium in thorium minerals and some thorium in uranium minerals, the experimental values obtained are in very close agreement with theory. From these experimental results it is assumed that uranium-lead and thorium-lead have atomic weights very close to, if not exactly 206.00 and 208.00 respectively. The question as to the exact atomic weights and isotopic composition of uranium-lead and thorium-lead may soon be solved by F.W. Aston by means of the mass-spectrograph operating on the volatile tetramethyl compound of lead from radioactive minerals as suggested by Piggot[1]. Helium has

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[1] Piggot, C.S.: Geophysical Lab. No. 659. Jour. Wash. Acad. Sci., vol.18, No.10, May. 19, 1928.

already been found to consist of a single isotope with atomic weight 4.00 exactly. The atomic weights of uranium and thorium have been very carefully determined by the usual chemical methods and foundto be definitely greater than whole numbers,[1] but their isotopic composition is not fully known, except is so far as uranium is believed to consist of two isotopes U I and U II with atomic weights about 238 and 234 respectively U II deriving from U I by disintegration.[2]

This basic principle upon which radioactive age determinations are based is due originally to Boltwood[3], who first suggested that lead is the end-product of uranium. Holmes[4] and Holmes and Lawson[5] later were active in developing the idea. At first it was not suspected that thorium might also change to lead, its end-product being thought to be bismuth. Eventually, however, the constant presence of lead and the absence of any important amount of bismuth or other possible end-product in high thorium minerals, together with the high atomic weight (near 208) of lead from thorium minerals in contrast with the low atomic weight (near 206)

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[1] The great majority of isotopes with one or two possible exceptions -- i.e., Sn and Xe, appear from Aston's work to be whole numbers within the limits of accuracy of his mass-spectrographic method.

[2] Since the above was written (1928) Aston has made mass spectroscopic analyses of lead from Norwegian uraninite, which showed 206 strong, 207 faint, 208 very faint. The isotope of atomic weight 207 is now believed to be the end product of actinium and it is strongly suspected that actinium is derived from an isotope of uranium which Rutherford has named actino-uranium and which probably has atomic weight either 235 or 239.

[3] Boltwood, B.B.: Am. Jour. Sci., 20,253,1905;23,78 (1907).

[4] Holmes, A.: Proc. Geol. Assoc.,26,289 (1905);Bull. Geol. Soc. Am.,28, 845 (1917).

[5] Holmes,A. and Lawson, R.W.: Phil. Mag.,28, 823,(1914); 29,673 (1915).

of lead from uranium minerals, has led to the general acceptance of lead as the stable end-product of thorium as well as uranium. Further, bismuth which formerly was supposed to have atomic weight 208, is now known, by more accurate determinations, to have an atomic weight of 209, which does not fit into the disintegration scheme unless we suppose that thorium-bismuth, if there is such a thing, is an isotope having the atomic weight 208. If such an isotope does exist it would probably be unstable (Fajans).

Thallium has also been suspected to be possibly an end-product of the disintegration, but so far as the writer is aware has not been found in radioactive minerals. Several Canadian thorium minerals tested by the writer for thallium yielded no evidence of its presence, whereas tests for bismuth have in a few instances indicated the possible presence of minute amounts of this element, but the results were not conclusive.

Some have thought nevertheless (e.g., Fajans, Radioactivity page 93) that uranium- and thorium lead may not really be the final end-products, but merely a stage in a further transformation to elements of lower atomic weights; the change being too slow to be detectable by the usual radioactive methods. If this is true then radioactive minerals are really older than is indicated by the lead ratio.

In the case of U-lead, the rate of change even if it is unstable, is probably so extremely slow as to have no appreciable influence on the results of age calculations. In the case of Th-lead, however, there has been more ground for this suggestion since age calculations where thorium minerals are concerned have not always given altogether consistent results. For instance R.W.Lawson[1] has shown that for eighteen minerals studied by Holmes and Lawson, all of which where from the Middle Devonian eleolite syenite of Brevig, Norway, the age according to the ratio Pb:(U + 0.384 Th) varied from 8.7 to 300 million years, the minerals having the greatest Th:U ratio yielding the lowest age results. Lawson explains these results by supposing that the high thorium minerals are of secondary origin and really are younger than the high uranium minerals from the same rock. There certainly is no doubt that mineralogical evidence cannot be safely neglected in making age determinations, since alteration of a mineral by natural agencies might easily make great changes in the relative proportions of the constituents. Thorianites, thorites, and monazites in particular and the complex tantalo-columbates often do not give as great age indications as might be expected in comparison with uraninites of similar geological periods. On the other hand some of the latest work on thorium minerals has shown fairly satisfactory agreement. For instance the Cardiff township, Ontario, uraninite, with an unusually high thorium content, yields lead ratios in excellent agreement with other uraninites of the Canadian Precambrian which

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[1] Das Alter der Thoriummineralien, Sitzungberichten der Kaiserl. Akademie der Wissenchaften, Wien, Abteilung, IIa, Bd. 126, heft 6(1917).

contain only about one-quarter as much thorium, and Fenner[2] has recently obtained almost identical lead ratios from monazite and samarskite occurring in Divino do Ubá, state of Minas Geraes, Brazil. Also, Holmes[2] has recently shown that contrary to the former impression, the lead ratios of the best-preserved Ceylon theorites and thorianites agree well with pitchblende from the same pegmatites, although some of the thorites in particular give abnormally low ratios, in one case only one-quarter that of the pitchblende. Holmes explains the irregularities of the Ceylon minerals as due to the greater relative leaching of lead from thorium minerals as explained further on.

The cause of the frequent discrepancies between age results from uraninites and from high thorium minerals is not yet altogether clear. Several explanations are possible. In the first place the rate of disintegration of thorium is not so accurately known as that of uranium, thus the amount of thorium lead produced and its stability seems less certain. Hence it may be that the factor (0.38 Th = equivalent U) most commonly used in recent years to express the amount of uranium equivalent to thorium, in lead producing capacity, is somewhat incorrect, though the fact that, as previously stated, some thorium-rich minerals do agree with uraninites would seem to indicate that the present generally accepted factor 0.36 is substantially correct. There is also the

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[2] Fenner, C.N.: Am. Jour. Sci., Nov. 1928; Geophysical Lab. No. 667

[2] Holmes, A.: Phil.Mag., 1,1060 (1926)

question as to the original isotopic composition of uranium and thorium. It may be that an isotope of shorter life was originally present, which has been mainly responsible for the production of lead.

Gerhard Kirsch[1] has investigated the possibility that thorium might be derived from the disintegration of a supposed isotope of uranium of atomic weight 236.1, but without conclusive results favourable for this theory.

Experiments up to the present have indicated that the rate of disintegration of the radio-elements is not affected by any change in temperature or pressure, physical state, or form of chemical combination. That is, uranium and thorium decay and produce lead and helium at exactly the same rate whether in the form of pure elements or in chemical combination with other elements and under any conditions of temperature or pressure which it is possible to apply experimentally. However, conditions comparable to those existing deep in the earth's crust have not yet been duplicated in a way to permit accurate determination of the rate under such conditions. Arrhenius[1] has suggested the possibility that extreme pressure may, in fact, slow down the rate of disintegration and that under sufficiently intense pressure and heat regeneration of uranium and thorium from their decomposition products might even occur. The chief geological interest of these speculations

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[1] Kirsch, Gerhard: Sitzungsberichten der Akademie der Wissenschaften in Wien: Mat.Naturw.Klasse, Abt.IIa, Band 131, heft 9, (1922)

[1] Das Werden der Welten 1907.

of Arrhenius lies in the fact that if there is any truth in the theory and earth crustal pressures do actually influence the rate, then the radioactive minerals are really older than is indicated by calculations based on the present generally accepted disintegration constants. Joly,[1] on the other hand, from a study of pleochroic haloes has thought that the rate of production of lead, more particularly from uranium, may have been greater in the past than at present, due possibly to the presence of a highly active and comparatively short-lived radio-element which has now completely decayed. As pointed out by Joly, pleochroic haloes afford the only direct evidence as to the constancy or otherwise of the rate of transformation in past geological ages. Pleochroic haloes are microscopic, concentric, spherical zones of darker colour surrounding minute inclusions in certain minerals, most often in micas. Joly[3] was the first to suggest that the coloration is due to alpha radiation from radioactive elements contained in the nucleus. As the range of the alpha particles from radio-elements emitting this type of radiation, is characteristic for each element and varies with the rate of disintegration of the particular element, the diameter of the halo rings can be used by suitable comparisons, as a means of checking the rate of disintegration in the past. A.S.Russell[4]

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[1] Joly, J.: Phil. Mag., March,1907, Feb. 1910; and
Fletcher, A.L.: Phil. Mag., April, 1910.

[3] Joly,J.: Roy. Soc.,Lond.,Phil. Trans.A.,217,1916-18, p.91 et seq
Proc.A, 102,1922-23, p.682 et seq.

[4] Russell, A.S.: Nature, Oct.15, 1927, pp. 545-546

has proposed explanations of the supposed abnormal halo rings observed by Joly and others[1], and very careful studies of this sort have been made recently on haloes in Precambrian biotite from Murray Bay, Quebec, by Kerr-Lawson[2], who finds no evidence to support the idea that there were irregularities in the rate of transformation in former times.

Thus it seems generally agreed at the present time that there is no reason to believe that the rate of production of lead and helium from uranium and thorium was different in past geological ages from what it is at present.

A criticism that has frequently been applied to the radioactive method of time determination is based on the possibility that the radioactive minerals may have contained some lead, either common lead or lead of radioactive origin, at the time of their formation. A test advocated by physicists for the initial presence of lead in uranium-thorium minerals is the determination of the atomic weight of the lead isolated from the mineral. Should the atomic weight found be in accord with the relative amounts of uranium and thorium originally in the mineral it is good evidence that no lead was originally present. If the atomic weight found does not agree with the calculated theoretical value the discrepancy is supposed to be due to common lead originally present in the mineral, and the amount of this supposed common lead originally

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[1] Mori, S., and Yoshimura, J.: Sci Papers, Inst., Phys. Chem.; Res. Tokyo 5, 11, 1926.

[2] Kerr-Lawson, D.E.: University of Toronto Studies No.24, 1927

present can be calculated. In a number of instances in which the atomic weight of lead derived from analysed radioactive minerals has been determined it has been found that the atomic weight does not agree with that to be expected theoretically and it has, therefore, been concluded that common lead was present.[1]

Although at first sight an atomic weight determination of the lead would apparently settle the question as to whether common lead was initially present, another factor must be considered, which mineralogists in particular have appreciated,[2] viz., the fact that alteratio leaching, replacement, or exchange of uranium, thorium, or lead by the action of aqueous solutions circulating in the rock, is easily possible and in fact is known to occur, and the effects of such differential leaching or replacement where both uranium and thorium minerals occur in the same deposit might easily lead to the same atomic weight results as would be obtained if a little common lead was really present.[3] Determination by means of the mass-spectrograph of the isotopic composition of the lead isolated from radioactive minerals as proposed by Piggot[4] will probably settle the question definitely in the near future. The isotopes of ordinary lea have already been determined by Aston[5] and it only remains to make

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[1] Kirsch, Gerhard: Über den genetischen Zusammenhang zwischen Thor und Uran and Über altersbestimmungen an radioactiven mineralien. Sitzungsberichten der Akademie der Wissenschaften in Wien. Mat. naturw. Klasse, Abteilung IIa, Band 131, heft 9, (1922)

[2] Ellsworth, H.V.: Am. Jour. Sci., Feb. 1925, p. 135

[3] Another explanation of the supposed presence of common lead may now be given, as it isbeginning to be suspected that actinium lea has atomic weight 207. It may well be that more actinium lead is present in the mixture of leads derived from radioactive minerals than has been supposed hitherto.

[4] Loc.cit.

Aston, F.W.: Nature, 120, 224, 1927- ordinary lead (207.20) was found to consist of the isotopes of masses 206, 207, and 208 in the approximate ratios 4, 3, and 7, respectively, and the existence in very small amounts of isotopes 203, 204, 205, and 209 was indicated.

similar studies of radioactive lead from various analysed uranium-thorium minerals. From observations of the mineralogy of pegmatites in which uranium and thorium minerals mostly occur it appears extremely unlikely that ordinary lead enters initially into the composition of the primary radioactive minerals found in them, as ordinary lead minerals scarcely ever occur in such deposits and when they do, only in minute quantities. The writer has examined a very large number of pegmatites in Canada and in only one instance was a small amount of any lead mineral, other than the radioactive minerals themselves, found. This was the occurrence of a few grammes of galena in association with sulphide segregations composed chiefly of pyrrhotite and pyrite in the MacDonald mine at Kybla, Ontario (page). The MacDonald dyke, however, is a rather exceptional type of pegmatite; further, the possibility exists that the lead of the galena in this case may be of radioactive origin derived from the uranium and thorium minerals present. Though the mineralogical evidence thus encourages the belief that common lead is not likely to be a constituent of the primary radioactive minerals which occur in ordinary pegmatites, the case is otherwise with certain minerals such as pitchblende and various secondary uranium and thorium minerals which are found either in ve vein deposits with sulphide minerals or as impregnations of porous or highly altered rocks.

The question as to whether lead may be an initial constituent of primary radioactive minerals may also be considered from the point of view of isomorphism and crystal structure. X-ray studies of various oxides and minerals enable not only the crystal structure and the arrangement of the constituent atoms to be determined, but even the distances between atoms to be calculated. These distances are characteristic for any particular oxide and in order that different oxides may replace one another in chemical compounds (isomorphism) the dimensions of their respective units of structure must be nearly the same. Such determinations have already been carried out on uraninite and the various oxides of U, Th, Ce, and Pb by V.M.Goldschmidt and L. Thomassen[1], who conclude that UO_2, ThO_2, and CeO_2, are isomorphous and they believe that uraninite and thorianite are isomorphous mixtures of these elements with PbO_2. Their conclusions with respect to PbO_2 are not, however, based on actual experimental results, and that lead dioxide really exists in radioactive minerals seems very improbable.

Perhaps at once the simplest and most conclusive line of attack on the question of initial lead in radioactive minerals as well as the validity of all the assumptions which enter into the method of radioactive age determination consists simply in the

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[1] Die Krystallstruktur, naturlicher and synthetischer Oxyde von Uran, Thorium and Cerium, Videnskapsselskapets Skrifter I, Mat.naturv.Klasse, 1923, No.2.

exact determination of lead, uranium, and thorium in different species of radioactive minerals and in different specimens of one species, from the same deposit. This, of course, is not always possible, but different species of primary uranium and thorium minerals quite often do occur in the same pegmatite, and if it should be found for a considerable number of such occurrences that two or more entirely different radioactive minerals gave identical lead ratios, all doubts regarding the accuracy of the method would disappear. Such comparisons of this sort as have been made up to the present have not given as concordant results as might be desired, probably because of the varying effects of alteration, leaching, or replacement processes on different mineral species.

The foregoing discussion with regard to lead applies also to radium or other short-lived radio-elements which if present in a radioactive mineral in greater amount than required by their equilibrium ratios would produce lead at a faster rate than is taken account of in age calculations, and the age would appear to be greater than it really is. The concentration of such radio-elements in rocks and minerals at any time is very small, and it is not likely that any important quantity would be included in minerals at the time of their formation, but during subsequent ages these elements might be slowly leached from some minerals while other minerals might be enriched.

Granted that all the foregoing assumption upon which the radioactive method is based are correct, there still remains the possibility that all the uranium, thorium, intermediate radio-elements, and lead end-products may not be preserved intact in the radioactive minerals owing to the action of circulating solutions which might conceivably remove one or more of these substances at a greater rate than the others or might even actually enrich a mineral in respect to one or more of the elements concerned. Such action would be quite in accord with the well-known geochemical processes of leaching, replacement, etc., the effects of which are often observed in the case of the more common mineral deposits. The occurrence of dissolved radium and radium emanation in natural spring waters proves the possibility of a slow migration of these substances. Though such migration doubtless would be very slow and the quantities involved at any instant very minute, nevertheless the effect over millions or hundreds of millions of years might be considerable. The writer believes that effects due to the natural processes just mentioned are the most probable cause of the irregular and discordant lead ratios sometimes obtained. Microscopic examination of thin sections or polished surfaces of radioactive minerals shows that they are invariably intensely shattered, every part being traversed by a network of cracks, which in the case of well-preserve minerals are fine and short and with but little evidence of alteration along the edges. In the case of more altered minerals;

larger cracks, with much greater evidence of alteration along the edges, traverse the mineral, connecting with smaller tributary fractures, somewhat like a river system, and perhaps extending to the outer surface of the mineral mass. This fracturing in radioactive minerals is always very much more intense and complete than the fracturing that occurs in the common non-radioactive minerals found in pegmatites which is due probably to rock movements, or perhaps sometimes to differences in the coefficients of expansion of the mineral and its matrix material. It may generally be noted that in descriptions of radioactive minerals they are described as being very brittle. A slight blow is usually sufficient to shatter them into small bits and though often hard they are rather easily crushed or ground because they break up readily along the pre-existing fractures. This so-called brittleness is really due tothe multitude of minute fractures, actual or incipient, which are present and the writer has noticed that the degree of brittleness for a given mineral species is closely connected with the uranium and thorium content, being more marked the greater the percentage of these elements present. Thus, for example, lyndochite from Lyndoch tp., a member of the euxenite-polycrase group containing only 0.71 per cent of U oxides and 4.95 per cent ThO_2 is much less brittle than the Sabine township euxenite with 8.31 per cent uranium oxides and 3.94 per cent ThO_2.

Not only are radioactive minerals themselves completely shattered internally, but the surrounding rock is also penetrated by fractures radiating from the radioactive mineral in all directions, for distances varying with the size of the radioactive mineral mass, from a fraction of an inch to several feet. This radial fracturing of the rock matrix (quartz or feldspar usually, sometimes mica) does not occur around the common non-radioactive minerals found in pegmatites (with the possible exception of zircon), but appears to be very definitely characteristic for radioactive minerals of any sort. Zircon in rock is usually, if not always, surrounded by similar radial fractures, but zircon often contains uranium and thorium in small amounts.

The internal shattering of radioactive minerals and the radial shattering of the rock matrix are believed by the writer [1] to be initially due to stress induced by increase in the volume of the radioactive minerals as a result of atomic and molecular rearrangement necessitated by the disintegration of uranium and thorium. The shattering of mineral and matrix thus initiated by th radioactive processes increases the permeability to gases and solutions circulating in the rock, with the result that the ordinary type of alteration involving oxidation, hydration, and silication, which almost all minerals suffer more or less, is speeded up, resulting in further increases in volume and incidental augmentation of the shattering. That radioactive

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[1] Ellsworth, H.V.: Geol. Surv., Canada, Sum. Rept. 1921, pt.D, p. 58; Amer. Jour.Sci.Feb.1925, pp. 137-139.

minerals do increase in volume with increasing alteration can be readily shown to be true. Such changes are perhaps best exemplified by uraninites, which are more constant in composition than many other radioactive minerals and, therefore, afford better comparative data. The best preserved uraninites have specific gravities between 9 and 10 whereas more altered specimens go as low as 7. The freshest portion of the Villeneuve uraninite for example had specific gravity = 9.144 ,whereas the more altered portion of the same specimen had specific gravity = 7.778. Some of the late Palaeozoic uraninites from Connecticut analysed by Hillebrand have specific gravities as high as 9.733[1] and it is probable that when first formed uraninites had specific gravities approaching that of UO_2, which is about 11.

Volume increase of radioactive minerals from the effects of atomic disintegration has been shown by the writer[2] to be probably due chiefly to autoxidation which must occur when uranium in the lower form of oxidation is present. In primary uranium minerals and particularly in uraninite there is usually if not always a considerable fraction of the total uranium present in the lowest stage of oxidation represented by the oxide UO_2, and there are good reasons to believe that when the minerals were first formed the conditions were favourable for reduction[3], and that probably all or nearly all

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[1] Hillebrand, W.F.: U.S.Geol. Surv., Bull. No. 78, p.64

[2] Ellsworth, H.V.: Pan-American Geologist, Nov.1924, and Am. Jour. Sci., Feb. 1925, pp. 137-139.

[3] Cf. The occurrence of carbon-hydrogen and hydrocarbon minerals

In association with uraninites and other radioactive minerals in pegmatites -- in Canada, Sweden, and Russia - pages......

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the uranium was originally in the lower state of oxidation. Starting with a newly formed mineral containing uranium with valency corresponding to UO_2, in the case of uraninite actually consisting of perhaps 95 per cent UO_2, atoms of uranium (and thorium if present) scattered at random throughout the mass will disintegrate throwing off helium atoms and electrons and changing successively to atoms of the radio-elements of the U and Th series as the case might be. The two oxygen atoms, which we may consider as belonging originally to the U or Th atom in UO_2 or ThO_2, would become available to oxidize any readily oxidizable compounds such UO_2 or FeO when the disintegrating atom changed to the emanation stage (radon or thoron), since these gaseous radio-elements cannot enter into chemical combinations. Being set free in the nascent state within the range of atomic attractions the oxygen atoms would oxidize UO_2 to UO_3 or U_3O_8, thus :

$$O + UO_2 = UO_3 \text{ or } 2O + 3UO_2 = U_3O_8 \ (2UO_3 \cdot UO_2).$$

In the case of minerals such as euxenite, samarskite, etc., which may contain besides UO_2 considerable iron presumably present originally as FeO, the iron seems to be autoxidized in preference to the UO_2 (cf The Mattawan, Sabine, and Maberley euxenite and the Woodcox calcio-samarskite). Thus, according to this conception all minerals containing UO_2 must automatically and irresistibly oxidize themselves at a rate depending on the rate of disintegration of uranium and thorium. The change from UO_2 to U_3O_8 results in a marked increase in volume (Sp. G of UO_2= 10.95, of U_3O_8=7.31) with consequent shattering, and the oxidation thus brought about in the first instance by autoxidation is supplemented by the action of circulating gases and solutions which because of the shattering can penetrate the mineral more freely causing further oxidation, hydration, and silication with still greater increase in volume and fracturing. As a result of all these effects it appears hopeless to expect ever to find old radioactive minerals absolutely fresh and unaltered except possibly in the case of those minerals whose content of U and Th is very small. Such minerals theoretically should yield the most accurate age results if sufficiently delicate methods of analysis were available.

Walker and Parsons[1] have suggested that the radial shattering

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[1] Walker, T.L., and Parsons, A.L.: University of Toronto Studies, 1925, pp. 25-28.

OF rocks surrounding zircon and radioactive minerals may be due in some cases to differences in the coefficients of expansion of rock matrix and mineral causing strains on cooling down from the molten condition. This explanation may be true for pure zircon, though it is not yet certain that zircon which is) free from U and Th causes shattering. It would be very remarkable and improbable, however, if all the radioactive minerals should have coefficients of expansion such as to cause shattering in such diverse minerals as quartz, feldspar, micas, and calcite, and it would be equally improbable that on the other hand all the common non-radioactive pegmatite minerals should have coefficients so similar to those of quartz, feldspar, and mica as to cause no shattering in these minerals. The evidence seems overwhelming that it is some property connected with radioactivity which causes all radioactive minerals, regardless of differences in composition, to produce fractures in t the surrounding rocks.

Although V.M.Goldschmidt and L. Thomassen (loc.cit.) have found by X-ray spectroscopic studies that some well-preserved uraninites apparently still retain their original UO_2 crystal structure, it is nevertheless true that UO_3 probably in the form of U_3O_8 is present, as shown by chemical analysis. Probably enough unaltered original UO_2 still exists in the mineral to produce the X-ray results mentioned while the amorphous U_3O_8 present does not produce a definite pattern. The complete distortion of the original crystal structure of old primary uranium minerals is indicated by the fact that all such minerals, no matter what crystal system they belong to, are optically isotropic. Secondary minerals and alteration products in which the uranium is in the UO_3 condition are not always thus optically anomalous and may be anisotropic. This, with the further fact that old monazite that often contains 10 per cent or more ThO_2 retains its original anisotropic character seems to the writer to indicate that the distortion of the original crystal structure evidenced by the present isotropic character of minerals which according to their crystal form should be anisotropic, is probably due chiefly to autoxidation of UO_2 originally present, as previously described. If the isotropic character were due entirely to normal alteration one would expect to find at least some small part of the interior of large masses of such radioactive minerals as euxenite, samarskite, fergusonite, etc., sufficiently well preserved to retain the anisotropic character. On the contrary, even the freshest euxenites examined by the writer, which show but very little signs of normal alteration, are perfectly isotropic. The fact that autoxidation must occur in minerals containing UO_2 has also been recognized by Gerhard Kirsch,[1] who discusses in detail the probable effects in the crystal lattice as a result of this action. Kirsch points out that from the point of view of crystal structure as revealed by X-ray studies, molecules like UO_2, UO_3, PbO, etc., do not exist individually as such, some of the atoms comprising the so-called molecule being shared by other neighbouring molecules, so that no particular two oxygen atoms, for example, can be said to belong exclusively to one uranium or thorium atom in UO_2 or ThO_2. This is evident from inspection of the atomic crystal lattice diagram prepared by X-ray investigators. Also, Kirsch believes that the force of recoil of a radio-element atom ejecting an alpha particle is sufficient to dislocate the parent atom from its place in the lattice and drive it for some distance through the spaces of the lattice,

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[1] Kirsch, Gerhard: Tschermaks- min.petr.Mitt. 38 223 (1925)
Geologie und Radioaktivitat, 1928.

the formerly associated oxygen atoms being left behind. However the effects may be achieved, there is no doubt about the simple fact that in ordinary chemical language two oxygen atoms in the nascent state become available to oxidize UO_2, FeO, or Pb, for each disintegrating U or Th atom of UO_2 or ThO_2 present.

The autoxidation reaction as conceived by the writer is much more complicated than as stated but it is not necessary to go into details here, as only its relation to alteration is under consideration. It might be noted, however, that the amount of autoxidation which theoretically should have occurred can be calculated for any analysed uranium mineral and is always found to be less than the actual amount, the difference being due presumably to normal alteration. It is not supposed that autoxidation itself in any way affects the lead ratio directly, its importance being due to the shattering it induces, which facilitates the passage of solutions causing normal alteration, leaching, etc.

Though the writer believes that autoxidation is probably the chief factor causing volume increase, shattering, and oxidation of uranium minerals, other effects of the U and Th disintegration no doubt also contribute to the distortion and enlargement of the crystal structure. At one stage in the disintegration of a U or Th atom it becomes a heavy, chemically inert gas, radon or thoron, which after passing through several more stages of disintegration as solid radio-elements changes finally to lead. During these stages there is a possibility that the atom may unite again with oxygen, but not with the two oxygen atoms originally attached to the U or Th atom (in UO_2 or ThO_2) which must have been set free at the time of change to radon or thoron and immediately seized by UO_2 to form UO_3 or U_3O_8 or by FeO if present, to form Fe_2O_3. Thus it would appear that atoms of radio-elements later than the emanation stage must either compete with other elements for the oxygen present in pre-existing oxides or wait until they have a chance to seize oxygen atoms set free nearby by the change of a disintegrating U or Th atom to emanation. This discontinuity in the passing down of the oxygen atoms must tend to disturb the atomic structure more or less regardless of what happens to the oxygen atoms.

The fact that the disintegrating U or Th atom becomes a gas at one stage also involves the possibility that this radioactive gas may escape to a certain extent from the mineral by diffusion. Nothing definite is known as to the extent to which such diffusion may take place, but as the gas is very heavy and present in only minute quantity at any instant, it does not appear likely that such loss can be important except possibly from a thin outer layer of a mineral. When an atom of a radio-element disintegrates by ejecting an alpha particle the parent atom recoils or tends to do so with equal force just as a gun does when fired. The force of this recoil has been calculated to be great enough to drive the parent atom through a distance of several units of the crystal lattice. The energy of the alpha radiation, which the experiments of Rutherford have shown to be capable of disrupting atoms of some of the lighter common elements, is practically entirely dissipated within the mineral and unknown but possibly important effects, besides the generation of heat, may be surmised to result from this radiation.

For instance water in appreciable amounts is always present in even the least altered specimens of radioactive minerals of all kinds. Some of this is doubtless chemically combined, some, more loosely held. It is known that radioactive radiations, more especially the alpha rays, decompose water forming a little hydrogen peroxide and liberating H_2,O_2 and O_3. This action may help to oxidize the mineral.

Further, Rutherford's experiments have shown that the alpha radiation has sufficient energy to displace hydrogen nuclei from some of the lighter elements thus effecting an actual transmutation of elements. During the hundreds of millions of years that the crystal lattice of a radioactive mineral has been subjected to alpha ray bombardment at the closest possible range appreciable effects from such action might conceivably result.

Heat generated in the interior of the mineral from radioactive disintegration may also have some effect in expanding the mineral and causing outward pressure and shattering. Such heat effects might be more marked if the mineral happened to be enclosed in a quartz matrix, as quartz is known to a poor conductor of heat. As a matter of fact it does sometimes appear that radial shattering around a radioactive mineral embedded in quartz is more strongly developed than when the same mineral is enclosed in other matrix minerals such as feldspar, mica, or calcite, but even if this observation is correct, the more intense effect in quartz may be due to the fact that quartz is more brittle and easily fractured than the other minerals.

The lead eventually formed by disintegration must be accommodated somehow in the atomic structure and probably increases the distortion due to other causes. Nothing is known definitely as to what state of oxidation the lead is in, or how combined in the radioactiv minerals. In uraninite it has been usually supposed to be combined as uranate. The writer some years ago made some vacuum distillation experiments on uraninites, with the object of gaining information as to the state of the lead. Some of the freshest uraninites from Parry Sound and Butt townships were powdered and placed in clear, transparent, silica glass tubes of about one-quarter inch internal diameter, closed at one end. The tube with the uraninite was then attached to a Langmuir mercury vapour pump system with McLeod gauge and exhausted.When it was certain that all air had been drawn out, the closed end of the tube with the uraninite was heated to a white heat with a gas blast lamp. Two slight sublimates formed on the inside of the tube, one yellowish to white, the other metallic looking, having the appearance of the thin film of "getter" metal seen on the inside of radio tubes. It was believed that the first-mentioned sublimate was lead oxide, the latter metallic lead. The tubing containing the supposed metallic lead coating was tested spectroscopically by Dr. E.G.Zier, spectroscopic expert of the Geophysical laboratory, who found nothing present but silica and lead. The supposed lead sublimate was comparatively small, thin, and transparent, and probably would have weighed less than a milligram. The supposed lead oxide sublimate was more abundant. This experiment seems to indicate that at least a small fraction of the lead may be present as uncombined PbO, and possibly a still smaller fraction as metallic lead, but probably the greater part is in the form of lead uranate as generally supposed. Thorium on the other hand is not known to form lead thorate and Holmes[1] recognizing the possible significance of this fact has put forward, in the writer's opinion, the most plausible explanation yet advanced for the abnormally low lead ratios of some thorium minerals. He supposes that in the case of uranium minerals the lead combined as uranate is very insoluble in the solutions that circulate in rocks; whereas in the case of thorium minerals in which there is little or no uranium the lead must exist as oxides or silicates which are probably much more soluble than the uranate.

In the foregoing paragraphs an attempt has been made to indicate the theoretical possibilities involved in the problem of

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[1] Phil. Mag. 1, p. 1066 (1926)

the alteration of radioactive minerals. The chief difficulties in connexion with the use of radioactive minerals as age indicators probably arise from alteration, leaching, or replacement of the minerals so anything having a possible bearing on such action seems worthy of serious consideration.

Something may now be said regarding the actual effects that appear to result from alteration, so far as can be judged from analytical studies of various radioactive minerals.

EFFECTS OF ALTERATION ON THE LEAD RATIOS OF URANINITES

In general, altered uraninites yield higher lead ratios than do less altered specimens of the same age, and the greater the alteration the greater the lead ratio. This effect, recognized by the writer some years ago, has been very strikingly confirmed by some of the analyses of Canadian uraninites, and particularly inthe case of the Villeneube uraninite (page) which see for a detailed discussion). So long as the uraninite remains black the lead ratio is not likely to be more than 0.01 too high, but when alteration goes so far that the UO_2 is all oxidized and the uraninite is completely changed to yellow or orange alteration products the lead ratio becomes unreliable.

Thus it appears that usually the effect of alteration on uraninites is to increase the lead ratio. (For other effects See the Villeneuve uraninite, page).

EFFECTS OF ALTERATION ON THE LEAD RATIOS OF THE COMPLEX TITANO-TANTALO-COLUMBATE MINERALS

Euxenites, samarskites, fergusonites, and similar minerals containing titanium, tantalum, and columbium, usually yield somewhat lower lead ratios than uraninites. According to the writer's analyses of such minerals from Canada (q.v.), the lead ratio appears to bear some relation to the silica content those minerals with the least silica yielding the highest lead ratios. If this observation should prove to be true generally, the silica content would constitute a very valuable criterion of the reliability of the lead ratio derived from such minerals. Unfortunately the silica has been rarely reported in older analyses of such minerals.

The following tabulation of Canadian minerals, all believed to be of middle Precambrian age, shows the figures from which this apparent relationship is surmised:

MINERAL	LOCALITY	SiO_2	UO_2	UO_3	FeO	Fe_2O_3	ThO_2	H_2O+ 100°	$\frac{Pb}{U\ 0.36\ Th}$
Euxenite	Mattawan tp.	0.03	6.42	0.43	0.29	1.40	0.97	2.83	0.155
Lyndochite	Lyndoch tp.	0.07	0.67	0.04	0.77	1.32	4.95	1.90	0.154
Euxenite	Sabine tp.	0.09	8.61	0.20	0.90	2.07	5.94	2.15	0.145
Euxenite	Maberley tp.	1.08	7.25	1.51	0.14	2.16	2.64	2.29	0.112
Toddite	Sudbury, dist., Ont.	1.77	8.71	2.37	4.38	4.63	0.47	3.59	0.042
Ellsworthite	Cardiff tp.	2.49	1.56	20.46	0.22	2.74	0.10	6.61 + (4.59 (-100°)	0.037
Calcio-samarskite	Parry Sound	1.92	---	---	---	---	2.16	5.76	0.028
Calcio-samarskite	Hybla	2.39	9.00	1.67	0.21	7.67	3.34	3.24	0.040

In the above table it may be noted that the only variable that might possibly be related to the lead ratio is the silica content. The water content does not seem to bear any very definite relationship to the lead ratio, as might have been expected, though it is true that the minerals with very low lead ratios, 0.05 to 0.08, have much more water than those with ratios of 0.11 to 0.15. The figures for UO_2 UO_3, FeO, and Fe_2O_3 have been inserted to afford a comparison of the amount of oxidation which has occurred and to illustrate the statement previously made that FeO is apparently oxidized in preference to UO_2.

It has been shown that the usual effect of alteration on uraninites is to increase the lead ratio; in the case of the complex columbate minerals tabulated here the effect of alteration involving hydration and silication is evidently just the opposite -- viz., the lead ratio is decreased.

EFFECT OF ALTERATION ON THE LEAD RATIO OF THORIUM MINERALS

Holmes[1] has made a very thorough study of the thorites and thorianites of Ceylon and he concludes that alteration of these minerals results in a reduced lead ratio, which he explains by assuming that the lead in these minerals exists as oxide or silicate which is more soluble than the lead uranate of uraninites. He has assembled the best analyses of these minerals in a convenient table, which is given below for reference:

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[1] Holmes, A.: Phil. Mag. 1926, pp. 1055-1074

THORIUM MINERALS (AND URANINITE) FROM CEYLON

(AGE-UPPER PRECAMBRIAN OR PALAEOZOIC)

Ref.	Mineral	U	Th	Pb	Th/U	Pb/(UX 0.37 Th.) (U X 0.37)
1	Thorianite	27.8	51.7	2.38	1.9	0.051
2	"	26.8	57.0	3.5	2.1	0.073
3	"	21.21	45.05	2.77	2.2	0.073
4	"	24.3	54.9	2.16	2.2	0.048
5	"	23.75	55.9	2.70	2.4	0.061
6	"	23.0	55.0	2.78	2.4	0.064
7	"	20.2	62.7	3.11	3.1	0.072
8	"	13.1	67.3	1.87	5.1	0.049
9	"	11.1	60.3	2.3	5.4	0.069
10	"	11.8	68.9	2.34	5.8	0.063
11	"	12.8	69.4	2.42	5.9	0.062
12	"	11.4	69.5	2.36	6.1	0.063
13	"	10.42	67.1	2.66	6.4	0.075
14	"	9.5	63.7	2.10	6.7	0.063
15	Thorite	4.57	62.80	1.28	14.	0.046
16	"	3.50	59.2	0.78	17.	0.030
17	"	1.62	54.4	0.36	34	0.017
18	2	1.88	65.38	1.71	35	0.065
19	Uraninite	71.40	7.86	4.75	0.1	0.066

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1, 4, 5, 6, 12. Analyst, Jones: Proc. Roy. Soc. A, lxxvii, p.546 (1906).
2, 7, 10. " Honigschmid: Privately communicated.
3, 18. Col. Reports, Misc. No.74, Ceylon Cd.5390 (1910).
8. Analyst. Ramsay: Nature, lxix, p. 559 (1904).
9. " Buchner: Nature, lxxv, p. 165 (1906).
11, 13, 14. " Blake: Proc. Roy. Soc. A, lxxvi, p.253 (1905).
15, 16. Col. Reports, Misc. No.87, Ceylon Cd. 7175 (1914).
17. Analysts, Soddy and Hyman: Trans., Chem. Soc. cv, p.1404 (1914).
19 Col. Reports, Misc. No.37, Ceylon, Cd. 3190, p.38 (1906).

The Canadian uranothorite from the Macdonald mine gives a very low lead ratio (0.04) for a Precambrian mineral.

The effects of alteration on the lead ratios of silicate and phosphate radioactive minerals has not yet been thoroughly studied. In the case of silicates one might expect, in general a diminution of the lead ratio with alteration, as occurs with thorites. In the case of phosphates there is a possibility that most of the lead may be in the form of phosphate, which being very insoluble might be expected to be pretty well retained by the mineral. The result for the Canadian Dickens township monazite yielding a lead ratio of 0.11 instead of 0.15 seems to indicate a considerable loss of lead. However, Fenner[1] obtained good agreement between monazite and samarskite from Brazil, but these may both be low due to alteration, as they have not been checked by uraninite from the same locality.

Kirsch[1] and Riss[2] from numerous analyses of individual uraninite crystals from Norwegian localities (Moss, Raade, Annerood Elvstad, etc), which give varying ratios for individual crystals from the same locality (e.g., 0.11 to 0.15 for crystals from Moss) conclude that it is not necessarily true that the discrepancies are du to alteration, leaching, or other causes, but that probably the lead ratios obtained indicate real differences in age for the individual crystals. They believe that the uraninite crystals with higher lead ratios may have been formed in the magma long before th reached the pegmatite in which they are now found. Thus a series of lead ratios such as that of the Moss uraninites would indicate a

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[1] Fenner, C.N.: Am. Jour. Sci., Nov. 1923, pp. 382-391; Geophysical Lab. Paper No. 667

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[1] Kirsch, Gerhard: Geologie and Radioaktivität 1928.

[2] Riss, Wilhelm: Mitt. aus dem Institut fur Radium-forschung Nr. 162, 1924

a long period of magmatic activity, in which the first crystals formed might be much older than the pegmatites in which they occur. Until more is known about the way in which pegmatites are formed, however, this must be considered as speculative, for on the other hand, according to one prominent school of American geologists, represented by Hess, Schaller, and Larsen, who believe that pegmatites are formed out of ordinary granite by replacement processes, the radioactive minerals must be younger than the pegmatites in which they occur, a view evidently exactly the opposite of that of Kirsch and Riss.

THE RADIOACTIVE CONSTANTS INVOLVED IN AGE CALCULATIONS [1]

There has been considerable diversity in reporting the ages of minerals, due to the use of different constants and different formulas, so that published age results expressed in years are not always strictly comparable. Recently, efforts have been made to secure more uniformity in this respect and Kovarik [1] has published a critique of the values of the disintegration constants indicating the values most acceptable at present (1931).

The rate of disintegration of the radioelements under normal conditions has been measured by various observers and by various methods with fairly concordant results, considering the difficulties involved.

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[1] For a comprehensive discussion of this aspect of the subject see: Alois F. Kovarik, in "The Age of the Earth", Bulletin No. 80, National Research Council (United States) 1931, also Arthur Holmes and R.W. Lawson in "Factors Involved in the Calculation of the Ages of Radioactive Minerals", Am. Jour. Sci., April, 1927

Rutherford and Geiger made a direct count of the alpha particles from uranium and thorium, their results indicating that:

(the disintegration constant for uranium) $= 1.47 \times 10^{-10}$ $year^{-1}$

(the disintegration constant for thorium) $= 5.3 \times 10^{-11}$ $year^{-1}$

λ_{Th}

According to these results:

1 gram uranium produces 1.26×10^{-10} gram lead per year

1 " thorium " 0.435×10^{-10} " " " "

From this it can be seen that 1 gram of thorium produces the same amount of lead as 0.384 gram uranium, and this value shortened to 0.38 has been most used in age calculations up to the present, though other values as low as 0.25 have been proposed for various reasons. Kovarik (loc.cit.) now prefers the value 0.36.

The disintegration constant of uranium (   ) may also be calculated from the following data: The ratio of radium to uranium when in radioactive equilibrium; the disintegration constant of radium; the relative amounts of actinium and uranium; the atomic weights of uranium and radium.

The amount of radium in equilibrium with uranium has been determined by many investigators with somewhat variable results depending on the minerals used, the old primary minerals giving results of from 3.2 to 3.7×10^{-7} gram of radium per gram of uranium. The value 3.4×10^{-7} is the generally accepted figure at present.

The first determination of the disintegration constant of radium by Rutherford and Geiger in 1908 indicated that 1 gram of radium gives off 3.4×10^{10} alpha particles per second. This value became 3.57×10^{10} when later corrected to the present radium standards. Later values by various methods have varied from 3.27 to 3.72×10^{10}. Kovarik (loc.cit.) prefers the value 3.495×10^{10} of Mlle. Gleditsch. Using this value in conjunction with the value $Ra:U = 3.4 \times 10^{-7}$, the disintegration constant for uranium becomes $1.52 \times 10^{-10} \text{year}^{-1}$.

When the percentages of lead, uranium, and thorium in a mineral are known, the age in years is given approximately by the simple formula:

$$\text{Age} = \frac{Pb}{U + 0.36\ Th} \cdot C \text{ million years}$$

Values of the constant C in above formula varying from 7400 to 8200 have been proposed. The value 7900 was much used in recent years but the preferred value is now 7600.

The above simple formula which has been much used in the earlier literature assumes, contrary to the facts, that constant amounts of uranium and thorium as found now were present throughout the life of the mineral in the same relative proportions, and though it is sufficiently accurate for young minerals it does not yield closely comparable results for young and old minerals. In the calculation of the age of the older minerals it is necessary to take account of the original content of uranium and thorium and the diminishing amounts of these elements present as time elapsed. The fundamental formula is:

$$t = \frac{1}{\lambda} \cdot \log_e \frac{U_o}{U_t} = \frac{\log U_o - \log U_t}{0.434\ \lambda}$$

Where t = elapsed time (age of mineral)

U_t = present uranium plus the U equivalent of the thorium = $U + 0.36\ Th$

U_o = original uranium

$= U_t + Pb + He$

$= U_t + 1.155\ Pb$

$\lambda = 1.52 \times 10^{-10}$

The formula now becomes:

$$t = \frac{\log\ (U + 0.36\ Th + 1.155\ Pb\ ) - \log\ (U + 0.36\ Th)}{6.6 \times 10^{-5}} \text{ million years}$$

Holmes and Lawson have developed a simplified form of the above formula as follows:

$$t = \frac{1}{\lambda} \cdot \log_e \frac{U_o}{U_t}$$

$$= \frac{1}{\lambda} \log_e \left(\frac{U + 0.36\ Th + 1.155\ Pb}{U + 0.36\ Th} \right)$$

but $X = 1.155 \frac{Pb}{U + 0.36\ Th}$

then $t = \frac{1}{\lambda} \cdot \log_e (1 + X) = \frac{1}{\lambda} (X - \frac{X^2}{2} + \frac{X^3}{3} \ldots\ldots)$

$$= \frac{X}{\lambda} \left(1 - \frac{X}{2} + \frac{X^2}{3} \ldots\right) \text{years}$$

$$= \left(\frac{Pb}{U + 0.36\ Th} \cdot 7600\right) \times \left(1 - \frac{X}{2} + \frac{X^2}{3} \right) \text{ million years}$$

Or : Corrected Age = Approximate age $\times (1 - \frac{X}{2} + \frac{X^2}{3})$

The effect of the presence of the actinium series in uranium minerals is believed to involve only a practically negligible correction to age calculations, as, according to the most generally accepted determination the activity of the actinium series constitutes only about 3 per cent of the total activity of the uranium series. However, one determination, by Boltwood, indicated that actinium amounts to 8 per cent. Little is known even yet as to the exact relationships of the actinium series and it is conceivable that it may eventually be found to have been more important in producing lead than is believed at present, in which case further modifications of the age formula will be necessary.

It may be seen that, using the analytical data of a given mineral, considerable differences in age results could be obtained by substituting various combinations of constants derived from the experimental results of different workers. In the case of a Pre-cambrian uraninite such differences could easily amount to a hundred million or more years.

Although the absolute value of the age results obtained is of considerable interest, particularly in estimating the extent of geological time and the probable age of the earth, nevertheless the chief value of age data in geology lies in the comparative rather than the absolute magnitude of the results obtained. It is, therefore, of but little importance geologically speaking if the present experimental values of the radioactive constants are slightl variable or even if they should prove eventually to be somewhat in error. It is important for purposes of comparison, however, that all results should be referred to a common invariable basis. Fortunately such a basis is afforded by the simple lead ratios themselves, which are really all that is needed for geological comparisons.

THE HELIUM RATIO METHOD

Calculations of the age of radioactive minerals may also be made from the helium ratio, but it has been found that the results from the helium ratio are always much lower than from the lead ratio of the same mineral and hence the helium method can only yield minimum values. Helium, being a very light gas which cannot enter into chemical combinations, always escapes from the mineral to a greater or less extent. The helium ratio method is best adapted to substances containing only such very small amounts of uranium or thorium that the lead cannot be determined by chemical methods. On the other hand, very minute amounts of helium can be accurately determined by gasometric methods, and when the amount of helium is very small it might be expected to be more completely retained by the mineral.

Since igneous rocks in general contain uranium and thorium in amounts which, though very minute, can be estimated with fair accuracy by the emanation method, and as the helium can also be determined with considerable accuracy, it might be supposed that the age of any igneous rock could be determined from the helium ratio. Some progress in this direction in fact has been made already by British and European workers, and it appears that fine-grained rocks retain helium better than those of coarser grain, and basic rocks better than more acid ones, fine-grained basalt being apparently the most favourable type.

While this method applied to rocks will always be subject to uncertainities such as possible loss or gain of helium, migration of uranium, thorium, and their radioactive products, etc., it may nevertheless eventually prove to be of considerable value in especially favourable cases.

The formula for the age of a mineral from the helium ratio is:

$$\text{Age} = \frac{0.00116 \times \text{He (Volume)}}{\text{U} + 0.27\ \text{Th}} \times 7{,}600 \text{ million years}$$

$$= \frac{6.45\ \text{He (Weight)}}{\text{U} + 0.27\ \text{Th}} \times 7{,}600 \text{ million years}$$

RELATIVE VALUES OF VARIOUS RADIOACTIVE MINERALS AS AGE INDICATORS:

It is evident that apart from the other considerations so far discussed the value of all age determination work in connexion with radioactive minerals depends on the accuracy of the analytical results. The exact analysis of some of the complex minerals is difficult, owing to the small amounts of Pb, U, and Th involved and the presence of interfering elements. It is quite possible that discrepancies in age results are sometimes due to inaccurate chemical analyses. In cases where the content of Pb, U, and Th is small and the analyses have been carried out in the usual way on perhaps only half gramme or one gramme portions, no great accuracy can be expected. Where exact determinations of small amounts of Pb, U, and Th are required it is necessary to operate on quantities of from 5 to 100 or more grammes of material in order to obtain results comparable in accuracy with ordinary determinations on rich minerals such as uraninites or thorianite. Thus, special analytical methods capable of being applied to large quantities of material must be used in order to obtain reliable results, but even then there is not quite the same certainty in the results from minerals low in Pb, U, and Th, for the relatively enormous amounts of other elements present increase the danger of loss of Pb, U, or Th from absorption by precipitates or by solubility in the larger amounts of solutions which must be employed.

Hence, owing to the limitations of present methods of chemical analysis, the value of various minerals as age indicators (always provided they are not too badly altered) depends first of all on the amount of U, Th, and Pb they contain: obviously the richer they are, the more accurate are the results, and the smaller the quantity of mineral necessary for the determination. But the value of such age indicators must also depend on the frequency of their occurrence and though the rich U and Th minerals such as uraninite, thorianite, and thorite naturally are the most desirable and valuable, since they can be analysed with comparative ease and the greatest accuracy, they are, unfortunately of rather infrequent occurrence. The complex radioactive minerals including the large group of titano-tantalo-columbates, the silicates, and the phosphates are much more frequently found than the oxides. The complex minerals usually contain from 1 to 20 per cent uranium with minor thorium, and when not too much altered may sometimes give results comparable to those obtained from uraninites. Allanite, judging from the writer's observations in Canada, is probably the most frequently occurring radioactive mineral. It not only occurs very often and usually in fair abundance, in pegmatites but also is not uncommon in small grains as a constituent of ordinary rocks. Because of its wide distribution this mineral may prove ultimately to be one of the most useful age indicators, if it should be found to yield reliable age indications. So far but little has been done with allanite, as it rarely carries more than a fraction of a per cent of uranium or over 3 per cent of thorium. Allanite often owes much of its radioactivity to minute inclusions of other minerals.

Other comparatively common pegmatite minerals that are essentially non-radioactive but may carry small amounts of uranium or thorium, due probably to inclusions of radioactive minerals, are: garnet, tourmaline, magnetite, titanite, and mica. Zircon and cyrtolite, which are rather common minerals in Canadian pegmatitic deposits, commonly contain some uranium and thorium. Zircon sometime occurs rather abundantly in rocks and as it can be separated and concentrated may be found to be of value as an age indicator.

Attempts that have been made to determine the age of granites by separating any minute grains of radioactive minerals, such as allanite, zircon, etc., contained in them have not been very success ful so far owing to the difficulty of obtaining a sufficiently pure concentrate, but it is quite likely that eventually suitable methods may be worked out. Prof. A.C.Lane has been very active in forwarding work along these lines and details of the experiments together with valuable summaries of radioactive work in general throughout the world may be found in the annual reports of the United States National Research Council's Committee on the Measurement of Geological Time by Atomic Disintegration, of which he is chairman. This committee has also done much work on the determination of the age of Swedish Kolm, a carbonaceous rock containing small amounts of uranium, and is investigating other carbonaceous rocks of the older geological periods, Precambrian and Cambrian, which it now appears may carry traces of uranium.

Finally, the effects of alteration on various types of radioactive minerals must be considered as an extremely important factor affecting their value as indicators. Uraninite stands out above all other minerals in this respect; so long as it remains black it appears to give results but little higher than they should be, even though the mineral is greatly altered. Accepting Holmes' theory of differential lead leaching in the case of thorium minerals, those minerals containing a good excess of uranium over thorium are more likely to give reliable results than those containing little uranium and much thorium . The complex columbates, silicates, and phosphates appear to give good results only when in the freshest possible condition.

The preceding paragraphs in regard to the most suitable minerals for age determinations may be summarized as follows:

(1) The freshest, least altered uraninites alone furnish results which may be accepted without qualifications at the present time. Altered uraninites usually yield slightly high lead ratios.

(2) High thorium minerals such as thorianites and thorites, the complex columbates, silicates, and phosphates when in the best possible state of preservation may yield ratios agreeing with uraninites of the same age, but results are often low, due probably to alteration and differential leaching.

(3) Minerals very low in Pb, U, and Th present analytical difficulties, but may eventually prove to be very useful indicators because of their wide distribution.

SEPARATION OF FRESH MATERIAL FOR ANALYSIS

In order to obtain useful results it is necessary to select the least altered material obtainable from the specimen being operated on. Two general methods are available for this purpose.

(1) Mechanical separation; based on differences in density, hardness, or friability betweenthe fresher and more altered portion The fresher material is in general,harder, less friable,and heavier than the altered portions. Crushing, grinding, sifting, and panning a procedure which combines all these factors, has been used, the more friable and lighter altered portions being washed away. Tablin

on a small Wilfley table has also been tried.

(2) Differential chemical attack by a suitable reagent.

Sometimes the altered material is more soluble than the fresher portions in some particular reagent. Thus uraninite is more soluble in hydrochloric acid the more altered it is. Davis[1] treated the North Dakota uraninite in this way previous to analysis in order to remove alteration products.

On the whole it seems to the writer that mechanical separations are to be preferred. The writer when operating on a mineral mass or fragments of sufficient size first grinds away the outer surfaces of the mineral on a wet carborundum stone, checking by hardness and binocular observations. The mass is then broken successively into smaller and smaller fragments which are checked under the binocular. Finally the fragments are coarsely ground, sized and panned, the finest powder being washed away, the residue after microscopic examination being air dried at room temperature and ground for analysis. Fenner has demonstrated the value of such procedure in his analyses (loc.cit.) of Brazilian monazite and samarskite, in which the less friable portions give lower lead ratios than the finer powder obtained by sifting.

THE RADIOACTIVE TIME SCALE

Holmes and Lawson[1] have proposed a radioactive time scale

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[1] Davis, C.W.: Am. Jour. Sci.(5) 11: 201-217 (1926),(5) 17: 557-558 (1929)

[1] Holmes, Arthur and Lawson, R.W.: Am. Jour. Sci.,April, 1927.

based on selected uranium minerals, which is essentially as follows:

	Lead ratio	Mineral	Geological age
	0.000		
Cainozoic	0.005	Brannerite, Idaho	Probably late Oligocene.
	0.008	Pitchblende, Gilpin co., Col.	Late Cretaceous or Tertiary
	0.01		
	0.02^8	Pitchblende Joachinsthal	Permocarboniferous
	0.03		
	0.033	Uraninites North Carolina	Probably late Carboniferous
Palaeozoic	0.039	Uraninites Glastonbury, Ct.	Devonian to Permian
	0.052	Uraninites Branchville, Ct.	Probably Devonian
	0.06		
	0.07		
	0.081	Pitchblendes Katanga, Congo	Pre-Devonian, perhaps late Precambrian
	0.083	Thorianites Ceylon	Probably late Precambrian
Upper Precambrian	0.091	Uraninites Morogoro, Tanganyika	Probably Upper Precambrian
	0.10		
	0.11		
	0.12		
	0.13	Uraninites Moss, Norway	Late Middle Precambrian
Middle Precambrian	0.155	Uraninites Arendal, Norway, and Ontario, Canada	Middle Precambrian
	0.16	Uraninites Llano co., Texas Samarskites Douglas co., Col.	Middle Precambrian
	0.17		
	0.187	Mackintoshite Woodgina, West Australia	Probably Late Lower Precambrian
	0.19		
	0.20		
Lower Precambrian	0.22	Uraninites Black hills, South Dakota	Early Precambrian?

The latest and most complete discussion, with references, of radioactive age data for minerals occurring in various geological horizons throughout the world is that by Arthur Holmes in the

"Age of the Earth", 1931.

AGES OF MINERALS FROM THE CANADIAN SHIELD

In the accompanying tables the radioactive age data for minerals from the Canadian shield have been assembled, together with other data having a bearing on the state of preservation of the minerals, i.e. specific gravity, content of UO_2 SiO_2 and H_2O . In the tables the quality or state of preservation of the material analysed has been indicated according to the following scheme:

1. **Superior:** For uraninite Sp.G. = 9 , Hardness = 6 , colour steely black, lustre almost metallic, fracture uneven. UO_2=50 per cent. H_2O less than 0.35 per cent, SiO_2 less than 0.75 per cent.

For tantalo-columbates: SiO_2 less than 0.1 per cent, brilliant, vitreous lustre, little alteration or bleaching showing along fractures in thin section.

For monazite: transparent, low SiO_2, very little alteration showing along fractures in thin section.

2. **Good:** For uraninite, Sp.G.= 8 to 9, Hardness$<$6, colour pitch black lustre non-metallic, fracture conchoidal, UO_2 35-50 per cent.

3. **Fair:** For uraninite, black, no coloured alteration products.

4. **Poor:** Alteration products present in appreciable quantity and practically inseparable from the better material.

The possible effects of alteration have been discussed in some detail in this chapter and with reference to special cases under the various descriptions of occurrences.

The analyses of radioactive minerals have been made with especial care. The determinations of lead, uranium and thorium were made in most cases on at least 2 grams of material, in many cases on 5 or 10 grams, observing every possible precaution to obtain precise results. Where sufficient material was available, several determinations were made as checks.

The best values for the lead ratio for pegmatites from the Grenville area are probably those derived from the Conger tp. (Parry Sound dist.) uraninite which was of very superior quality in all respects. This ratio (0.154) to the best of present knowledge represents an age of 1077 million years and corresponds to Middle Precambrian on the radioactive time scale.

The significance, if any, of the lower ratios obtained in several cases for minerals other than uraninite is so far uncertain. These low ratios may be due merely to alteration and leaching of the minerals, and more work will be necessary before any of them can be accepted as actually indicating a younger age for the minerals in question.[1] Thus, only the ages indicated by the better preserved uraninites need be given serious consideration for the present. Among the best preserved uraninites it may be seen that the majority of those in the area characterized by the presence of Grenville

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[1] Recent work by Lauri Looka [2] on Finnish Wilkite is especially interesting because of the very high lead ratios obtained from some specimens and the lack of agreement between many of the lead ratios. Wilkite is a complex titano-tantalo-columbate isomorphous with samarskite (Lokka) and it seems unusual for minerals of this class to be too high in lead, according to experience in Canada. The lead ratios found vary as follows: 0.056,0.082, 0.103, 0.156, 0.170, 0.172, 0.182, 0.188, 0.192, 0.407. Lokka believes that the ratios 0.170 and 0.172 derived from"muolaite"(an intergrowth of two as yet unknown minerals(are the best values, placing the pegmatites at the base of the Middle Precambrian. These results serve further to emphasize the greater reliability and consistency of results from uraninites in contrast with the results from other minerals.

[2] Lokka, Lauri, Uber Wilkit.Bulletin de la Commission Geologique de Finlande No.82 (1928(

sediments yield ratios near .154 . The comparatively small differences may be in part due to actual differences in age of the intruded pegmatites. One exception occurs, the Henvey tp. uraninite. This material is not in the best stage of preservation, but nevertheless its ratio is so much lower than those of any of the other uraninites, that it must be considered probably really younger than those with ratios grouped around 0.154.

The Manitoba uraninite has so high a ratio that it must be considered to be definitely much older than the others. The analysed material by its fairly high specific gravity, the moderate silica content, and its general physical properties must be rated as good. Alteration products which were present on the outer parts of the crystals were apparently completely removed by the concentration treatment in acid. The ratio may be somewhat too high but quite possibly not very much too high.

The Manitoba uraninite and the South Dakota uraninite analysed by Davis indicate a much greater age for the Precambrian than was previously supposed probable.

RADIOACTIVE AGE DATA FOR MINERALS FROM THE CANADIAN SHIELD

Mineral Locality	Quality Material	Sp.G.	SiO_2	H_2O	UO_2	UO_3	Total U	Th	Pb	Lead Ratio	Age Million Years	Analyst References
Uraninite Villeneuve	1-2 mass	----	0.19	1.47	34.67	41.06	64.74	5.65	10.46	0.157	1100	Hillebrand pp.
Uraninite Villenouve	1-2 of mass Interior/	9.144	0.21	1.70	41.08	34.98	65.34	5.65	10.61	0.157	1100	Ellsworth pp.
Uraninite Villeneuve	3 Black zone	7.778	0.34	5.97	9.49	62.42	60.33	5.48	9.96	0.160	1117	Ellsworth pp
Orange layer of uraninite Villenouve	4 alteration prod.	5.275	3.81	9.42	0.00	60.36	50.24	6.73	13.85	0.263		Ellsworth pp.
Uraninite Conger tp.	1 30 crystals	9.116	0.29	0.72	53.63	26.32	69.19	2.83	10.83	0.164	1077	Ellsworth pp.
Uraninite Conger tp.	1 30 crystals	9.026	0.35	0.74	51.27	28.37	68.81	3.12	10.76	0.154	1077	Ellsworth pp.
Uraninite Conger tp.	2 single crystals	----	1.36	1.53	38.05	39.13	66.12	2.94	9.76	0.143	1019	Ellsworth pp.
Uraninite Butt tp.	2 several crystals	8.788	0.36	0.74	43.35	33.42	66.02	1.08	9.82	0.149	1045	Ellsworth pp.
Uraninite Butt tp.	2 single crystal	8.859	0.51	0.61	--	--	67.41	1.37	10.02	0.148	1037	Ellsworth pp.
Uraninite Butt tp.	3 single crystal		2.04	1.92	--	--	64.24	0.99	9.61	0.149	1045	Ellsworth pp.
Uraninite Butt tp.	3 mixed fragments		1.02	1.53	--	--	64.80	1.60	9.14	0.140	985	Ellsworth pp.
Uraninite Cardiff tp.	1-2 Crystals from felspar	9.082	0.43	0.61	45.18	24.90	60.56	10.02	9.65	0.150	1050	Todd pp.

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Mineral Locality	Quality Material	Sp.G	SiO_2	H_2O	UO_2	UO_3	Total U	Th	Pb	Lead Ratio	Age Million Years	Analyst References
Uraninite Cardiff tp.	1-2 Crystals from felspar	9.062	0.19	0.70	39.10	32.40	61.44	9.32	10.19	0.157	1100	Ellsworth pp.
Uraninite Cardiff tp.	3-4 massive with magnetite	7.178	0.58	1.60	13.55	52.04	55.26	11.92	10.25	0.172	1195	Ellsworth pp.
Uraninite Cardiff tp. Ont.	2-3-4(?) Large crystals from fluorite						53.52	10.37	9.26	0.162	1127	R.C.Wells pp.
Uraninite Derry tp. Que.	3-4 crystal with thucholite		3.46				58.46	5.94	9.17	0.151	1057	Ellsworth pp.
Uraninite Huron cl. S.E.Man.	2-3 Conc.from crystals	8.032	0.67				53.50	12.46	15.44	0.266	1775	Ellsworth pp.
Uraninite Huron cl. S.E.Man.	1-2 conc.in acid from crystals	8.968	0.37				55.01	12.25	15.50	0.261	1745	Ellsworth pp.
Uraninite Henvey tp. Ont.	3 conc.from 50g.thucholite pres.	8173	1.36	1.44	49.35	29.76	68.29	1.56	8.04	0.117	835	Ellsworth pp.
Uraninite Henvey tp. Ont.	3 conc.from 50g.thucholite pres.	7.827	1.76				67.26	1.52	7.51	0.111	792	Ellsworth pp.

Mineral Locality	Quality Material	Sp.G.	SiO_2	H_2O	UO_2	UO_3	Total U	Th	Pb	Lead Ratio	Age Million Years	Analyst References
Uraninite Henvey tp. Ont.	3 conc. from single crystal	7.809	2.12				67.30	1.85	7.57	0.111	792	Ellsworth pp.
Uraninite March tp., Ont.	2 black crystals	8.674	0.64	1.55	49.44	24.28	65.80	4.32	10.77	0.165	1150	Ellsworth pp.
Uraninite Craigmont, Ont.	From old mill concentrate								9.10			Ellsworth pp.
Coracite Mamainse	Extremely altered		4.35	4.64			50.30	?	4.97	0.1(?)		J.D.Whitney pp.
Euxenite Sherbrooke S.tp., Ont.	Best grains from large concentrate	4.933	1.08	2.37	7.25	1.51	7.56	2.32	0.94	0.112	801	Ellsworth pp.
Euxenite Mattawan tp., Ont.	1 masses	4.918	0.05	2.87	6.42	0.43	6.01	0.85	0.98	0.155	1085	Ellsworth pp.
Euxenite Sabine tp. Ont.	1 masses	5.002	0.09	2.23	8.61	0.20	7.76	2.46	1.25	0.145	1019	Ellsworth pp.
Lyndochite Lyndoch tp. Ont.	1 masses	4.909	0.07	1.96	0.67	0.04	0.63	4.35	0.34	0.154	1077	Ellsworth pp.

Mineral Locality	Quality Material	Sp.G.	SiO_2	H_2O	UO_2	UO_3	Total U	Th	Pb	Lead Ratio	Age Million Years	Analyst References
Hatchettolite Woodcox Mine, Hybla, Ont.	Dark Massive	4.509	1.57	4.29	11.40	4.41	13.72	0.46	0.60	0.036	267	Todd pp.
Hatchettolite Woodcox Mine, Hybla Ont.	Light Massive	4.417	1.56	5.05	5.72	5.08	9.27	0.37	0.22	0.023	172	Todd pp.
Calcios-amarskite Woodcox Mine Hybla, Ont.	Black Massive	4.738	2.39	3.64	9.00	1.67	9.52	2.93	0.41	0.040	297	Ellsworth pp.
Ellsworthite, Mac Donald mine Hybla, Ont.	Dark Massive	3.753	2.68	11.42	8.42	10.58	16.31	---	0.38	0.023	172	Todd pp.
Ellsworthite, Mac Donaldmine Hybla, Ont.	Light Massive	3.608	2.54	12.22	---	13.50	15.40	---	0.22	0.014	105	Todd pp.
Uranothorite MacDonaldmine Hybla, Ont.	Black Crystals	4.414	19.55	9.24	7.67	9.46	14.63	40.72	1.22	0.042	312	Ellsworth pp.

Mineral Locality	Quality Material	Sp.G	SiO_2	H_2O	UO_2	UO_3	Total U	Th	Pb	Lead Ratio	Age Million Years	Analyst References
Ellsworthite, Cardiff tp., Ont.	Black to Brown Crystals	3.705	2.49	11.20	1.56	20.46	18.41	0.09	1.61	0.087	630	Ellsworth pp.
Calciosamarskite, Conger tp., Ont.	Black Masses	4.485	1.92	6.44	----	---	11.35	1.90	0.35	0.028	210	Ellsworth pp.
Toddite Sudbury dist, Ont.	Black Masses	5.041	1.77	3.94	8.71	2.37	9.65	0.41	0.41	0.042	312	Ellsworth pp.
Monazite Dickens tp. Ont.	Partly transparent Crystals	5.270	1.54	0.40			0.27	6.43	0.31	0.120	854	Ellsworth pp.

LITERATURE

The literature of radioactivity even in so far as it relates to geology is extensive. The latest and most comprehensive work, with references, in English is by Arthur Holmes and Alois F. Kovarik in "The age of the Earth"; Bulletin 80 of the National Research Council, Washington, D.C., 1931 ($5.00). Subsequent references will be most conveniently found in the reports of the National Research Council (Washington, D.C.)Committee on the "Measurement of Geological Time by Atomic Disintegration". A very good work(in German(reviewing the subject up to 1928 is "Geologie und Radioaktivitat" by Gerhard Kirsch, published by Julius Springe Vienna and Berlin. An excellent low priced popular account of radioactivity as related to geology is "The Age of the Earth" by Arthur Holmes, in Benn's Sixpenny Library No. 102, London.

CHAPTER XI

GEOLOGY OF THE RARE ELEMENT MINERALS

INTRODUCTION

The majority of the rare element minerals found so far in Canada occur in pegmatites. In fact such minerals are, in general, confined almost entirely to pegmatites and veins related in origin to pegmatites, but there are a few important exceptions worth noting in which rare element minerals have been removed from the igneous rocks in which they originated and have been concentrated by superficial agencies to form secondary deposits of commercial importance. Thus in unglaciated countries residual, placer, and beach sand deposits of certain minerals such as monazite, thorite, zircon, and baddeleyite may accumulate as the result of long weathering of igneous rocks containing these minerals. The world's supply of thorium and rare earths is obtained chiefly from monazit bearing beach sand, ancient sand dunes, and placers in India, Ceylon, and Brazil. North and South Carolina were also producers. Thorite and thorianite have been obtained from the gravels of Ceylon. Zircon and baddeleyite the commercial ore minerals of zir(ium have been recovered from gravels in North Carolina and Brazil respectively. Many of the black sands of British Columbia contain minute microscopic zircon crystals in considerable quantity and i is possible that deposits of such sands sufficiently rich in zirc to be workable might be found. Cassiterite may also occur in work placer deposits, and in fact has been found with gold and platinum in certain stream gravels of British Columbia and the Yukon.

As nearly the whole of Canada was severely glaciated during the last ice age it is unlikely that important residual or placer deposits of rare element minerals will be found. The glacier in their advance for the most part scoured out the old pre-Glacial river sands and gravels, ground and mixed them with boulder clay which it carried great distances and distributed over wide areas. Nevertheless it is possible that some particularly favourable situated pre-Glacial placers may have partly or wholly escaped destruction, as has actually happened in the case of some gold placers in British Columbia. There are a few comparatively small areas in Canada which were apparently not overridden by the ice of the last Glacial period, notably certain areas in the Yukon. Unfortunately the great central Precambrian shield around Hudson ba with its wealth of rare mineral-bearing pegmatites, was very thoroughly scoured and practially all loose and weathered material was carried away leaving only highly polished fresh rock surfaces as we see them today when the covering of boulder clay is removed. There can be little doubt that placer concentrations of such minerals as gold, tinstone, monazite and other rare element minerals, zircon, beryl, corundum, and possibly platinum and diamonds must have once existed in this area as the result of many millions of years of pre-Glacial weathering. The 20,000 to 50,000 years which it is estimated have elapsed since the retreat of the ice have not been sufficient to permit any appreciable weathering of the rocks or placer concentration.

Another important exceptionto the pegmatitic type of occurrence is the case of certain secondary uranium and vanadium minerals that may form deposits of commercial importance and which occur in sedimentary rocks. The most important of these minerals is carnotite which along with various other uranium or vanadium minerals, chiefly hewettite, metahewettite, volborthite, roscoelite, etc., occurs disseminated in sandstones of Jurassic age in Colorado and Utah, United States.The sandstones and associated strata are believed to be[1] mostly continental deposits, that is were not laid down in the sea but in freshwater or possibly partly as subaerial deposits. The sandstones are horizontal or nearly so and show well-marked crossbedding over great areas. They are rather soft and friable and often contain partly carbonized wood and reeds as well as animal bones. Sometimes the wood is so thoroughly impregnated with carnotite as to form rich ore. The carnotite in a general way is most prominent in the sandstones of the McElmo formation, whereas the vanadium minerals are most characteristic of a lower horizon,th LaPlata formation. The carnotite ore-bodies usually are lenticular in form and rarely more than 100 feet in diameter by 5 feet thick,

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[1] U.S.Geol. Surv.,Bulletins 262,315,340,530.
U.S.Bur. of Mines Bulletins 70, 103,104

usually less. The deposits on the whole are low grade, the ore as mined in quantity probably averaging between 1 per cent and 2 per cent U_3O_8 and less than 5 per cent V2O5. A considerable amount of material carrying less than 1 per cent U_3O_8 was mined during the later years of production. Occasional small, rich concentrations of newly pure carnotite were found in seams and pipe-like deposits called "bug-holes" where it is believed to have been concentrated by circulating water. The typical carnotite sandstone is yellow coloured, but the presence of various vandium minerals as well as iron and copper minerals in some cases obscures the yellow colour and the uranium-vanadium-bearing sandstones may be yellowish greenish, brown, or black. These sandstones for many years furnished nearly the whole of the world's production of radium and a very considerable amount of vanadium. Production of this type of ore for radium extraction practically ceased in 1923 as a result of the development of the rich pitchblende deposits of the Belgian Congo, but up to that time 250 grams of radium had been produced from these ores. Opinions differ as to how the carnotite got into the sandstones and nothing is known as to why these particular sandstones carry carnotite and others apparently do not. The climate of Colorado and Utah is dry and much of the country is desert. Whether the dry climate with scanty rainfall has had anything to do with the concentration of the carnotit within recent times in uncertain, but the scanty vegetation must at least have been a highly favourable factor in prospecting for the deposits. The carnotite whether it formed as its host the sandstone was being formed or at a much later date, was surely deposited from solutions. The source of the materials held in solution is unknown. So little is known as to what were the essential conditions which brought about the formation of the carnotite ores that it seems useless to speculate as to whether similar ores may yet be found in Canada. Shales from British Columbia with yellowish coatings closely simulating carnotite in appearance have been examined in several instances but the yellow encrustations were found to be iron compounds and no uranium or vanadium could be detected. The Upper Carboniferous sediments of New Brunswick and Nova Scotia locally contain a good deal of copper in the form of chalcocite, chalcopyrite, malachite, azurite, etc. usually concentrated around carbonized wood or coaly matter. In some cases the wood is actually more or less replaced by chalcocite. Vanadium might be looked for in such rocks, but samples so far tested by the writer have yielded negative results.

Uranium has also been found in small amounts not of commercial interest in a black carbonaceous shale called "kolm" which occurs in Sweden. The kolm contains a few fossils and from both geological and palaeontological evidence is definitely known to be of Upper Cambrian age.

Vanadium of course, accompanies uranium in the mineral carnotite and various other minerals previously noted that occur in the same way as carnotite in the sandstones of Colorado and Utah. Sedimentary rocks such as sandstones, carbonaceous shales, and petroleum quite often contain small amounts of vanadium.The element seems to have a marked affinity for carbon and carbon compounds. It occurs as a constituent of asphaltic veins and impregnations resulting from the evaporation of petrolum, and such deposits may be of commercial important. The most remarkable deposit of this sort, which for some time produced a large part of the world's supply of vanadium, is in the Andes of Peru, some 16,000 feet above sea-level. The ore-body, consisting chiefly of vanadiferous hydrocarbons such as quisqueite, with some impure vanadium sulphide (patronite), and various other vanadiferous minerals, occupies a shear zone in Mesozoic shales. The vanadiferous materials are believed to represent the residues from the natural distillation of petroleum. The high-grade ore of this deposit has now been worked out, but a considerable production still appears possible from the lower-grade material.

No indications of the occurrence of vanadiferous sediments of commercial importance have been noted so far in Canada. What appeared to the writer to be the most promising possibility was the great occurrence of the so-called tar sands in Alberta and Saskatchewan, unquestionably a petrolum residue. Tests of this material, however, have been disappointing, as it contains no more than minute traces of vanadium, if any. The New Brunswick albertite a material which might be suspected to carry vanadium was also tested and found to contain when pure only 0.07 per cent ash which carries only a negligible trace of vanadium.

Thus it appears that the outlook for finding uranium and vanadium-bearing sediments or asphalts in Canada is not particularly promising, though the possibility of such occurrences especially in British Columbia should be kept in mind.

So far, various types of rare mineral deposits of other than primary origin have been briefly discussed. Those originating in igneous rocks will now be considered. For the reasons just noted it appears unlikely that rare element minerals will be found in appreciable amounts in Canada otherwise than as primary deposits in igneous rocks, more particularly in connexion with granite, syenites and similar types.

PEGMATITES AND PEGMATITIC VEINS

The percentage amount of rare elements occurring in the rocks of the earth's crust is exceedingly small as may be seen from the following estimates based on the average of thousands of rock analyses.

AVERAGE CHEMICAL COMPOSITION OF THE IGNEOUS ROCKS OF THE EARTH

SiO_2	59.12
Al_2O_3	15.34
Fe_2O_3	3.08
FeO	3.80
MgO	3.49
CaO	5.08
Na_2O	3.84
K_2O	3.13
H_2O+	1.15
CO_2	0.101
TiO_2	1.050
ZrO_2	0.039
P_2O_5	0.299
Cl	0.048
F	0.030
S	0.052
$(Ce,Y)_2O_3$	0.020
Cr_2O_3	0.055
V_2O_3	0.026
MnO	0.124
NiO	0.025
BaO	0.055
SrO	0.022
Li_2O	0.008
Cu	0.010
Zn	0.004
Pb	0.002
	100.000

F.W.Clarke and H.S.Washington: Proc. Nat. Acad. of Sci., vol.8, 1922, pp. 108-115

AVERAGE COMPOSITION OF IGNEOUS ROCKS IN TERMS OF ELEMENTS

	1	2	3
1. Oxygen	46.41	47.29	47.2
2. Silicon	27.58	28.02	28.0
3. Aluminium	8.08	7.96	8.0
4. Iron	5.08	4.56	4.5
5. Calcium	3.61	3.47	3.5
6. Sodium	2.83	2.50	2.5
7. Potassium	2.58	2.47	2.5
8. Magnesium	2.09	2.29	2.5
9. Titanium	0.720	0.46	0.33
10. Phosphorus	0.157	0.13	0.22
11. Hydrogen	0.129	0.16	0.17
12. Manganese	0.124	0.078	0.075
13. Chlorine	0.096	0.063	0.04-0.025
14. Barium	0.081	0.093	0.03
15. Sulphur	0.080	0.10	0.06
16. Chromium	0.068	0.034	0.01
17. Zirconium	0.052	0.017	0.02-0.01
18. Carbon	0.051	0.13	0.22
19. Vanadium	0.041	0.017	0.00_x
20. Strontium	0.034	0.034	0.005
21. Nickel	0.031	0.020	0.005
22. Fluorine	0.030	0.10	0.04-0.025
23. Cerium, Yttrium	0.020	...	0.00
24. Copper	0.010	...	0.000^{x-x}
25. Lithium	0.005	0.004	0.004
26. Zinc	0.004	...	0.000_x
27. Cobalt	0.003	...	$0.00_{x,x}$
28. Lead	0.002	...	0.000_x
29. Boron	0.001	...	0.00_x
30. Glucinum	0.001	...	0.00^x_x
	100.000	100.000	100.000

1. Igneous rocks. Clarke and Washington, 1922.

2. Igneous rocks. Clarke, Bull. 695, 1920, p.28.

3. Igneous rocks. Vogt. Zeits, prakt, Geol., 1898, p. 324

AVERAGE IGNEOUS ROCKS, NORTHERN NORTH AMERICA

	1	2	3	4	5	6
SiO_2	60.19	57.14	63.31	56.19	52.70	58.34
Al_2O_3	15.76	15.48	16.67	16.67	16.38	15.79
Fe_2O_3	2.87	3.93	2.18	3.31	4.58	2.21
FeO	3.67	4.72	2.46	4.65	5.83	3.99
MgO	3.16	1.55	2.25	3.39	3.27	4.57
CaO	4.80	3.51	5.05	5.34	5.29	5.66
Na_2O	3.90	6.98	3.85	4.40	4.88	3.54
K_2O	3.07	3.25	2.82	3.00	2.65	3.18
H_2O +	1.01	1.12	0.78	1.08	1.09	1.14
TiO_2	1.01	1.50	0.77	1.25	2.20	0.69
ZrO_2	0.01	0.12	----	----	----	----
P_2O_5	0.26	0.19	0.18	0.19	0.21	0.33
MnO	0.10	0.21	0.10	0.13	0.17	0.14
BaO	0.04	...	...	0.04	0.06	0.11
Incl.	0.15	0.30	0.12	0.26	0.59	0.31
	100.00	100.00	100.00	100.00	100.00	100.00

1. North America, including Greenland, Mexico, Central America, and West Indies, 1709 analyses.
2. Greenland, including East and West Greenland and Ellesmere island. 41 analyses.
3. Alaska. 24 analyses.

4. Canada, including Alaska, eastern Canada, and British Columbia. 138 analyses.
5. Eastern Canada, including Ontario, Quebec, Maritime Provinces, an Newfoundland. 99 analyses.
6. British Columbia, including Alberta. 60 analyses.

RARER ELEMENTS IN IGNEOUS ROCKS

	1	2
Rubidium	.000,x	.00x,x
Arsenic	.000,x	.00x,x
Molybdenum	.000,x	.000,0x
Tin	.000,x	.00x,x
Bromine	.000,x	.00x
Caesium	.000,0x	.000,00x
Scandium	.000,0x	.000,000,000,xx
Antimony	.000,0x	.00x,x
Cadmium	.000,0x	.000,00x
Mercury	.000,0x	.000,00x
Iodine	.000,0x	.00x,x
Bismuth	.000,00x	.000,000,x
Tungsten	.000,00x	.000,00x
Thorium	.000,00x	.000,000,x
Columbium, tantalum	.000,00x	.000,000,x
Uranium	.000,00x	.000,00x
Silver	.000,00x	.000,000,x
Selenium	.000,00x	.000,000,x
Platinum	.000,000,x	.000,000,0x
Tellurium	.000,000,x	.000,000,0x
Gold	.000,000,x	.000,000,0x
Thallium	.000,000,0x	.000,000,00x
Indium	.000,000,00x	.000,000,00x
Gallium	.000,000,00x	.000,000,00x
Germanium	.000,000,000,x	.000,000,000,x
Radium	.000,000,000,00x	....

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1. Clarke and Washington, 1932.

2. Vogt, 1898.

It may be noted that some of the rarer elements i.e., various individuals of the rare earths -- are not included in the above tables, owing no doubt to lack of available data. These are all included under cerium and yttrium. Certain elements can be more readily detected and estimated than others when present in minute traces, because they may respond to particularly delicate spectroscopic or radioactivity tests. Thus uranium and thorium because of their radioactive properties can be estimated even when present in the most minute amounts owing to the sensitiveness of the electroscopic test for radioactivity.

Igneous rocks of ordinary grain size rarely contain rare-element minerals visible to the naked eye or even under the microscope, with the exception of zircon, allanite, beryl, and monazite, which occasionally occur as small crystals or grains, chiefly in granites and syenites. The fact that masses of rare-element minerals of appreciable size occur as primary minerals only in pegmatites and pegmatitic veins indicates that some process of concentration has acted whereby the rare-element content of the pegmatites or veins has been greatly increased relatively to that of the fine-grained rocks with which the pegmatites are associated. Pegmatite is a more or less elastic term which may be applied in a general way to any unusually coarse-grained rocks representing some of the latest material to crystallize from invading masses of molten rock or magma. As usually understood, however, the term pegmatite when used without qualification means more particularly granite pegmatite a very coarse-grained rock consisting chiefly of potash feldspar and quartz, and occurring typically in connexion with granites, quartz syenites, and quartz monzonites. This is the common type of pegmatite that occurs so abundantly in the rocks of the Canadian Shield and which is often worked for feldspar and muscovite. Most of the known rare-element occurrences in Canada are in granite pegmatites.

Calcite Granite Pegmatites. In the Haliburton-Bancroft area, Ontario, many of the pegmatite dykes contain considerable calcite along with the usual quartz. In some of the larger dykes, masses of calcite weighing at least 100 tons have been encountered in the course of mining for feldspar. The calcite is sometimes in pure masses, sometimes intergrown with quartz, and in one instance at least (the MacDonald mine at Hybla, Ont.) carried very considerable quantities of radioactive minerals and cyrtolite. The calcite in these pegmatites has the same relationships as the massive quartz and appears to be just as much a primary mineral as the latter.

Syenite Pegmatites. Syenite pegmatites are those in which quartz is practically absent, the rock consisting chiefly of potash and soda feldspars. These are comparatively rare in Canada, but there ar some well known occurrences in Hastings and Renfrew counties, Ontari particularly in the neighbourhood of Craigmont, where they contain corundum crystals and were extensively worked for this mineral years ago. The mining of corundum, however, ceased with the development of methods for making artificial abrasives such as carborundum and alundum by means of the electric furnace. Uraninite and other rare-element minerals occur very sparingly in the pegmatites of Craigmont.

Plagioclase Feldspar Pegmatites. A very few small dykes have been seen which locally at least appeared to consist chiefly, if not altogether, of plagioclase feldspars. Such dykes present an unusual, whit chalky appearance due to superficial kaolinization.

Nepheline Pegmatites Nepheline pegmatites occur in connexion with nepheline rocks in the Haliburton-Bancroft area, Ontario. These consist chiefly of coarse nepheline and plagioclase feldspar; usually with some mica in small plates up to an inch in diameter. Hornblende and garnets may also be present and grains of calcite appear to be an almost invariable constituent. Some of these dykes carry corundum, but so far no rare-element minerals have been found in them. It must be admitted, however, that but few dykes of this sort have been opened up, and those that have been only in a very small way, so that there is no great amount of actual evidence against the possibility of such dykes carrying rare minerals. Cryolite and related minerals particularly might be looked for in areas where nephelite pegmatites occur. Beautifully coloured blue corundum occurs in this connexion along York river near Bancroft and it is possible that the very valuable transparent gem variety sapphire might be found.

Calcite-Fluorite-Apatite Vein Dykes. A number of rather unusual vein dykes that have been opened up for fluorite in the Harcourt-Wilberforce area, of Haliburton county, may perhaps be best classified as basic pegmatites. They are in general vein-like masses of widths rarely more than 6 or 8 feet composed chiefly of interbanded calcite and dark purple fluorite, with abundant apatite, hornblende or pyroxenes of various kinds, feldspar crystals, titanite, and sometimes they carry radioactive minerals such as uraninite, allanite, or ellsworthite. More detailed descriptions of individual examples of the various types of pegmatites will be found in Chapter , but something more may be said here of the granite pegmatites in general.

THE GRANITE PEGMATITES

FORM AND STRUCTURE

Pegmatites may occur as irregular masses, as locally regular tabular dykes, or as lens-shaped bodies. They cut the older rocks around the margins of granitic intrusions or they may cut the parent granitic body, or a portion of the granite mass itself may be locally pegmatitic, the pegmatitic area being without sharp definite boundaries and passing gradually into the normal granite. The more regular pegmatites of the Canadian Shield as seen in longitudinal sections at the surface, are typically long, nearly straight , relatively narrow, lens-shaped bodies, often pinching and swelling more or less at intervals but on the whole widest in the middle and thinning toward one or both ends. The dip is most often steep or nearly vertical, but bodies occur in every possible attitude. Dykes are especially likely to be seen on hillsides and as the contacts are rarely completely exposed it is sometimes difficult to ascertain their true attitude and dimensions. In order to ascertain the true width of a dyke it is necessary to know the attitude or dip. In some cases what appears at first sight to be a very wide dyke proves on closer investigation to be a comparatively narrow one lying flat or nearly so. Even the segregated type with massive quartz may be deceptive under such conditions.

Dykes may vary from less than 1 inch to more than 100 feet in width and from a few feet to more than 1,000 feet in length, but the characteristic features of texture may be as well displayed by the inch-wide dyke as by one 50 or 100 feet wide. Thus a small dyke only an inch wide may show typical segregation of feldspar at the sides with quartz in the middle. Some of the largest and longest dykes are, so far as can be seen, entirely of the graphic pegmatite type. Others may be chiefly graphic pegmatite with occasional patches of coarse quartz and feldspar, or the graphic pegmatite may pass gradually into a segregated type with the quartz and feldspar more or less completely separated into large pure masses. The segregated region occupies typically the centre of the lens. Sometimes a large mass of graphic pegmatite may pass laterally into a more segregated phase along one contact. Dykes of the segregated type may also occur as lateral offshoots from a large mass of graphic pegmatite. The graphic type of pegmatite seems to represent a stage of temperature and consolidation intermediate between the parent granite and the highly segregated pegmatite. The latter material ordinarily constitutes only a comparatively small proportion of the dyke.

Many CanadianPrecambrian pegmatites, particularly the segregated type worked for feldspar in Ontario and Quebec, have practically the structure of a banded vein; i.e., - soda-lime feldspar occurs as a comparatively narrow border on each side, near the wallrock.Each of these is bordered by a roughly parallel and relatively wider band of coarsely crystallized microcline; the middle is occupied by a band of massive white quartz. This arrangement of course is subject to much distortion and variation in the relative widths of the constituent bands, but nevertheless can often be plainly traced. The common ferromagnesian minerals have a tendency to occur chiefly with the soda-lime feldspar in such cases.

TEXTURE

Pegmatites may vary greatly in texture and grain size.For convenience in description three main types may be distinguished: graphic, granular or granitoid, segregated.

Graphic Type. In the graphic type the feldspar and quartz are arranged in such a way as to form a pattern resembling oriental writing. Optical examination of such material shows that the quartz grains over a considerable area may behave as if they were parts of one crystal and the enclosing feldspar similarly may behave as a single crystal, indicating that this is an intergrowth of quartz and feldspar crystals. In such intergrowths the ratio of quartz to feldspar is usually fairly constant in about the proportion of 25 per cent quartz to 75 per cent feldspar. The grain size may vary considerably, from examples in which the grains are measurable in millimetres to those in which the quartz grains are an inch or more long.

Granular or Granitoid. In this type all the quartz and feldspar grains are about the same size, lack crystal faces, and there is no definite arrangement or orientation of the mineral grains. The grain size varies as a rule from half an inch to an inch or two, but may be greater or less. This texture is simply that of granite on a large scale.

Segregated. In this type the quartz and the feldspar occur for the most part separately as large pure masses, each mineral being practically free of the other. This is the type of pegmatite that furnishes the highest grade of No. 1 crystal pottery feldspar of commerce. Crystallization in such dykes may be on a gigantic scale. Masses of practically pure white quartz as much as 30 feet in diameter and microcline crystals 10 feet in diameter have been noted in

Canadian pegmatites worked for feldspar. Occasionally masses of albite (soda feldspar), lime soda feldspars, and even calcite may be associated with the microcline and quartz. The quartz masses commonly have a tendency to occur in the middle of the dyke with feldspar on both sides, producing the effect of a banded vein. At other times the quartz may occur along one wall or may be irregularly distributed in masses alternating with feldspar. The quartz is often moulded around definite crystal faces of microcline, apparently indicating that the massive quartz is later than the microcline. Such crystal faces of microcline in some cases attain a diameter of 3 feet or more. Commonly there is a little plagioclase present and this almost invariably occurs as a lining next to one or both walls. The order of crystallization would appear to be, first the plagioclase next the walls, then the microcline, and finally the massive quartz in the middle.

In addition to the types of texture just described the term "miarolite" is often used to describe the occurrence of cavities lined with inwardly projecting crystals. Such crystals may be unusually well formed, with sharp faces and good terminations, resulting from their free, uncrowded growth.

RELATION OF TEXTURE TO RARE MINERAL OCCURRENCES

The rare-element minerals found so far in Canada have, most often, been in greatest abundance and in the largest individual masses in the segregated type of pegmatite. Small grains may be found in the graphic and granitoid types but the size of the rare mineral concentraseems to vary directly with the grain size of the pegmatite. A qualification to the first part of the above statements may be noted in the case of allanite which often occurs abundantly as relatively small crystals in graphic and granitoid pegmatites. In the segregated pegmatites individual allanite crystals or masses may attain a weight of several hundred pounds.

COMPOSITION

Typical Canadian granite pegmatites consist chiefly of the potash feldspar, microcline, and quartz. The microcline varies in colour from almost pure white through cream and pinkish shades to almost red, depending on the iron content and its state of oxidation. The green variety, amazonite, is also quite often found. Perthitic intergrowths of microcline with quartz, albite, or more basic feldspar are common. Plagioclase feldspar commonly occur as a narrow lining next one or both walls, and usually carry a greater or less amount of iron and ferromagnesian minerals such as magnetite, ilmenite, pyrite, pyrrhotite, garnet, hematite, or martite, hornblende or pyroxene, titanite, biotite, allanite. Masses of albite, lime soda feldspars, or even calcite may sometimes occur associated with the microcline and quartz in the body of the dyke, but such cases are rather exceptional. A variety of albite called clevelandite that has a peculiar platy structure often with small cavities due to criss-cross growth of the platy crystals sometimes occurs and is likely to be associated with beryl. The larger masses of quartz are usually white and very pure though sometimes more or less stained by iron rust from percolating waters. Smoky quartz commonly occurs and a peculiarity of this variety is that it often seems to be much more granular and more easily shattered by a hammer blow for example, than the white massive quartz. One gets the impression that it is probably made up of numerous individual grains crowded together and that the tendency to fracture easily is due to the lines of weakness at the junction of the grains. The white massive quartz on the other hand seems to be tougher and less easily shattered and th this may be because it consists of large homogeneous crystalline growths. The dark colour of the smoky quartz is completely discharged on heating to a temperature below redness even in the absence of air. The researches of Holden[1] indicate that the dark colouration is probably due to the presence of atoms of elementary silicon set free by the action of radioactive radiation. The presence of smoky quartz in a dyke is a favourable indication of the possible occurrence of radioactive minerals. White and black mica (muscovite and biotite usually) are commonly present in greater or less amount.The mica plates or crystals may vary from a fraction of an inch to a foot or two in diameter. Lithia mica (lepidolite) occurs in some instances. In the eastern Manitoba pegmatites it occurs as compact masses of closely packed, minute scales with a purplish colour. At the Leduc mine, Wakefield tp.,Ottawa co.,Que., it takes the form of plates up to a foot or more in diameter of a brownish colour, and might

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[1] Holden, E.S.: Am. Min. 10, pp. 203-252 (1925)

easily be mistaken for dark muscovite, as in fact it was for some time. Minor amounts of a considerable number of the common minerals often occur, such as tourmaline, hornblende, pyroxene, titanite, epidote, garnet, magnetite, ilmenite, hematite, pyrite, pyrrhotite, molybdenite. It is unnecessary to itemize here the very numerous rare-element minerals that may occur as accessory minerals in pegmatites as the list would include the great majority of these minerals. Up to the present the following rare-element minerals occurring in Canadian pegmatites have been identified: annanite, amblygonite, beryl, cassiterite, chrysoberyl, columbite-tantalite, cyrtolite, euxenite, ellsworthite, gadolinite, gummite, hatchettolite, ~~hatchettolite~~, knopite, lepidolite, lyndochite, monazite, phenacite, polycrase, samarskite, spodumene, thucholite, toddite, uranothorite, uranophane, xenotim zinnwaldite, zircon. Typical occurrences of these minerals are discussed in detail in Chapter . Topaz occurs in the lithium pegmatite of the Silver Leaf mine, Manitoba, and in a pegmatite in Tache township, Quebec. Among the most interesting and remarkable minerals occurring in Canadian pegmatites are substances such as thucholite (page) composed chiefly of carbon or hydrocarbons which when burned leave an ashy residue rich in uranium, thorium, and rare earths. These minerals resemble coal or hard tar and when embedded in the quartz or feldspar might be easily mistaken for uraninite or other black minerals, but, of course, are readily identified by their light weight and combustibility. The remarkable occurrences of great masses of calcite associated with the massive quartz and microcline in dykes in the neighbourhood of Hybla, Hastings county, Ontario, are possibly unique. At the MacDonald mine the calcite carried abundant zircon or cyrtolite and ellsworthite. It appears from these occurrences of carbon and hydrocarbon minerals and calcite in pegmatites that carbon is a more frequent and more important constituent of magmas than has been hitherto supposed.

CLASSIFICATION OF PEGMATITES ACCORDING TO ACCESSORY MINERAL CONTENT

Various authors have classified pegmatites partly or wholly on the basis of their content of characteristic accessory minerals, such classifications sometimes going into great detail based on rather fine-drawn distinctions. A classification by Niggli[1] is of this type as is another applied by Reuning[2] to the pegmatites of southwest Africa. Lacroix in describing the Madagascar pegmatites uses the accessory minerals only as a secondary basis of classification but carries this out in very great detail. Rastall[3] on the other hand is content with a much simpler scheme. He divides the ore-bearing pegmatites into three principal groups, as follows:

1. The tourmaline-tin-tungsten type.
2. The rare earth type.
3. The apatite dykes

Rastall also recognizes another group:

4. The quartz veins with precious metals and states that to

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[1] Niggli,P.: Lehrbuch der Mineralogie.

[2] Reuning, E: Pegmatite und pegmatitmineralien in Sudwestafrika Zs. Krest,58,448-459 (1923)

[3] The geology of the metalliferous deposits.

this category belong many gold-quartz veins which contain a certain, though often small amount of feldspar, mica, and other distinctively igneous minerals.

When one attempts to apply any such elaborate classifications as some of those just cited, to the Canadian pegmatites, contradictions immediately become apparent due to the fact that Canadian pegmatites often contain in one deposit several of the leading accessory minerals which form the basis of these classifications.

Rastall's broad classification, more especially with regard to his types (2), (3), and (4) is quite applicable to Canadian occurrence. His type I, the "tourmaline-tin-tungsten" pegmatites, however, are so far not known in Canada. Tourmaline occurs in countless Canadian pegmatites in which no tin or tungsten has been found, and may or may not occur along with beryl, lithium minerals, and uranium and rare-earth minerals. The few occurrences of cassiterite and wolframite or scheelite in situ in this country may be briefly mentioned. In Nova Scotia a few, small, fine-grained pegmatites and pegmatitic quartz veins associated with Devonian granites carry cassiterite sparingly, with, so far as known, no tourmaline. In the northern Manitoba lithium pegmatites occasional grains or small masses of cassiterite occur, with tourmaline practically absent or unimportant. Wolframite and scheelite are more characteristic of the pegmatitic quartz veins. At Burnthill brook in New Brunswick a quartz vein carries considerable wolframite with topaz. Scheelite occurs in pegmatitic quartz in Nova Scotia, in southern Quebec, and has also been found in the workings of the Hollinger mine, and in gold quartz veins in one or two other places in northern Ontario. Cassiterite has not yet been found in commercial quantities in Canada. Attempts have been made to work tungsten-bearing veins in Nova Scotia, New Brunswick, and Quebec, but these deposits do not appear to be of commercial interest at present.

The writer does not believe that any very detailed classification of Canadian pegmatites on the basis of accessory mineral content can be sufficiently applicable to be necessary or desirable. Nevertheless, there are a few mineral associations which seem to be more or less characteristic and related to a particular type of pegmatite, though exceptions and more or less overlapping may be noted almost always.

(1) The lithium pegmatites containing large masses of scaly lepidolite with spodumene or amblygonite or both.

(2) The beryllium pegmatites containing beryl in considerable quantity.

(3) The uraninite pegmatites.

(4) The complex titano-tantalo-columbate mineral pegmatites, which may be called for short the euxenite pegmatites.

Both the lithium and the beryllium pegmatites are characterized by the presence of considerable albite, in addition to or more or less replacing the usual microcline. Schaller and Hess' theory of the albitization of pegmatites (page) appears to apply in Canada more particularly to these two types of pegmatites. It has been mentioned earlier in this chapter that beryl when occurring in any considerable quantities is usually, if not always, associated with the peculiar variety of albite called clevelandite characterized by very pure white lamellar crystals which often intersect each other forming small angular cavities. In this connexion it is also worth mentioning again that the very valuable caesium mineral pollucite, judged from specimens seen by the writer, appears to have occurred in contact with clevelandite, as some of the platy albite crystals may be seen attached to the pollucite. Beryl occurs in some of the lithium pegmatites of Manitoba, whereas certain beryl-bearing pegmatites in Ontario carry no lithium, and the pegmatite at the old Leduc mine, Wakefield township, Quebec, carries abundant large plates of lepidolite up to 1 foot in diameter and 2 to 3 inches thick, and much tourmaline but no beryl or spodumene.

The pegmatites that carry uraninite are typically exceptionally rich in quartz, which is segregated into large more or less pure masses, and usually contain considerable muscovite often accompanied by biotite. They are in fact the type of pegmatites likely to be prospected or worked for mica. The feldspar is mainly microcline, though a certain amount of plagioclase is usually present. There may be more quartz than feldspar. A noteworthy point in connexion with several of the Canadian uraninite occurrences is that the remarkable carbon-rare-element mineral thucholite occurs in close association with the uraninite. Other uranium and rare-earth minerals such as samarskite, or allanite, may occur and zircon or cyrtolite in small crystals is almost always present in small amount, often very closely associated with uraninite and thucholite.

The euxenite pegmatites constitute the most abundant and commonplace types of rare-element bearing pegmatite especially characteristic of the southern portions of the Precambrian shield in Ontario. They are the kind of pegmatites that attract the attention of the searcher for commercial feldspar. Usually they are well segregated dykes in which the quartz and feldspar are more or less separated into pure masses, but the quartz is not so preponderant in amount as in the preceding type. The feldspar is predominantly practically pure microcline, though sometimes a very small amount of perthitically intergrown plagioclase may be present, and as mentioned before, a narrow band of plagioclase feldspars may occur next the wall-rock, on one or both sides of the dyke. The majority of our known rare-mineral-bearing pegmatites are of this type, and minerals of the complex titano-tantalo-columbate family along with columbite-tantalite are next to allanite the most frequently occurri rare minerals, euxenite itself being the columbate most often found.

It may be noted that on this basis of classification the remarkable calcite-bearing pegmatites of north Hastings county, Ontario, as well as the calcite-fluorite-apatite vein dykes of Haliburton are classed with the uraninite and euxenite pegmatites.

GENESIS OF PEGMATITES

The great reservoirs of molten or potentially molten rock deep beneath the earth's surface are the source of pegmatites as of all other igneous rocks. Such molten rock or magma is believed to be a silicate solution containing chiefly the common elements oxygen, silicon, aluminium, iron, calcium, sodium, potassium, and magnesium, which are the essential constituents of the common rock-forming minerals quartz, feldspar, mica, hornblende, pyroxene, etc., along with smaller amounts of the other more common elements and minute traces of the rare elements (Table ,page). Certain of the elements present in the magma, notably hydrogen in part combined with oxygen in the form of water, carbon dioxide and monoxide, fluorine, chlorine, boron, phosphorus, and sulphur are believed to exercise a great influence on the fluidity of the melt. That is they act as fluxes or mineralizers, increasing the mobility of the solution and enabling it to remain fluid at lower temperatures than would otherwise be possible. At various times in the earth's geological history magmas have risen and penetrated the overlying rocks. When such intrusions are in the form of great masses sometimes miles in area, which never reach the surface, they are called batholiths, when in smaller sheet-like forms they are known as dykes if more or less vertical, as sills if more or less horizontal. When the magma actually penetrates through the surface rocks to form volcanoes, the overflowing molten rock not only cools very quickly but also loses a large proportion of its more volatile constituents or fluxes such as water, carbon monoxide and dioxide, fluorine, boron sulphur, etc., and consequently quickly solidifies either as a glass or with development of the fine grain, gas bubble holes or pillow structure characteristic of volcanic rocks formed under various conditions.

On the other hand the deep-seated intrusives that never reach the surface cool very slowly under great pressure and with but comparatively slow and gradual loss of the volatile fluxes by diffusion into the overlying rocks. Thus in a large granite batholith with falling temperature the first material to solidify is normal granite consisting essentially of crystalline grains of potash feldspar and quartz. The removal in this way of vast quantities of granite from the magmatic solution results in a relatively greater concentration of the rarer elements and fluxes in the still fluid portion or mother liquor, which consequently can remain liquid at a much lower temperature than could the original magma, permitting the growth of the large crystals of feldspar, quartz, and other minerals characteristic of pegmatites during their relatively long period of mobility . The earliest pegmatite, formed under comparatively high temperature conditions, comprises doubtless the graphic and granular types of relatively small grain size. This is succeeded at a lower temperature by the very coarse segregated type, which in turn passes into pegmatitic quartz veins. As feldspar and quartz separate out the rare elements become more and more concentrated in the mother liquor and finally crystallize as definite minerals, more particularly in the segregated pegmatites which represent the highest concentration of these elements in the mother liquor. Thus the rare minerals occurring in a pegmatite dyke possibly represent a concentration of the rare elements originally present in cubic miles of the parent magma.

Actual measurements on volcanic lavas show that magmas must have an initial temperature of 1,000 degrees C.or more, and there is good evidence indicating that granites and similar rocks crystallize between 575 degrees C. and 800 degrees C., and that pegmatites are probably formed from around 575 degrees C. down to perhaps 300 degrees and quartz veins at still lower temperatures. Silica crystallizes as quartz only below 800 degrees; above that temperature it forms tridymite, a mineral with crystallographic and optical properties distinct from quartz. Quartz formed above 575 degrees C. has different crystallographic and optical properties from that formed below 575 degrees, and the two varieties can be distinguished by suitable tests such as the character of the etch figures produced by corrosive reagents.[1] As calcite occurs as an important, apparentl primary constituent in many pegmatites in central Ontario, as also in certain Norwegian pegmatites, it is interesting to note that differences have been detected in the physical properties of the high and low temperature forms of this mineral also. Within recent years much emphasis has been placed on the genetic connexion of quartz veins with granites and pegmatites, though as pointed out by

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[1] Wright, F.E., and Larsen, E.S.: Am Jour. Sci.,4th ser.,vol.28, 1909, p.421.

Spurr this connexion was recognized long ago by early observers,[1] to be more or less obscured by subsequent theories which gained a temporary ascendency. It is now generally agrees that mineralized quartz veins represent the final stage of magmatic injection, following the pegmatites in time and temperature of consolidation. It has been shown that pegmatites sometimes pass gradually into quartz veins and that many quartz veins which cannot thus be actually seen to change to pegmatite nevertheless show a well-marked pegmatitic character in their content of small amounts of typical pegmatite minerals such as feldspar, tourmaline, molybdenite, etc. The gold-bearing veins of Ontario and Quebec may be cited as examples.

The manner in which pegmatites, as well as igneous rocks in general, are able to cut through older rocks, often apparently without regard to bedding, schistosity, or other line of weakness, has given rise to much speculation as to what are the forces by which such tremendous effects are achieved. Igneous intrusions, of course, often do follow lines of weakness such as fault planes, joints planes of bedding or schistosity in the overlying rocks, but even such intrusions imply the action of enormous forces. It does not seem reasonable to suppose that actual open fissures or cavities of any appreciable size exist at the great depths in the earth's crust where the rock is potentially molten and plastic. Various theories

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[1] Scheerer, 1846, Elie de Beumont, 1847, Thomas Belt, 1861.

have been proposed to account for the penetrating power of igneous rocks. Daly has supposed that magmas eat their way into older, solid rocks partly by dissolving them, partly by stopping down blocks or fragments which later may be more or less assimilated. Spurr on the other hand does not see much field evidence to support Daly's theory and believes that the molten rock is injected by the action of tremendous pressure caused mainly by the expansive force of gases comprising a portion of the magmatic solutions. Others have thought that the expansive force resulting from the crystallization of rock minerals in minute fractures may gradually spread apart the enclosing rock walls about the fracture. An unbiased observer might be disposed to admit the possibility of any or all of these forces acting in varying degrees in different instances.

The foregoing represents probably the most generally accepted ideas concerning the origin, in a general way, of pegmatites. Two somewhat exceptional views regarding the method of their formation from the parent magma may be noted. Spurr[1] seems to believe that the residual magmatic material from which quartz veins (and by inferenc pegmatites) are formed is in the form of a pasty or gelatinous hydrous silicate melt, which is locally injected under great pressure into the surrounding rocks, is likely to be pinched off from the parent mass by crustal movements, and presumably slowly crystallizes and segregates en masse by molecular rearrangement. It is

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[1] Spurr, J.F.: "The Ore Magmas".

perhaps more generally supposed that the sometimes enormously large crystals of feldspar and other minerals so characteristic of pegmatites would be likely to be formed under conditions favouring free movement of the constituent molecules- i.e., a high degree of fluidity and a long period of slow regular cooling. Schaller[1] apparently believes that pegmatites in general are formed by replacement of normal granites by highly fluid residual solutions emanating from the magma.

Hess[2] also lays great stress on the replacement process in pegmatites. His very interesting paper is based chiefly on observations of lithium pegmatites of Dakota. He believes that albitization (replacement of earlier minerals, especially microcline and quartz, by albite) is the dominant and most characteristic and widespread evidence of replacement. He states that replacement of other minerals by albite is a common phenomena in pegmatites. Hess and Schaller both believe that practically all the rare minerals found in pegmatites even when in the form of definite, well-developed crystals, are not of earlier formation than the enclosing matrix as has generally been supposed hitherto, but are later replacements of the matrix minerals. The solutions that affect the replacements are believed by Hess to be the final residual magmatic fluids (largely water) remaining after the consolidation of the granites

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[1] "The Genesis of Lithium Pegmatites" by Waldemar T. Schaller; Am. Jour Sci., vol. 10, 1925, pp. 269-279.

[2] Hess, F.L.: "The natural history of the pegmatites"; Eng. and Min. Jour. Press, August 22, 1925.

and pegmatites comprising a batholithic intrusion, such fluids bein being still sufficiently heated to be in gaseous form and capable of penetrating and replacing the already solidified but still hot primary pegmatite. The replacement process is believed to be possibly very slow and continued over a very long period.

Hess and Schaller's views as to the importance of replacemen in pegmatites appear to be practically identical. Both authors, however, have arrived at these views from observations on lithium pegmatites in which albitization and other replacement phenomena are much more pronounced than in the case of the ordinary microclin pegmatites of Ontario. It may be noted, however, that the replacement theories of these authors are scarcely more than a broader and more intensive application of the old idea of pneumatolysis, i.e., the action of later vapours on the earlier minerals, transforming these in some cases to entirely different minerals. Unquestionable instances of such action on a moderate scale are occasionally seen even in the ordinary microcline pegmatites. Thus for example at the Villeneuve mine (page) tourmaline crystals are sometimes partly or wholly changed to muscovite. At the Wallingford mine (page) thucholite replaces tourmaline, preserving the original crystal form of the latter. At the Lyndoch beryl deposit (page) later albitization seems to be have occurred and the lyndochite may be a replaceme of columbite. At a dyke about 20 miles east of Sudbury, garnets are partly or wholly altered to muscovite. Such instances, which might be multiplied, serve to prove that a later, partly destructive, partly reconstructive phase may and does occur in pegmatites after consolidation. Opinion as to the extent of this action, however is largely a matter of personal interpretation of the observer. Schaller appears to believe that even graphic granite is a replacement of earlier normal granite, that perthitic albite in microcline is due to replacement. Schaller and Hess apparently both agree that the rare minerals occurring in pegmatites are due to later replacement: conclusions with which possibly the majority of observers are not yet prepared to concur.

THE NORWEGIAN PEGMATITES

The granite pegmatites of southern Norway are particularly interesting because they appear to resemble very closely those of the southern part of the Canadian Shield in Ontario and Quebec, which have been extensively worked for feldspar and which consequently are the best known Canadian occurrences. The southern Norwegian pegmatites also are of Precambrian age, possibly on the whole slightly younger than those of Ontario (Chapter) and like the latter have long been worked for feldspar, mica, and quartz. These Norwegian pegmatites may be considered the classic examples of such deposits, having been known and studied with great thoroughness and detail over a long period of years by such well-known authorities as Brogger, Nordenskiold, Vogt, and others. The most complete description is that of Brogger,[1] from which the following data have been obtained.

The pegmatites described occur chiefly along the southern coast of Norway within a radius of 900 miles southwest of Oslo and include such classical localities as Moss, Kragero, Arendal, Hittero, etc. These pegmatites have furnished large quantities of microcline feldspar for the porcelain industry besides by-products such as quartz, mica, and minerals containing the rare earths and the rare acids (Tantalum, columbium) for the chemical and electric light industries. The dykes sometimes contain large masses of pure quartz segregated in the middle of the dyke with microcline feldspar on both sides,[2] a very characteristic feature of many pegmatites of the Precambrian Shield in Ontario and Quebec. Syenite and nephelite syenite pegmatites also occur. Brogger distinguishes three general types of granite pegmatites, but states they are not sharply defined, one grading into another:

(1) Ordinary granite pegmatite with microcline perthite, quartz, and biotite, the latter usually chloritized, as chief primary minerals. These include several sub-types based on predominant rare mineral content.

(a) Columbite, samarskite, and monazite abundant. These occur chiefly to the eastward from Kristiania fjord.

(b) Euxenite (polycrase, bloomstrandite) with gadolinite orthite, yttrotitanite, thorite, xenotime, etc., abundant. These occur chiefly in the dykes to the south west of Kristianiafjord.

(2) Tourmaline granite pegmatites more or less rich in tourmaline,

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[1] Brogger, W.C.: Die Mineralien Der Sudnorwegischen Granit-pegmatitgange-Viderskabs-Selskabets Shrifter-Math-Naturv. Klasse, 1906.

[2] Vogt, J.H.L. "Magmas and Igneous Ore Deposits", Econ. Geol., May. 1926, p. 229

(3) Muscovite-rich granite pegmatites: characterized by microcline perthite, acid plagioclase, albite, oligoclase, andesine, quartz and muscovite, with biotite often very subordinate or absent. These are usually rich in beryl, with topaz and fluorite also abundant.

Lithium minerals such as spodumene, lepidolite, amblygonite, lithia, tourmaline, etc., and other minerals found in lithium pegmatites such as eosphorite, dickinsonite and other manganese phosphates, cassiterite, pollucite, and minerals such as cryolite typical of fluorine rich pegmatite have never been found in the southern Norwegian pegmatites.

PEGMATITES OF THE BLACK HILLS, SOUTH DAKOTA

The Black hills of South Dakota comprise a notably well-mineralized region, about 7,000 feet above sea-level and 3,000 to 4,000 above the surrounding plains. The geology is complex, the rocks range in age from Precambrian to Oligocene, and the region has produced minerals in great variety and of great value. The Homestake gold mine, one of the oldest and greatest mines in the world, is included in the region and the pegmatites associated with the Precambrian rocks are remarkable for variety and quantity of rare-element mineral constituents. The discovery of lithium and tin-bearing pegmatites in southeastern Manitoba which seem to bear a family resemblance to those of the Black hills renders the latter area particularly interesting for comparison.

As described by Connolly[1], the Black Hills uplift has the shape of an elliptical dome. The central core, consisting of Precambrian metamorphic and igneous rocks, is surrounded by concentric outcrops of Palaeozoic and Mesozoic sediments. The Precambrian core and the outwardly dipping sediments are overlapped by sediments of Oligocene age. Three types of rocks make up the Precambrian nucleus, metamorphosed sediments, metamorphosed basic igneous rocks, and pegmatitic granites. The granites are coarse-grained, alkaline granites consisting chiefly of microcline, orthoclase, quartz and muscovite, with rather large amounts of black tourmaline. In addition to the main batholithic mass there are many subordinate stocks and bosses, and numerous bodies of lithia pegmatites. Definitely related to the pegmatites are many tin and tungsten veins.

The following account of the pegmatites has been taken chiefly from articles by Hess[1] and Schwartz[2]. The literature on the area is very voluminous. Ziegler[3] gives a very complete bibliography up to 1913 and Connolly[4] gives references to later papers.

Ziegler lists 182 minerals found in the Black Hills and surrounding region. Of these Schwartz states that many are comparatively rare but 80 are reasonably east to find, the greater number being found in the pegmatites surrounding the main granite body.This

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[1] Connolly, J.P.: "The Tertiary Mineralization of the northern Black Hills"; South Dakota School of Mines, Bull. 15, pp. 12-16; (1927).

[1] Hess, F.L.: U.S.Geol. Surv.,Bull 380 (1908)

[2] Schwartz, G.M.: "The Black Hills Mineral Region", Am. Min. Feb., 1928.

[3] Ziegler, V.: "Minerals of the Black Hills, South Dakota School of Mines, Bull, 10, p.229, (1914)

[4] Op.cit.

granite body is apparently only the top of a large batholith and much of the main mass is pegmatitic. Extending outward into bordering schists, in all directions are dykes and irregular masses of pegmatites. The most interesting and economically important are these masses in the schists.

The Etta pegmatite is roughly oval in outline, 200 by 300 feet and is very coarse. The mine developed in this body is remarkable for the huge crystals of spodumene which occur. The largest was 42 feet long, 3 to 6 feet in diameter, and contained 37 tons of spodumene Many others nearly as large have been mined. The pegmatite mass shows a rude zonal arrangement with the main body of quartz, spodumene and feldspar, surrounded by a finer-grained aggregate of muscovite, quartz and feldspar. Normally the spodumene crystals are embedded in masses of milky quartz. Columbite-tantalite, lepidolite, apatite, beryl, lithiophyllite, cassiterite, triphyllite, and opal are also more or less common. In some places the feldspar is albite; in other microcline. Cassiterite has been found in masses weighing 50 to 60 pounds each. In parts of the dyke feldspar occurs in larger masses than elsewhere and here columbite occurs in larger crystals and masses up to 600 pounds in weight.

The Hugo mine is in a huge mass of pegmatite notable for its large masses of nearly pure microcline. It also carries large crystals of spodumene, large masses of amblygonite, black tourmaline, and blue apatite, and considerable amounts of muscovite.

The Peerless mine produces mica, feldspar, beryl, amblygonite, columbite-tantalite, and lithiophyllite. Cassiterite is common. The pegmatite body is said to dip northwest and to be roughly stratified, with muscovite, vermiculite, some quartz and feldspar near the base, followed by a middle zone of amblygonite, quartz, beryl, etc., and with chiefly feldspar and quartz on top.

CALIFORNIA LITHIUM PEGMATITES

The following account of the California lithium pegmatites is derived from an article by Schaller.[1]

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[1] Schaller, W.T.: "The genesis of lithium pegmatites, Am. Jour. Sci., 5th ser., vol. 10, (1925).

The gem tourmaline field of southern California, as the area containing the lithium pegmatites is conveniently termed, lies in northwestern San Diego county and southwestern Riverside county. The region near Pala has been studied in greater detail than any of the others and most of the dykes described by Schaller are near Pala. The rocks around Pala are chiefly granodiorite and a dark basic rock which may be called gabbro. Most of the lithium pegmatites lie in the gabbro; one is in schistose granodiorite; another is partly in gabbro and partly in granodiorite, a third is partly in gabbro and partly in a schistose rock of uncertain origin. The dykes strike in general west of north, approximately parallel to the fault lines and general structure of the region. They dip southwest at angles ranging from 10 to 45 degrees. Their thickness varies from 1 foot to 50 feet.

A few dykes show almost no difference between their upper and lower sides; in others the rock composing the upper part is very different in mineral composition, texture, and general structure from that forming the lower part. Some show a gradual transition from the upper part to the lower part whereas other show a sharply defined contact line between the two parts. In many of the dykes there is a seam of rock different from either the upper or lower part and in which the lithium minerals are concentrated. This seam lies between the two parts and mostly in the lower portion of the upper part. It is in this middle seam that the gem minerals (tourmaline, kunzite, beryl, garnet, topaz, etc. [are found as well as the lithium minerals (lepidolite, amblygonite, etc.).

Those dykes which show almost no difference between the upper and lower parts are composed of graphic granite. An indefinite, not always well characterized, middle seam, if present, is of coarser texture and carries minerals other than the quartz and microcline of the graphic granite.

The upper part (approximately the upper half) of those dykes in which the upper and the lower parts are different, is essentially graphic granite. Other minerals are almost entirely absent. At the extreme top of some, there is a narrow zone of muscovite with quartz and albite. There are also coarser-grained layers and irregular masses, especially in the lower portion of the upper part that carry varying quantities of albite, muscovite, biotite, garnet and black tourmaline. There are also small, fine-grained masses of the same minerals.

The middle seam, if present is a coarse aggregate of all the minerals mentioned as well as the lithium minerals. The middle seam represents in volume, on an average, perhaps 10 per cent of the upper part.

The lower part of most of the dykes consisting of two contrasting parts, is a fine-grained aplitic rock consisting essentiall of albite and quartz with in most cases, many straight and wavy bands of brownish garnets.

THE NEW ENGLAND PEGMATITES[1]

The pegmatites of the New England states, and particularly those of Maine, are especially interesting because they have yielded a great variety of minerals including valuable gem varieties of beryl and tourmaline and the rare caesium mineral pollucite. Pollucite as described on page.... is the richest caesium mineral and has recently become very valuable as a result of the use of caesium oxide for coating the filaments of radio tubes. The mineral is said to be worth $40 per pound. It is known to occur in only three localities: on the island of Elba, at mount Rubellite near th village of Hebron, Maine, and at Rumford, Maine. As indicating the

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[1] Bastin, E.S.: "Geology of the pegmatites and associated rocks o Maine; U.S. Geol. Surv., Bull. 445 (1911).

value which may be attached to even such semi-precious stones as tourmaline and beryl a quotation from E.S.Bastin may be cited: " The largest flawless gem ever cut from tourmaline from Mount Mica weighs 69¼ carats and is now in the Tiffany collection. It was part of a crystal found in November 1893 and was sold by Merrill and Stone (Hamlim, A.C.: The history of Mount Mica, page 71). for $1,000". Bastin states further that "the total value of the gems and cabinet specimens which have been taken from the locality (the Mount Mica mine near the village of Paris, Oxford county, Maine) up to the present day (1910) probably exceeds $50,000." Most of the gem material yielded by the New England pegmatites has been cut and locally sold to tourists and others at prices rather above the average value in the open market. The exploitation of some of these pegmatites in some cases purely for gems and museum specimens of rare minerals affords a lesson which Canadian prospectors and feldspar and mica miners might well note with profit to themselves. The possible value of such material as museum specimens even when present in only small quantity makes it well worth saving and putting aside instead of burying it in the dump as is usually done in this country.

A noteworthy feature of these pegmatites is the occurrence in abundance of miarolitic cavities or pockets lined with inwardly projecting crystals of coloured tourmaline, albite (clevelandite), clear and smoky quartz, lepidolite, cassiterite, spodumene, amblygonit and other rare minerals, whereas the floors of the pockets generally consisted of a sandy or clayey mass composed of kaolin, with decomposed fragments of clevelandite albite, lepidolite, and the hydromica cookeite, in which were likely to be embedded scattered crystals of the above species which had become detached from the walls or roof. Sometimes these cavities reached very large dimensions. Bastin shows a photograph (loc.cit., p. 86) of one measuring 20 by 12 by 7 feet.

The almost complete absence of such cavities in the pegmatites of the Ontario and Quebec Precambrian accounts to a large degree for the failure so far of these pegmatites to yield gem material of any appreciable size or quantity. Crystals completely in matrix, even if originally of gem quality are likely to be shattered by strains set up during cooling due to unequal contraction by any movements inthe rock, or finally by the blasting and hammering necessary to remove them.

The granites of Nova Scotia, New Brunswick, and southern Quebec are believed to belong to the same period of intrusion as those of New England with which,the pegmatites are associated, so that there would appear to be possibilities of finding similar pegmatites in these provinces. A few small pegmatites of the New England lithium type have been found in Nova Scotia (page   ) and E. Poitevin has collected specimens of pink tourmaline and lithium mica from a small pegmatite dyke (page   ) cutting dunite at Kings mountain, Coleraine township, Megantic county, Quebec, and which must belong to the same period of intrusion.

According to Bastin, the pegmatites in all parts of Maine show great similarity in their principal minerals but exhibit notable differences in their minor constituents. The principal constituents are potash and soda feldspars, quartz, muscovite, biotite and black tourmaline. If biotite is abundant, black tourmaline is almost always rare or absent, and vice versa. Accessory minerals present in almost all pegmatites are garnet, magnetite, and green, opaque beryl. Accessory minerals present only in certain pegmatites number over 50 species, the most important probably being lepidolite, amblygonite, spodumene, blue, green and pink tourmaline, transparent, green, pale blue, or golden beryl, colourless to amber-coloured topaz, and rose and amethystine quartz.

THE BARINGER HILL PEGMATITE, TEXAS[1]

Baringer hill is within an area of Precambrian rocks intruded by granitoid rocks. In many places the granites are cut by pegmatite dykes ranging in width from a few inches to 60 feet. Baringer hill is formed by a pegmatite body having irregular walls and the form of a pipe or short dyke. An outer band 1 foot to 5 or 6 feet wide is of graphic granite. In the main body of the pegmatite feldspar seems to occupy most of the western and southern sides and quartz the centre and much of the eastern side. One quartz mass is more tha

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[1] Hess, F.L.: U.S.Geol. Surv., Bull. 340, pp. 286-294.

40 feet across and displays distinct white bands from 1/8 to ½ inch wide, the white banding being due to small liquid inclusions. Between the bands the quartz is glassy and clear. At one time, before mining commenced, a vug was found large enough for a man to enter, lined with "smoky" quartz crystals reaching 1,000 pounds or more in weight. The feldspar is an intergrowth of microcline and albite and occurs in large masses reaching over 30 feet in diameter and as huge crystals some of which are 2 to 3 feet long. Large crystals of fluorspar, measuring a foot along the edge, occur in the quartz. Ilmenite forms radiating bunches of sheets or blades ranging from 1 inch to 11 inches in width. With them occur like bunches of biotite, sheets of which are said to be as much as 3 feet wide. Small flakes of lithia mica are found but muscovite is rare.

The principal interest in the occurrence centres in the accessory minerals, particularly those that are rare-earth minerals. Allanite occurs in large masses, one of which weighed 300 pounds and was embedded in fluorite. Cyrtolite is rather common. Fergusonite forms bunches of irregular crystals one such aggregate weighing over 65 pounds. Gadolinite occurs in crystals and in irregular masses up to 200 pounds in weight. Polycrase forms grains, small masses and plates. Other rare-earth minerals found are yttrialite, rowlandite, nivenite, guminite, thorogumminite, makintashite, and tengerite; these are apt to occur in any part of the dyke.

THE MADAGASCAR PEGMATITES

Madagascar, an island nearly 1,000 miles long by 360 miles wide lying to the east of Africa, is noted for the number and variety of its pegmatitic minerals. The geology and mineralogy of Madagascar have been described by A. Lacroix in three large volumes entitled: "Mineralogie de Madagascar", vol.I, 1922, II, 1922, III,1923,Paris, which is one of the most complete and comprehensive works of the sort ever attempted. An excellent résumé of the mineralogical part of this work referring to radioactive minerals has been published by Henry W. Turner[1] but otherwise the original must be consulted. Owing to the immense amount of descriptive matter comprised in the Mineralogie de Madagascar it is often difficult to obtain a particular item of information desired and no translator or abstractor could do justice to it unless he were thoroughly familiar with all three volumes. This applies particularly to the geological descriptions and the present writer for example has been unable to come to any definite conclusion as to what are Lacroix' views regarding the geological age of the pegmatites, a point which is of considerable interest because they contain numerous radioactive minerals, the age of which might be calculated from the lead-uranium-thorium ratios for comparison.

The geology of the island is extremely complicated, but in a general way there are two main areas. About one-third of the island

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[1] Review of the Radioactive Minerals of Madagascar, Econ.Geol., vol. XXIII, No. 1 (June, 1928).

west of a line drawn more or less parallel to the western coast is composed chiefly of Permian or later sediments, volcanics, and granites, the latter in comparatively small amount.The eastern two-thirds of the island consists of a great elevated area of highly deformed crystalline ortho- and para-gneisses and schists, quartzites, crystalline carbonate rocks, amphibolites, pyroxenites, etc., cut by granites, pegmatites, diabase, and gabbro. The description of these rocks reminds one of the ancient complex of Grenville sediments and Precambrian intrusives in Ontario and Quebec. The legend for this area on the geological map (vol. III) of the island is "Crystalline schists and ancient eruptive rocks". Thus, although Lacroix evidently believes these rocks to be geologically old there is doubtless the usual uncertainty as to the age of the granite and pegmatite intrusives. In most of the analyses of radioactive minerals quoted by Lacroix, lead is either not mentioned or is stated to be a trace, which according to the radioactive method of age determination would indicate a very late age for the pegmatites, but the extreme topical weathering to which all the rocks have been subjected may have affected the minerals to such an extent that the lead ratio values would be unreliable. As in alltropical countries the rocks are greatly weathered and much of the country is covered by red earth and lateritic clays. The rocks are softened to such a degree that much of the mining even in the pegmatites is done with pick and shovel. The majority of the pegmatites that have been worked for rare minerals occur in the older complex at about the middle of the island. As in the Precambrian pegmatites of Ontario, allanite and the titano-tantalo-columbate minerals seem to be the most abundant and widely distributed. In Madagascar these comprise euxenite-polycrase, betafite, ampangabeite, fergusonite, samarskite, blomstrandite, and priorite-blomstrandite. A considerable quantity of such minerals, chiefly betafite and euxenite, has been mined and shipped to France for treatment. According to Hess [1] 80.8 metric tons of betafite were produced from 1912 to 1923 inclusive, in 1924 according to L.M.Jones [2] 4.9 metric tons of betafite and, in 1923-24, 6.6 tons of euxenite were produced. Hess [3] states up to November 1926, 103.55 metric tons of betafite, probably including some euxenite, was shipped, and from 1923 to Oct. 1926 7.5 tons of euxenite was shipped. Between 1909 and 1923, 36.9 tons of autunite, uranocircite ore was shipped. This was derived from an alluvial deposit in which these secondary minerals occur mixed with earth and peat. Monazite, beryl, and lithium minerals have also been produced and shipped according to Lacroix.

Uraninite appears to be rare, having been found in small quantity only in two localities - at Malakialina, province of Fianarantsoa, and in the province of Vohemar. Unfortunately no analyses of these uraninites are given. Thorite and thorianite occur

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[1] Mineral Resources for the U.S., 1923.

[2] Mineral Resources of the U.S., 1925.

[3] The Mineral Industry, 1926.

Beryl is one of the most common minerals being found in many of the pegmatites. Certain minerals occur as beautiful transparent crystals of gem quality among which are beryl, tourmaline, garnet, danburite, diopside, zircon, and orthoclase. Spectacular gemstones cut from Madagascar minerals may be seen in the Morgan collection at the Museum of Natural History, New York city. Among these perhaps the most remarkable are the beautiful, flawless, transparent yellow gems cut from orthoclase. This sort of orthoclase is stated by Lacroix to come from pegmatite at Itrongay.

The Madagascar pegmatitic minerals of economic interest all occur in alkali feldspar pegmatites, i.e., those containing chiefly microcline or albite or both, with very little or no lime-soda feldspars.

PITCHBLENDE OCCURRENCES

VEIN DEPOSITS OF PITCHBLENDE

Although uranium minerals are not uncommonly found in pegmatites the comparatively small production of betafite and euxenite from Madagascar represents the only uranium ore of pegmatite origin which has been utilized in commercial quantities of some importance for the extraction of radium. The world's supply of uranium and radiu has been derived essentially from two other types of deposits; the carnotite-bearing sandstones of Colorado and Utah and the pitchblende-bearing veins of Saxony, Bohemia, and the Belgian Congo. The recently discovered pitchblende deposits on Great Bear lake, Canada, are described in another chapter of this volume.

According to the most recent ideas a close connexion is believed to exist between pegmatite dykes and vein deposits proper, and actual visible evidence of the gradation of one to the other has been described. The mineralized veins, in short, are believed to represent merely a later stage of the same magmatic process of concentration by which the pegmatites are produced. The veins are thus believed to have been formed at a lower temperature in general and in the presence of more abundant mineralizers, particularly water.

Uranium occurs in both the pegmatites and in mineralized veins, but so far as primary minerals are concerned, as different mineral compounds, which are characteristic for the two types of deposits. In the pegmatites uranium appears chiefly either as uraninite or as complex compounds with thorium, rare earths, titanium, tantalum, and columbium, whereas in veins uranium occurs as a primar mineral only as pitchblende. Similar secondary uranium minerals resulting from oxidation and weathering, may of course occur in both pegmatites and veins. Uraninite and pitchblende have been grouped together in the older mineralogy and the two terms are sometimes used synonymously, but there are really great differences between the uraninites found in the pegmatites and the pitchblendes found in veins. Uraninite invariably contains thorium oxide, sometimes to the extent of 12 per cent, with also invariably a few per cent of rare earths. Pitchblende contains no thorium or only traces and very little or no rare earths. The ratio of UO_2 to UO_3 is high in uraninites; in well-preserved specimens it greatly exceeds the ratio $UO_2 \cdot 2UO_3$ in the oxide U_3O_8 whereas in the pitchblendes this ratio approaches that of the oxide U_3O_8 or less. Uraninite, in short was originally UO_2 plus ThO_2 and rare earths oxides, but some of the UO_2 has been changed to UO_3 by the autoxidation incident to radioactive disintegration. Pitchblende on the other hand was probably in most cases largely U_3O_8 even when first formed. Both minerals contain lead derived from the radioactive disintegration of the uranium. The two minerals differ also in form. Uraninite is usually crystallized in forms of the cubic system, whereas pitchblende never shows indications of crystal form. Thus it seems advisable to consider these as two different minerals.

Pitchblende may occur in gold-bearing pyritiferous quartz veins as in Gilpin county, Colorado, in veins with native silver and bismuth, sulphides, arsenides, etc., as in Saxony and Bohemia, and with tin and copper deposits as in Cornwall. The deposits of the Belgian Congo are believed to be connected with the same phase of igneous activity which produced the large copper deposits in the same region.

PITCHBLENDE IN GOLD QUARTZ VEINS,[1] COLORADO

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[1] Bastin, E.S. and Hill, J.M.: Prof. Paper 94, U.S.Geol. Surv., 1917, pp. 121-125.

Years ago, in the earlier days of the radium industry, severa tons of pitchblende from gold quartz veins in Gilpin county, Colorado, were shipped to Europe. The pitchblende occurred as a minor constituent at several mines which were worked primarily for gold and silver. In a number of instances the pitchblende had the appearance of having been deposited contemporaneously in intergrowths with chalcopyrite, pyrite, and probably grey quartz. In other specimens examined the pitchblende was traversed by later veinlets of pyrite, sphalerite, and galena.

Bastin and Hill believed that the pitchblende mineralization together with the gold and sulphides was genetically related to the Tertiary intrusive monzonites, a conclusion which was later verified by the age derived from the lead uranium ratio. An analysis of Gilpin County pitchblende gives Pb 0.65, U 72.60, $\frac{Pb}{U} = 0.009$ and age about 69 million years.

PITCHBLENDE ASSOCIATED WITH TIN AND COPPER IN CORNWALL

In Cornwall deposits of tin and copper were worked by the ancient Phoenicians and have been worked more or less intermittently every since. The tin-copper-uranium mineralization is in veins connected with the intrusion of large granite masses of Perme-Carboniferous age, into chiefly, Devonian slates. The granites contain much tourmalin a local phase consisting largely of quartz and tourmaline, is well know under the same luxullianite. Although the granites become locally somewhat coarser, or are altered to greisen, no pegmatite dykes are known to occur.

The minerals mined were chiefly cassiterite and stannite along with chalcopyrite and various other copper minerals. Native bismuth, nickeliferous and cobaltiferous sulphides and arsenides, galena, zinc blende, scheelite, etc., occurred in minor amount. The gangue usually consisted of quartz containing tourmaline with sometimes topaz, axinite, and fluorite. The pitchblende occurs, it is said, in small later veins cutting the main tin-copper deposits and it is typically most prominent at a somewhat greater distance from the granite than the major tin-copper deposits.

The deposits are still being worked in a small way for tin and pitchblende, the tin workings being very deep at present. Pitchblende is obtained largely from old dumps and stope fillings. An analyses of Cornish pitchblende by Dr. H.F.Harwood yields a lead ratio of 0.047, indicating a late Palaeozoic age. Cornwall was credited with a production of 5 grams of radium up to 1926 (Min. Ind., 1926).

Two descriptions[1] of the uranium occurrences in Cornwall and Devon have recently appeared and on them the following account has been based.

The chief uranium minerals are pitchblende, antunite and torbenite. The antunite and torbenite are alteration products of the pitchblende and are confined to zones of secondary alteration. They occur as bunches of crystals encrusting vugs or fissures. Zippeite, another alteration product, occurs as fibrous or scaly encrustations but is

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[1] Dines, H.G.: Mining Magazine, April, 1930.
Robertson, T and Dines, H.G.: Mining Magazine, Sept. 1929

less widely distributed.

The deposit at South Terras is the only known vein in Cornwall in which the chief minerals are ores of uranium. The vein contained sufficient uranium ore to warrant mining. The high grade ore carried up to 36 per cent U_3O_8 and the low grade ores down to 3 per cent U_3O_8.

The vein is in slates intruded to the north by the St.Austell granite mass. In the area south of the granite body, the slates are traversed by mineral-bearing veins most of which strike east parallel to the margin of the granite, but a number cross the general direction about at right angles. The veins striking east are mainly tin and coppe bearing and represent the earliest stage of mineralization being characterized by minerals which crystallize at relatively high temperatures. The veins running north and south carry such minerals as ores of cobalt, nickel, lead, uranium and iron, with, in some instances, a little arsenic and copper pyrites. These north-south veins appear to be younger than those running east-west and inturn form two classes, namely those carrying iron and those carrying cobalt, nickel and uranium, and it is probable that the two classes are not contemporaneous.

The uranium lode at South Terras is a typical fissure vein with a quartz gangue. The width varies between ½ and 3½ feet. Quartz generally occupies the full width and shows a comb structure. Apart from the ore-shoot, metallic minerals are scanty and occur usually as small, scattered crystals either in the quartz or lining vugs. The uranium minerals in one part of the ore-shoot formed a seam varying from a film to 7 or 8 inches wide and traceable for about 600 feet.

PITCHBLENDE-BEARING VEINS OF SAXONY AND CZECHOSLOVAKIA

The Erzgebirge comprises a mountainous area on the border between Saxony and that part of Czechoslovakia formerly known as Bohemia. Included in this area are the following general localities often mentioned in the literature as producing pitchblende; Schneeberg, Annaberg, Johanngeorgenstadt, and Joachimsthal. The deposits are more or less similar in nature and origin and only those of Schneeberg and Joachimsthal will be particularly noted. The Joachimsthal area is said to be much the most important producer of pitchblende.

Silver and cobalt minerals have been mined at Schneeberg, Saxony, since about 1470. A very interesting account of the mining history of this district has been translated in part by G.R.Mickle[1]. The veins were remarkably rich in native silver, argentite, ruby silver, and silver chloride as well as smaltite, chloanthite, niccolite, bismuthite, native bismuth. Chalcopyrite, chalcocite, and cinnabar also occurred with cobalt bloom and other secondary minerals. The pitchblende seemed to be associated chiefly with native bismuth and cobalt-nickel minerals. The veins occur in altered slates cut by granite masses. The gangue minerals are calcite, ankerite, barite, fluorite, and quartz, the quartz being later than the others. The silver minerals are said to be later than the other minerals.

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[1] Ont. Bureau of Mines, vol.XIX, part II.
(Der Kobaltbergbau und die Blaufarbenwerke in Sachsen bis zum Jahre 1653, von W. Bruchmueller, 1897.)

At Joachinsthal, Bohemia, now Jachymou, Czechoslovakia, the country rock is chiefly mica schist and hornblende schist with some crystalline limestone, the whole intruded by large masses of late Palaeozoic granite and cut by numerous dykes of quartz porphyry and of basalt and phonolite of Tertiary age. The veins are narrow and may be divided into two groups which strike in different directions. The veins cut dykes of quartz porphyry and are themselves cut by the basalt. The gangue is in some veins mostly calcite and dolomite, in other a brittle clay, with quartz and hornstone. Ore minerals are chiefly native silver, argentite, ruby silver and various other silver minerals, niccolite, chloanthite, millerite, smaltite, native bismuth, bismuthinite, native arsenic, arsenopyrite, pitchblende. Lead, zinc and copper sulphides, pyrite, and marcasite occur occasionally. Cassiterite occurs near the granite masses. The silver ores are said to be younger than the others. The pitchblende from this district was used by the Curies in their early experiments on radium. It is estimated that this region had produced 42 grams of radium up to 1926 inclusive. (Min. Industry, 1926) and that since the war the production has been 14.6 grams. (Min. Industry, 1928).

References. Miller, Willet G., and Mickle, G.R.: Rept. Ont. Bureau of Mines, 1905, pt.II, pp. 61-63; also vol. XIX, pt.II, pp. 234-25.
Lindgren, W.: Mineral Deposits.
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Step, J., and Becke, F.: Sitzungsber.K.Akad.Wis Wien, vol.113, pp.585-618 (1904)

Kraus, Max: Das Staatl. Uranpecherzbergbaurevier bei S. Joachimsthal in Bohmen. Bergbau und Hutte 1914.

Bastin, E.S. and Hill, J.M.: Prof. Paper 94, U.S.Geol.Surv., 1917, p. 122.

PITCHBLENDE DEPOSITS OF THE BELGIAN CONGO

Since 1923 the development of extremely rich pitchblende deposits in Katanga province of the Belgian Congo has enabled the Belgian operators to control the world's radium supply and to set new low prices for radium ($50,000 to $70,000 per gram(which have so far practically killed competition from the American carnotite ores formerly supplying the major part of the world's radium production.

Full detailed descriptions of the Katanga deposits have not yet been published; it is said that the Belgian operators exact a pledge of secrecy from anyone who is permitted to visit the deposit. It is known, however, that extremely rich ore has been produced in large quantities. Large blocks of practically solid pitchblende weighing several tons have been seen by visitors to the works in Belgium.

The best available general account of the deposits is probably that of C.H.Laja, entitled "A General Note of the Country and the Minerals being exploited in the Katanga Province of the Belgian Congo", given at a meet of the Chemical, Metallurgical, and Mining Society of South Africa and published in the Journal of the above Society of April, 1924. There is much of interest in this account and the ~~following~~ statements in the following paragraph are entirely based upon it.

The mine lies 30 miles west of Panda. The principal minerals of the ore are pitchblende, gummite, kasolite, curite and torbernite. The ore occurs in lenses in dolomite schist but only in a very restricted area. One characteristic form of occurrence is as lenses occurring en echelon in depth in a narrow zone of the schist itself impregnated with torbernite crystals. The strike of the lenses coincides roughly with the strike of the schists. Where solid dolomite is met, very small lenses of pitchblende have been observed. A rough estimate of the radioactive contents in the high-grade ore being stripped at present is one gram of radium content to 7 to 10 tons of ore.

Rene Van Aubel[1] as a result of an examination of specimens collected at Katanga, has stated that he finds crystallized uraninite associated with the pitchblende and that he believes the pitchblende has resulted from pneuno-thermal alteration of uraninite. Van Aubel refers to a statement by T.A.Ricard[2] to the effect that the pitchblende ores occur in pegmatites and writes that so far as he knows no deposits of such a nature occur in the region.

From the various notices of the Belgian Congo pitchblende deposits it appears that they occur in deformed dolomitic rocks and are closely associated in origin with the large copper deposits of

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[1] Sur la presence d'uraninite cristallisee dans les gites uraniferes de Kasolo (Katanga); Academie des sciences, Paris, Comptes rendus, vol. 185, pp. 586-588.

[2] Eng. and Min. Jour. Press, Jan.2, 1926

the same region. There are indications, in the form of uraninite crystals, that perhaps an earlier, more pegmatitic phase of deposition was succeeded by intense hydrothermal action.

The Union Miniere up to 1928 inclusive, was reported to have disposed of about 250 grams of radium and was said to have on hand large stocks of both high-grade ore and refined radium. It is said that the average ore shipped is of 40 per cent grade, lower values being left at the mine.

CHAPTER XII

CANADIAN OCCURRENCES

BRITISH COLUMBIA

INTRODUCTION

The mountainous country, approximately 400 miles wide, embracing British Columbia, Yukon, and part of western Alberta and extending into Alaska and southward through the United States and Mexico, is commonly referred to as the Cordilleran region. This region has been comparatively only slightly explored; prospecting effort has been concentrated chiefly on the search for gold and the commoner economic minerals and there is but little on record in regard to the occurrence of pegmatites and pegmatite minerals. The rocks[1] of the region range in age through practically the whole of the geological column, from Precambrian to Recent, and include great areas of sediments volcanics, and plutonics. The plutonic rocks appear to have been injected chiefly during the Mesozoic, but there are also some large bodies of Tertiary intrusives in southern British Columbia. The intruded rocks vary from granites to gabbros, with acid types greatly predominating. The Coast range, nearly 1,000 miles in length, is chiefly composed of granitic rocks, with associated more basic types of Mesozoic age.

As the pegmatites which are the chief source of the rare element minerals are derived from granitic rocks the presence of such

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[1] For a concise account of the geology of the region see: "Geology and Economic Minerals of Canada", by Young; Geol. Surv.,Canada Econ. Geol. Ser.No. 1 (1926)

great areas of granite in British Columbia would seem to present very favourable conditions for the occurrence of the pegmatites and these might be looked for chiefly in the older rocks adjacent to the intrusive granite.

Besides the possibilities of pegmatitic deposits of the rare element minerals, placer deposits of cassiterite, monazite, zircon, or other valuable minerals derived from pegmatites might be found. The presence of areas of nepheline rocks opens up the possibility of the occurrence of corundum, and hence it is not beyond the bounds of possibility that rubies and sapphires might be found in placers in such areas.

The sedimentary rocks do not appear to be favourable for the occurrence of secondary deposits of uranium and vanadium minerals (carnotite, etc.) like those of Colorado and Utah, as the corresponding Jurassic rocks in British Columbia are said to be of marine origin. Nevertheless so little is known in detail of the geology of this vast area that it might be well to remember that such deposits are associated with Jurassic sandstones formed as continental deposits under semi-arid conditions.

Vanadium is particularly likely to be associated with rocks containing carbonaceous material and is frequently found in small quantities in carbonaceous shales. Dr. W.F.Ferrier has informed the writer that many years ago he had tests made for vanadium on certain black shales of British Columbia and that small amounts (less than 1 per cent) were found to be present.

Pitchblende is sometimes found in metalliferous deposits with ores of gold, silver, cobalt and nickel, copper, tin, so that the possibility of the occurrence of uranium in metalliferous ore deposits should not be overlooked.

Although a considerable number of specimens from British Columbia have been tested for radioactivity during the past few years, with the exception of the Quadra island carnotite none so far examined has been found to contain uranium or thorium in economic amounts.

The following include all that is on record, so far as the writer is aware, regarding British Columbia occurrences of rare-element minerals. The necessary geological conditions for the occurrence of pegmatites are present and there can be little doubt that such minerals will be found eventually, when the granite-contact areas are more intensively explored.

TETE JAUNE CACHE:BERYL

Reference: McEvoy, James: Geol. Surv.,Canada, vol. XI, pt.D, pp. 38-40

Beryl has been found in a pegmatite dyke at what was known as the Bonanza mica mine, 7 miles south of Tete Jaune Cache. The district is largely underlain by various types of mica schists and many pegmatites are present, some of the bodies being 50 feet or more broad. Similar pegmatites are said by Spence[1] to characterize a broad zone

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[1] Spence (De Schmid),H.S.: "Feldspar in Canada", Mines Branch,Dept. of Mines, Ottawa.

stretching southward to Revelstoke.

The beryl-bearing pegmatite where it had been opened at the so-called mica mine, was about 15 feet wide and dipped at an angle of 40 degrees. In it quartz, feldspar and muscovite occur separately in large masses.

KAMLOOPS: COLUMBITE-TANTALITE

In September, 1914, Mr. R.A.A. Johnston identified columbite-tantalite said to be from the neighbourhood of Kamloops, B.C. The specimen had a specific gravity of 6.4 and was judged by Mr. Johnston to be about midway between columbite and tantalite. No further information regarding this mineral is available.

CLINTON: SLIGHTLY RADIOACTIVE MINERAL

In the Geological Survey files is a record of a qualitative examination by R.A. Johnston of a black mineral said to be from a pegmatit vein near Clinton. Mr. Johnston reported (June 2, 1915) that it containe less than half of one per cent uranium oxide, a small amount of cerium earths, no thorium, and considerable titanium. The specimen was suspected by Mr. Johnston to be not a single mineral but a mixture of ilmenite with some rare earth mineral.

MOOSE CREEK: KNOPITE AND PEROVSKITE

Reference: Ellsworth, H.V. and Walker, J.F.: Geol. Surv., Canada, Sum. Rept., 1925, pt.A, p.230

On Moose creek, southeast of and about 26 miles by trail from

Leanchoil, Knopite occurs in small bunches, up to 2 or 3 inches in diameter, in a fairly coarse pegmatite composed essentially of hornblende, biotite, and magnetite. The knopite forms a very small percentage of the rock; the magnetite composes 10 to 15 per cent of the body. The pegmatite outcrops at an elevation of 8,500 feet on the ridge between Moose creek and the west branch of Vermillion river. It is lenticular, 30 feet wide, occurs in an intrusive body of alkaline rocks, and appears to be an intrusion and not a segregation. The presence nearby of numerous finer-grained dykes of similar composition but in which no knopite has been observed, also suggests that the knopite-bearing body is intrusive.

Specimens from the pegmatite body resemble other specimens received from the same general locality, perhaps from the same body, and which were closely examined. One such specimen was an irregular fragment the size of a small walnut and having the general appearance of magnetite except that the lustre was somewhat more brilliant. Examined with a microscope, small, dark brown, almost opaque grains wit a high index of refraction were visible associated with much magnetite. The magnetic constituent was separated and found to make up 14.32 per cent of the total weight of the specimen and to contain 15.2 per cent TiO_2.

The non-magnetic part contained in addition to the chief mineral a few small grains of rock minerals such as mica, plagioclase, and possibly nepheline. An analysis (for analysis see page...) indicates the similarity of the mineral to the so-called knopite which is really a ceriferous perovskite. Knopite is cited by Dana as occurring in crystalline limestone in Alno, Sweden, and the neighbouring mainland. The mineral was first described by P.J.Holmquist.[1]

A mineralographic examination of the specimen shows that it is a very intimate intergrowth of two or more minerals. The groundmass consists of an apparently quite uniform mixture of two minerals resembling remarkably an eutectic. Veinlets of magnetite penetrate the groundmass. It is assumed that the eutectic consists of knopite and a mineral having the appearance of magnetite very finely intergrown, for the supposed magnetite component of the eutectic has the same appearance under high magnification as the larger areas of definitely identifiable magnetite. A serious objection to this conclusion, however is the fact that there appears to be more intergrown magnetite than is indicated by the results of the magnetic separation and by the iron content of the non-magnetic part. For this reason the iron determination was very carefully checked and found correct. It may be that knopite is really an intergrowth of perovskite with some rare earth-bearing mineral in fairly constant proportions.

Another small specimen from the same locality, received about the same time as the one described, was brown in colour and more translucent under the microscope. This appears to be perovskite.

QUADRA (VALDEZ) ISLAND:CARNOTITE

During the latter part of 1930 carnotite was discovered on

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[1] G.For Forh.16,73,1894

Quadra island by Mr. R. Crowe-Swords of Vancouver who has kindly furnished the information upon which the following account is based.

While making an examination of copper deposits in the vicinity of Gowland harbour Mr. Crowe-Swords noticed small fissures in the rocks, carrying a soft greenish yellow material, samples of which were subsequently identified at the University of British Columbia as carnotite. Analyses, I made under the direction of Dr. [illegible] of the University of British Columbia, and II made by the Division of Ore Dressing and Metallurgy, Mines Branch, Ottawa, yielded the following results:

	I	II
Silica	17.54	10.6
Uranium oxide	27.70	28.9
Vanadium oxide	19.00	21.1
Iron oxide	22.0	2.9
Calcium oxide	4.5	—
Sodium oxide	2.2	—
Potassium oxide	3.2	—
Water	5.0	4.9

The samples analyzed were obtained at a point where patches of sandstone overly granite near a contact of sandstones and volcanics.

Very little work or exploration had been done up to the spring of 1932.

The general geology of Quadra island has been described by D.D. Cairnes[1] who states that the consolidated rocks consist of Jurassic or Triassic (?) sediments, Cretaceous or Jurassic volcanics and Coast Range granitic intrusives.

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[1] Cairnes, [illegible] 58

NORTHWEST TERRITORIES

PITCHBLENDE DEPOSITS AT GREAT BEAR LAKE, N.W.T.

BY D.F.Kidd

References: Knight, Cyril W. "Pitchblende at Great Bear Lake"; Can. Min. Jour, vol.51, No.41, Oct. 10th, 1930.
Kidd, D.F.: "Great Bear Lake-Coppermine River District". Can. Min. Jour., vol.53, No. 1, January, 1932.

The deposits are located on the east side of McTavish arm, Great Bear lake, district of Mackenzie, Northwest Territories. The only deposit examined is at Labine point, on the east side of this arm and about 35 miles south of Hunter bay. Labine point (Lat.66°05' Long. 118°01½) is the north point of Echo bay, an indentation 15 or more mil deep. The shore line of the east side of McTavish arm is highly indented and in the northern part there are numerous islands offshore. They are not so numerous farther south. The country is rugged with relief up to 1,000 feet and bedrock widely exposed.

The area is approximately 1380 miles by boat from the railhead at Waterways, Alberta, and 850 miles from that place by the usual aircraft route. The boat route down Athabasca, Slave and Mackenzie rivers to Norman, thence up Great Bear river and across Great Bear lake. On Slave river 16 miles of rapids lie between Fort Smith, and Fitzgerald, round which a motor road has been built. On Great Bear river there are 3 miles of rather shallow, fast water. In 1931 the freight rate by boat for small shipments was $200 a ton from the east side of Great Bear lake to Norman and $145 a ton from Norman to Waterways. It is 250-300 miles by air from Labine point to Fort Rae on

Great Slave lake from which place the freight rate to Waterways was $120 a ton in 1931.

The deposits of pitchblende and associated silver at Labine point were discovered in May, 1930, by G.A.Labine and E.C.St.Paul. Claims were staked and the identity of the pitchblende being suspected, samples were sent out for determination. Between this time and the summer of 1931, further claims were staked by Labine and others prospecting in the region. In February 1931, Labine and a small crew of men together with supplies and equipment were flown to the area. During the spring, summer, and autumn of 1931 trenching and exploration were carried on at the site of the original discovery and further prospecting was undertaken. Native silver had been found with the pitchblende but its discovery was not generally known to the public till July, 1921. Following this date a number of prospectors entered the district by aircraft and a large number of claims were staked. Most of these men left the area in September or December but a few planned to stay all winter. In the autumn of 1931 further discoveries of pitchblende were reported to have been made 2 miles northeast and 8 miles southeast of the original discovery.

The rocks along the east side of McTavish arm were reported in the year 1900 by J. Macintosh Bell as "Granite and greenstone".[1] A

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[1] Report on the Topography and Geology of Great Bear Lake and of a Chain of Lakes and Streams thence to Great Slave Lake":Geol.Surv., Canada, Ann. Rept. New Series, vol. XII, 1899, p. 17c.

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geological party under the writer was sent to the area in 1931 to commence areal mapping. Preliminary observations only on the general geology are made below.

The consolidated rocks examined fall into three main groups: flat-lying sandstones and conglomerates; granitic intrusions; and a complex chiefly of altered sediments and volcanics. In addition there are basic dykes and sills; and large quartz veins.

The oldest strata are a complex of tuffs, conglomerates, arkoses sandstones and quartzites, some flows, fine-grained sediments (probably in part of volcanic origin), lean iron formation, limestone and dolomite. The strata have been provisionally grouped together though there are probably two or more major divisions. Intruding these rocks are granites, granodiorites, and other acid plutonic rocks. They also have been grouped together though they are thought to be of various ages. Granite pebbles in some of the folded conglomerates show there is (or was) older granite in the vicinity.

Younger than these rocks is a series of flat-lying sandstones and conglomerates which have been found north and west of the northeast corner of McTavish arm.

Cutting all these rocks are basic dykes and sills, and a system of very large quartz veins. The dykes and sills are widespread and are up to 200 feet in width. The system of quartz veins has been traced for 60 miles in a belt several miles wide. Individual veins reach a width of several hundred feet and length of several miles. The age relation of the basic dykes and the quartz veins is not known.

(Insert Figure 2)

AtLabine point, the site of the original discovery, the rocks are of the old complex and consist of fine-grained, banded sediments, volcanic agglomerate, perhaps some flows, and impure limestone, all considerably metamorphosed. Granite outcrops along the west side of the point on the tips of small points and on offlying islets for several miles north of the point, the main body apparently being under the lake to the west. This granite has baked and granitized the sediments to such an extent that over large areas the bedding has been completely obliterated and a mottled, pink and greenish grey, massive, fine-grained rock has resulted.

Magnetite is particularly widely distributed in the rocks of the point. Iron sulphides,mostly pyrite, occur in places disseminated through the rocks, and in weathering have formed large gossans in which limonite and gypsum are abundant.

A basic sill up to 200 feet thick intrudes the sediments and volcanics and outcrop on the island at the south end of the point and on the next point to the east, one-quarter mile away. It is found again on the lake shore one and one-quarter miles north of the point. An examination of one thin section of a specimen of the sill indicates that the rock is a quartz norite.

Sufficient remains of the bedding of the rocks at Labine point to show that the strata have a general north strike and westerly dip, with numerous local variations. The sill intruding these rocks on the island at the south end of the point, dips to the southwest,whereas on the next point a quarter of a mile east, it and the neighbouring sediments dip to the east.The intervening bay apparently conceals an anticlinal axis.

At Labine point the pitchblende and native silver with other minerals occur in shear and shatter zones traversing the altered rocks of the point. Development work has so far been done on three zones. These strike in a general east-northeast direction, converging somewhat in that direction. All three zones have a general steep dip to the northwest. They have been numbered 1,2 and 3 from southeast to northwest.

The width of the shattered zones is irregular from 1 foot up to 50 feet. No.1 zone has been traced for 1,000 feet, partly in shallow water along the lake shore, and has a possible extension of 1200 feet to the northeast and 1400 feet to the southeast. No.2 zone has been traced, with one gap of 350 feet, nearly continuously for 1400 feet from the lake shore to a small pond under which it disappears. The pond and a small swamp extend along the strike for 1200 feet and in the exposures beyond this interval, the zone has not been recognized. No.3 zone has been traced from the lake shore for 600 feet beyond which it has not definitely been recognized.

Along No.2 zone the metamorphism induced by the granite has been more intense than in the adjacent rocks. In all three zones quartz has been introduced, cementing a breccia of country rock or forming a stockwork where the movement of the rocks has not been so extensive.

In Nos. 1 and 3 zones, quartz is the main filling, in No.2 zone it is less prominent, particularly in the northern part of the zone. Specular hematite and a light brown or yellow iron-bearing carbonate are abundant in places in No. 1 zone.

In addition to the three main zones, there is a second set of fractures trending slightly east of north. They are generally occupied by rather regular quartz and carbonate veins up to 3 feet wide. In many instances these veins do not intersect the main shear zones but rather branch out from them. In one case at the south end of No. 2 zone there is an intersection, but there is little, if any, displacement.

A variety of minerals have been found in the deposit. These comprise arsenopyrite, magnetite, hematite, pyrite, limonite, chalcopyrite, bornite, covellite, native copper, tetrahedrite, malachite, azurite, sphalerite, galena, cerussite(?), native silver, argentite, ruby silver (?),pitchblende, gummite and other alteration products of pitchblende, skutterudite and nickel skutterudite, smaltite- chloanthite and cobaltite (last four identified by H.V.Ellsworth), rammelsbergite (?), another cobalt-nickel mineral (?) erythrite, annabergite (?(nati bismuth, and two unidentified minerals. Non-metallic minerals include quartz, a manganese-bearing carbonate (rhodochrosite?) and its weathering products, siderite and other carbonate minerals, actinolite, chlorite, biotite and possibly barite and fluorite. Other minerals will probably be discovered when further work is done.

Pitchblende was one of the earliest minerals introduced into the zones. It is found at most places on the hangingwall side of the fracturing, and at some places there has been some movement subsequent to its emplacement. It occurs as (1) sinuous persistent veinlets 1/8 inch to 1 inch wide with mamillary surfaces, several often paralleling each other and closely spaced, (2) as colloform masses in a matrix of quartz and (3) as angular fragments in a quartz matrix. The last two varieties in the hand specimen are dark brown, have a glassy lustre and are much lighter than solid pitchblende. Pyrite, arsenopyrite, bornite, tetrahedrite, sphalerite, chalcopyrite, galena, covellite and native silver are all later than pitchblende and most of them have been found in cracks in it. Arsenopyrite has been found with angular boundaries against pyrite. It is much earlier than chalcopyrite and sphalerite. Pyrite occurs as clusters of residual grains in massive chalcopyrite. Tetrahedrite is associated with galena and sphalerite. On one specimen it is cut by veinlets of chalcopyrite. Bornite is usually partly replaced by chalcopyrite. At one place it is associated with minerals of the cobalt-nickel group. Argentite has only been identified in a single specimen where it is associated with covellite, tetrahedrite and galena. The presence of one of the ruby silvers (proustite or pyrargyrite) is suspected. Native silver is present as: (1) a mass of wires in a manganese carbonate gangue; (2) as plates and leaves, in some places with the carbonate, in others between the surfaces and in cracks of mamillary pitchblende or holding it together; and (3) in only slightly fractured country rock as plates in fractures and as tiny wires disseminated through it. Native bismuth has so far always been found associated with the cobalt-nickel group minerals. Only a few tiny specks of native copper have been seen.

The native silver, where abundant is usually associated with the manganese-bearing carbonate. In places, however, it is associated with chalcopyrite, bornite, galena, sphalerite and tetrahedrite. The single specimen in which argentite was found also carried these minerals.

In all three zones and in some other fissures, a rather definite late mineralization stage of cobalt-nickel minerals, chalcopyrite native bismuth, quartz, and an iron-bearing carbonate (ankerite) is found. It consists of narrow sharply defined fissures as much as a few inches in width, with a selvage of cobalt nickel group minerals on which are grown quartz crystals, on which in turn are often grown crystals of chalcopyrite. In places these line a vug, but frequently the cavity is filled with the carbonate in which are scattered grains of native bismuth. The writer has not identified silver associated with the cobalt-nickel group minerals.

Surface alteration products include, yellow and orange pitchblende alteration products, yellowish-green stains probably copper-uranium minerals, azurite, malachite, erythrite, and apple green stain probably annabergite, and sooty and clinkery manganese minerals.

The pits indicated on the accompanying figure show the extent of development at the end of the 1931 field season. In addition a considerable amount of careful surface prospecting has been done.

(Insert Figure 3 (?))

In No. 1 zone, one pit 22 feet long and said to be 13 feet deep, has been sunk at the lake shore. At the time of the writer's visit it was flooded. Eleven inches of solid pitchblende is said to be exposed over most of the length of the bottom of the pit. Three hundred and fifty feet north in this zone in a surface exposure a lense of pitchblende 6 inches wide is visible. Much of the zone intervening is under the lake.

In No.2 zone, pitchblende has been found at a number of points. It is present in nearly all the pits indicated on Figure 2. At some other places also yellow surface stains may indicate its presence. In most of the zone it occurs as colloform masses or fragments in a quartz matrix. These form lenses which are often present where there are slight changes of strike in the zone. In the northern part of the zone it occurs as veinlets of comparatively pure pitchblende. Channel samples were taken across the greatest widths of some of the lenses of lower grade material. The assays of these samples are quoted below:

	No.1	No.2	No.3	No.538
U_3O_8	15.94 %	22.78%	10.74%	51.60%
Radium(calc.)mg.per ton	41.44 mg.	58.22mg.	27.92 mg.	82.36 mg.
Silver Troy oz.per ton	11.69 oz.	43.25 oz.	24.84 oz.	1.44 oz.
Gold Troy oz.per ton	trace	none	trace	trace

Sample No. 1. Across maximum width of lense (1.75) in trench 800 feet from south end of No. 2 zone.

Sample No.2. Across a width of 0.65 feet of same lens as represented by sample No. 1, but 7 feet to the north.

Sample No. 3. Across a width of 0.65 feet of same lens but 7 feet north of place represented by sample No. 2.

Sample No. 538. Across maximum width of lens (1.45 feet) of glassy pitchblende in trench 600 feet, from south end of No. 2 zone.

The narrow seams of mamillary pitchblende found inthe northern part of No. 2 zone have a much higher uranium content. Assays giving as high as 64 per cent U_3O_8 have been made of this material. These seams of pitchblende are 1/8 inch to 1 inch wide, several nearly parallel ones often occurring in a width of a foot or less across the zone.

In No. 3 zone pitchblende has been found in the two southernmost of three small pits sunk. In the northern of these two pits, a lense of pitchblende is visible and in the other pit 40 feet to the south is a single persistent ½ inch seam of mamillary pitchblende.

Estimation of the quantity of pitchblende in the deposit is not yet possible. In the course of development the following tonnages of pitchblende were cobbed and sacked from different test pits:

No. 1 zone; pit 22 feet long, 4 to 6 feet wide and 13 feet deep; 8 tons sacked.

No. 2 zone; pit at lake shore south end of zone; pit 30 feet long, 3 to 6 feet deep; 1½ tons sacked.

No. 2 zone; pit 800 feet north from lake shore (pit from which samples 1,2 and 3 were obtained); pit 36 feet long, 4 to 6 feet wide, 6 feet deep on one side and 10 feet on the other; 10 tons sacked.

The amounts of pitchblende obtained from these pits probably represent what can be obtained from the apparently richer parts of the zones.

The native silver has been found in some abundance in the northern part of No.2 zone. It has also been found at two other places in No. 2 zone, and in small amounts at several other places on the property. In the summer of 1931 it had not been found in No. 1 or No.3 zones but further development work in No. 1 zone at the lake shore in the autumn is said to have disclosed some native silver.

No other deposits of pitchblende were examined by the writer. In the autumn of 1931 pitchblende and silver were reported to have been found in a shear zone cutting "syenite" on claims believed to lie about 8 miles southeast of Labine point. Pitchblende is also reported to have been discovered 2 miles northeast of Labine point about on the strike of the veins at the point.

The adjacent granite or its parent rocks, is the most obvious source of the mineralization. The Labine point pitchblende-silver deposit and other silver deposits which have been found in the district, lie in shatter and shear zones in rocks adjacent to their contact with intrusive granite. The basic sill at this locality and similar basic dykes and sills in the region were searched for fissures, shear and fracture zones, or quartz veins cutting them and none of importance were found. It seems safe to conclude that the major movements in the shear zones antedated the formation of the sill. The silver, however, is a late mineral in the deposit, and therefore, as yet, the possibility remains that the sill or its parent rock was t the source of the silver part of the mineralization.

ALBERTA AND SASKATCHEWAN

The rocks over the greater part of Alberta are sediments of Mesozoic and Tertiary age with no known granitic intrusions. Only the northeast corner of Alberta which include a portion of the Canadian Shield, can be considered favourable for the occurrence of pegmatites. Nearly the whole northern half of Saskatchewan is underlain by Precambrian rocks in which pegmatites may be expected to occur. The southern portion comprises Cretaceous and Tertiary sediments in which there is no possibility of finding rare mineral deposits. No rare mineral occurrences have yet been reported from Saskatchewan. Mr. J.F.Wright reports having seen very numerous pegmatites in the course of his work during the summer of 1928 in northern Saskatchewan.

MANITOBA

INTRODUCTION

Southwestern Manitoba is underlain by sediments ranging in age from Ordovician to Cretaceous, but the remaining, greater part of the province is occupied by Precambrian rocks of the Canadian Shield. The can be little doubt that numerous pegmatites will be found in the Manitoba Precambrian as in Ontario and Quebec. Important discoveries of lithium-bearing pegmatites have already been made in southeastern Manitoba in the neighbourhood of Pointe du Bois and one of these pegmatites holds considerable quantities of the lithium ores, spodumene and lepidolite . Lithium minerals have also been reported from various localities over a north and south range of approximately 60 miles from Cat lake in the north to West Hawk lake on the south, so that there is reason to believe that the lithium-bearing type of pegmatite may be found over a large area in this region.

The lithium pegmatites are notable for containing at times a great number of rare mineral species, most of which, however, are only of mineralogical interest. Minerals of economic value which may occur are: lepidolite, spodumene, amblygonite, cassiterite, columbite-tantalite, various rare earth and uranium minerals, beryl, and topaz. Gem varieties of beryl, topaz and tourmaline may occur as crystals lining vugs, when such so-called "miarolitic" cavities are developed in pegmatite. Spodumene, when clear and well coloured, is rather valuable as a gem stone. Hiddenite, a yellow green to emerald green variety, and kunzite of a delicate pink to lilac colour are well recognized gem varieties of spodumene. Caesium minerals such as pollucite and caesium beryl occur in lithium pegmatites. Cassiterite has been found in certain of the lithium pegmatites and, at Shatford lake, in a pegmatite which appears from specimens so far received to be the ordinary quartz-microcline-muscovite type. The close association of tinstone with tungsten ores (wolframite and scheelite) in foreign deposits suggests that these latter minerals might be looked for also.

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The occurrence of lithium minerals, beryl, and cassiterite over considerable areas in southeastern Manitoba would seem to indicate that we have here a region comparable to the Black hills of South Dakota (page), where lithium-bearing pegmatites are notably developed and considerable quantities of commercially valuable pegmatite minerals such as the lithium minerals, spodumene, amblygonite, lepidolite, besides beryl, columbate-tantalite, and microcline, have been mined. More recently the rare and valuable caesium mineral pollucite has been recognized and produced in some quantity. Tinstone and wolframite occur and placer deposits of these have been worked. Any or all of these minerals might be expected to occur in southeastern Manitoba.

In neither southeastern Manitoba nor in the Black hills of Dakota, does there appear to be any important development of the type of cavernous or miarolitic, lithium pegmatite characteristic of Maine and other New England states, and which seems to be necessary for the production of gem minerals. Gem-bearing pegmatites are usually of comparatively young geological age. The older the pegmatites are, the more likely that any material originally of gem quality will have been shattered, altered, or decomposed by natural agencies. The horizon at which pegmatites occur, relative to the original roof or capping probably has a great influence on the production of gem-bearing cavernous pegmatites. Those formed close under the roof might be supposed to contain more volatile matter than those formed deeper down, favouring the production of cavities and free- growing crystals at the higher levels.

BEAR MINERAL CLAIM

References: Wright, J.F.: Geol. Surv.,Canada, Sum. Rept. 1924, pt.B, pp. 100-102 (1926).

Spence, H.S.: Mines Branch, Dept. of Mines, No. 687, p.24, (1926).

Stockwell, C.H.:Geol. Surv.,Canada, "Lithium Deposits" in Memoir..169 Geology and Mineral Deposits of a part of southeastern Manitoba by J.F.Wright (1932)

This property comprises two claims, each 1,500 by 1,500 feet, owned by the Silver Leaf Mining Syndicate of Bradford,England. It is the only occurrence in southeast Manitoba that has so far been opened up sufficiently to prove the existence of commercial quantities of lithium ores. The following account is taken from a description by C.H.Stockwell who examined the occurrence in 1927.

magma. A considerable amount of replacement took place in some albite-bearing and all lithium-bearing bodies by reaction between earlier crystallized minerals and still liquid magma. Some volatile constituents probably escaped, but no large amount of material was brought in by a flow of solutions from outside sources. It was essentially a closed system. The evidences used to reach this conclusion are based chiefly on mineral relations and structures observed in the field. An account of them would be long and involved and will not be given here.

6 ~~BEAR MINERAL CLAIM~~

The Bear mineral claim is 3 miles slightly south of east from Lamprey falls on Winnipeg river. A winter road and pole tramway each 3½ miles long have been constructed from the property westward to a point on Winnipeg river 1 mile south of Lamprey falls. From the end of the road it is 6½ miles southwest along the river to Pointe du Bois where railway connexions are made. A shorter overland route into the property is by way of a trail, 1½ miles long, which extends from the property northwest to Winnipeg river, but motor boats going from Pointe du Bois to the end of this trail must pass Lamprey falls, which is possible only at certain times. Camps have been erected at the property and on the bank of the river at the end of the road.

The deposit (*See* Figure ~~9~~ 3) was discovered in July, 1924, by F. B. Evans and R. G. O. Johnston. They did a small amount of stripping and trenching on the deposit and it was then taken over by the Silver Leaf Mining Syndicate (Canada), Limited. The syndicate has since done ~~a~~ considerable amount of development work. Some stripping, quarrying, and open-cutting have been done on a hillside where part of the deposit outcrops. The larger part of the deposit is covered by swamp into which six pits have been sunk and the deposit exposed in four of them. In addition, 1,000 feet of trenching has been carried out in the swamp for the purpose of draining it, the plan being to drain it to a depth of 10 feet so that further stripping and test pitting in the swamp can be carried on without interference from water. During 1926 and 1927 about 75 tons of lepidolite and spodumene were shipped to various countries, including the United States, England, and Germany, for purposes of quantity sampling and experimental work. The deposit was not worked during the summer of 1929 or since that time.

The deposit is a lithium-bearing dyke which cuts volcanics. Exclusive of a broad granite phase on its north side, the dyke strikes slightly north of west, has been traced at intervals along the strike for a distance of 525 feet, and has a maximum exposed horizontal width of about 100 feet. Of the total length, 175 feet is well exposed at the east end on the side of a hill, 40 feet in height, where the dyke rounds off and comes to an end; the remainder lies to the west under a swamp and has been exposed at four localities by means of open-cuts. On the hillside the dyke is cut by a fault which strikes slightly north of east and dips 65 degrees north. The part of the dyke that lies on the south side of the fault is displaced about 75 feet horizontally to the east of the part that lies on the north side.

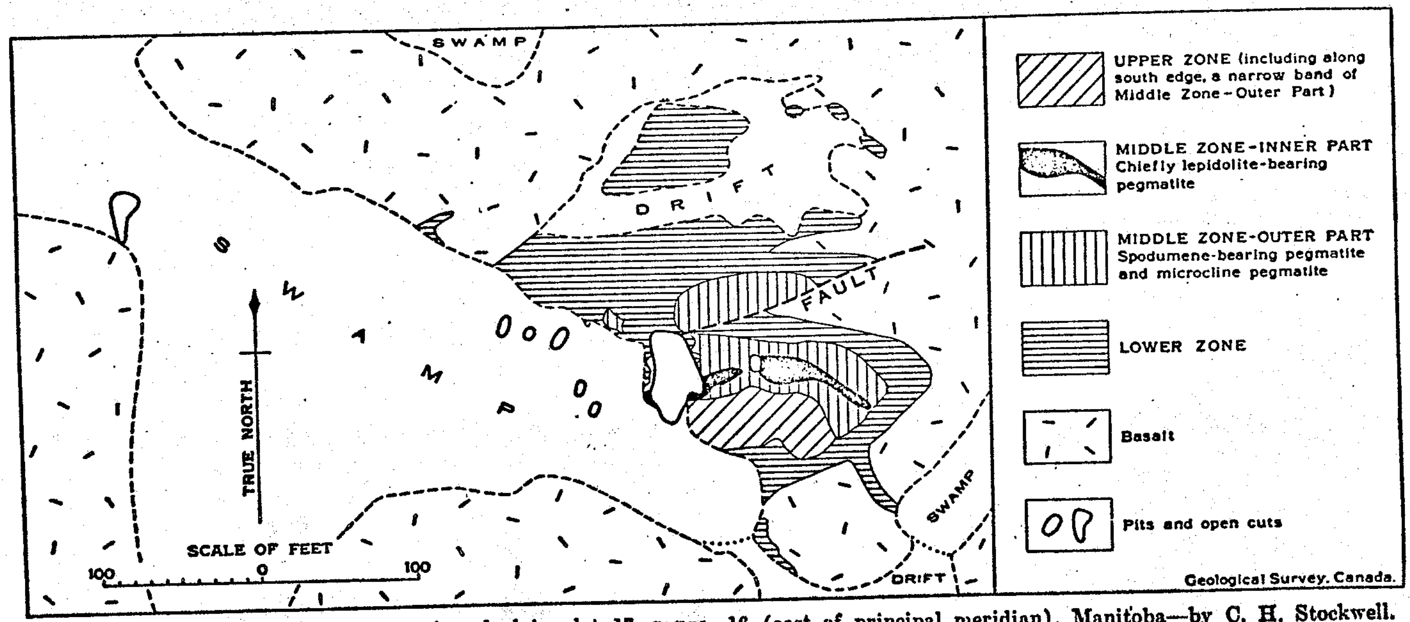

Figure 3. Pegmatite dyke on Bear mineral claim, lot 17, range 16 (east of principal meridian), Manitoba—by C. H. Stockwell.

The dyke is a complex body comprising three zones, a lower zone, a middle zone, and an upper zone. On the hillside, on the south side of the fault, the lower zone outcrops as a crescent-shaped band, about 20 feet in horizontal width, that extends along the south side, around the east end, and along the north side of the dyke. Its lower, outer surface is in contact with volcanics and dips from all sides toward the middle of the dyke. Its upper surface is curved and consequently has irregular dips, but, in general, also dips toward the middle. The dips of both surfaces suggest that this eastern portion of the dyke is trough-shaped and may not extend to any great depth. In the southern portion of the trough is an area of the upper zone forming a nearly flat-lying sheet 100 feet long and 30 feet wide. The middle zone fills the remainder of the trough, probably underlying the flat-lying sheet of the upper zone. It outcrops as a very narrow band between the flat-lying sheet of the upper zone and the south arm of the crescent-shaped band of the lower zone and it also outcrops as a large area 150 feet long and with a horizontal width of 30 to 40 feet between the flat-lying, upper zone and the northern arm and eastern end of the crescent-shaped band of the lower zone. Along the middle of the large northern area of the middle zone are several masses, up to 75 feet long and 20 feet wide, forming a subzone. The under surfaces of several of these masses are almost horizontal.

On the hillside on the north side of the fault the lower zone covers a broad, nearly circular area 150 to 200 feet across and the middle zone forms small patches on the south side of this broad area.

In the swamp, a short distance west of the main area, the lower zone is exposed in a test pit. The middle zone shows in a second pit, and the upper zone in two other pits. All three zones are exposed in an open-cut, several hundred feet farther west. In this open-cut the lower zone occurs on the north side, the upper zone occurs on the south side, and the middle zone occurs between the two and has a horizontal width of 10 feet. The part of the dyke in the swamp apparently dips south.

The lower zone is composed chiefly of albite granite, overlain by banded albite aplite with a layer of cleavelandite rock. Small amounts of lepidolite, zinnwaldite, and spodumene occur in the aplite. The upper zone is composed chiefly of quartz-muscovite rock underlain by a narrow band of cleavelandite rock. Lithium-bearing minerals are present chiefly in the middle zone.

The outer part of the middle zone is composed chiefly of large microcline and quartz-spodumene crystals. The microcline occurs as scattered crystals up to 2 feet across chiefly in an area 75 feet long and 5 to 15 feet wide in the northeast portion of the large outcrops on the hillside south of the fault. A few quartz-spodumene crystals are associated with the microcline, but are most abundant outside of the microcline area where they are scattered or are closely packed together and make up the major portion of the outer part of the middle zone. The microcline and quartz-spodumene crystals lie in a groundmass of, or have the interstices filled with, various mixtures of quartz, cleavelandite, lepidolite, radiating lithia mica, and curvilamellar lithia mica. The two last-mentioned minerals contain only small percentages of lithia, are not abundant, and are of no economic value. These materials in some places simply fill spaces between or surround the microcline or quartz-spodumene crystals, in other places they form veinlets cutting them and, quite commonly, they form masses partly or almost completely replacing them. Other minerals noted in the outer part of the middle zone include bluish green curvilamellar lithia mica, zinnwaldite, pale lilac lithia mica, garnet, fluorite, and calcite.

The inner part of the middle zone is composed chiefly of lepidolite which is associated with cleavelandite and quartz and locally with pale lilac lithia mica, spodumene, or beryl. A chemical analysis of the pale lilac lithia mica shows that it contains only a small percentage of lithia and is of no economic value. It can be distinguished in the field from the lepidolite by its paler colour. One area from 5 to 10 feet across in the inner part is of quartz and cleavelandite with smaller amounts of spodumene, topaz, beryl, purple muscovite, montebrasite, and lithiophilite. The purple muscovite can be distinguished from lepidolite by its paler colour, transparency, and absence of lithia as shown by a blow-pipe test. The montebrasite contains a satisfactory percentage of lithia (8·20 per cent) for commercial purposes, but only a few masses up to a foot across are exposed. The presence of this mineral is interesting and further work on the property may result in finding amounts large enough to be of economic value. The topaz is generally greyish, bluish, or greenish and turbid and occurs as crystals from 1 to 5 inches in cross-section. Jacob Papish[1] succeeded in extracting 0·019 gms. of germanium dioxide from 18·3 gms. of this topaz. A very small amount of clear sky-blue topaz, probably of gem quality, was found and a search for more of this or similar material should be made. The beryl is present in only small quantity and is usually milky-white. A small amount of it is pale pink and transparent, but the crystals are considerably fractured and too pale in colour to be valuable gem material.

The minerals of chief economic interest are the spodumene of the outer part, and the lepidolite of the inner part, of the middle zone. The spodumene is intimately associated with quartz and a mixture of the two forms quartz-spodumene crystals. The crystals are tabular-shaped and usually measure from 1 foot to the side and 2 to 3 inches thick to a maximum observed size of 3 feet by 7 inches. The spodumene in these crystals is of two types, an earlier spodumene and a later spodumene. The earlier spodumene is white and forms plates ¼ to 1 inch in length lying in the quartz and oriented, for the most part, with their vertical crystallographic axes normal to the larger faces of the tablets. In a typical specimen the ratio by weight of spodumene to quartz is 55:45 and most of the material appears to have about this ratio. In some crystals the proportion of quartz to spodumene is much greater than the typical case given above. There are nowhere any masses of pure spodumene or even any with a ratio of spodumene to quartz any greater than about 50:50. The later spodumene occurs as an alteration of the earlier spodumene plates and of the associated quartz of many but not all of the quartz-spodumene crystals. In some cases the alteration is only partial and in other cases

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[1] Econ. Geol., vol. XXIV, 1929, pp. 471-472.

is almost complete. The later spodumene is a very fine-grained, white rock almost identical in appearance with aplite. Quartz remnants are usually mixed with the later spodumene and are in variable proportions, but on the average the alteration product probably contains a greater proportion of spodumene than do the unaltered quartz-spodumene crystals.

The quartz-spodumene crystals constitute the major portion of the outer part. On the hillside south of the fault the crystals, exclusive of the microcline area, occur over an exposed area of 2,700 square feet. In some parts of this area they constitute about 90 per cent of the material and in other places constitute only about 50 per cent of the material. On the average they constitute roughly 75 per cent, the remaining 25 per cent being of the interstitial and groundmass materials. In the middle of the exposure similar proportions are locally exposed over vertical thicknesses up to 9 feet. The total thickness is probably considerably greater than this, but in estimating tonnage it should be borne in mind that this part of the dyke is probably trough-shaped and accordingly that the material may not extend to any great depth. Toward the edges of the trough the thickness apparently gradually thins to zero. Similar proportions likely occur beneath exposures of the inner part of the middle zone and beneath the exposure of the upper zone and an additional area of 3,300 square feet is thus probable. Quartz-spodumene crystals constitute about 90 per cent of the material exposed in one open-cut in the swamp, but in the most westerly open-cut they constitute only about 50 per cent of the material of the outer part of the middle zone and the outer part here is only a foot or two wide. A much larger tonnage of spodumene may be present beneath the swamp which covers the major portion of the deposit and here may extend to considerable depths. A considerable tonnage of quartz-spodumene crystals is thus indicated. The crystals could readily be hand-sorted from the interstitial or groundmass material, but the spodumene of the quartz-spodumene crystals could not be separated in this way from the quartz of the quartz-spodumene crystals. No representative analysis of the quartz-spodumene rock has been made, but pure spodumene plates after careful separation from the intergrown quartz have been found to contain 6·47 per cent Li_2O. The quartz-spodumene crystals, as already stated, generally contain about 50 per cent of quartz and accordingly the Li_2O content would be about 3·2 per cent. Some of the quartz-spodumene crystals contain less, and others contain more, than 50 per cent of quartz and would accordingly contain correspondingly more or less than 3·2 per cent Li_2O. Spence[1] reports that a representative sample of "spodumene" was found to contain 4·0 per cent lithia. Wright[2] gives an analysis of a "hand-picked sample judged to represent approximately the spodumene-bearing rock after 50 per cent gangue has been removed." The analysis shows 4·76 per cent of Li_2O, but also shows considerable percentages of fluorine and phosphoric acid suggesting that the sample contained some montebrasite. Cole and Eardley-Wilmot[3] give an analysis of spodumene? (also probably a mixture of amblygonite and spodumene) showing 5·23 per cent of Li_2O. The grade of spodumene ore mined in the Black hills

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[1] "Mineral Resources and the Mining Industry, 1926"; Mines Branch, Dept. of Mines, Canada, p. 16.
[2] Geol. Surv., Canada, Sum. Rept. 1924, pt. B, p. 103.
[3] "Mineral Resources and the Mining Industry, 1925"; Mines Branch, Dept. of Mines, Canada, p. 72.

or elsewhere is not known, but analyses of the spodumene crystals mined show a lithia content varying from 4·90 per cent to 6·78 per cent and these are apparently picked clean from gangue materials. It is probable that the quartz-spodumene crystals on the Bear mineral claim are too low in lithia content to be profitably used for extraction of lithia compounds, but if some cheap method could be developed for the separation of the spodumene from the closely associated quartz a profitable extraction of lithium compounds might be possible. The quartz-spodumene rock may possibly be used to advantage in glass work in place of lepidolite.[1]

The lepidolite of the inner part of the middle zone occurs on the hillside as three large masses elongated parallel to the strike of the dyke and as one mass in the most westerly open-cut. The largest of the masses on the hillside is near the east end of the dyke. It is 75 feet long and 20 feet in maximum horizontal width. The western end of the mass is exposed on the side of a short shaft where it is seen to be flat-lying and only about 3 feet thick. It probably thins to the east. This mass is composed of lepidolite mixed with quartz and cleavelandite, but 50 to 75 per cent of it is of pure lepidolite or of lepidolite mixed with small amounts of quartz or cleavelandite in rounded and irregular-shaped areas from 6 inches or less to 3 feet across. The pure or nearly pure lepidolite rock could be hand-sorted from the other materials, but apparently only a small tonnage is available. The second largest of the masses on the hillside lies close to the swamp, has been quarried out to a considerable extent, and is mostly covered. It is apparently about 40 feet long and is exposed at one place over a width of 12 feet. Its thickness is not known. The central and main portion of the mass is of pure lepidolite or, locally, is of lepidolite mixed with small amounts of quartz, cleavelandite, and tanalite-columbite. One specimen, apparently from this mass, is a fine-grained mixture of lepidolite, spodumene, and quartz. Near the north edge of the mass the lepidolite is intimately mixed with considerable quantities of cleavelandite and quartz. At its southern edge the pure lepidolite grades into a mass of pale lilac lithia mica which has only a low content of lithia. Most of the lepidolite ore which has been shipped from the deposit has been obtained from this mass, but apparently a considerable tonnage still remains. The third mass on the hillside lies between the two just described. It measures 18 feet by 11 feet on a horizontal plane. At its west end it is exposed on the face of a quarry where it is seen to be flat-lying and only about 2 feet thick. It is composed chiefly of pure lepidolite, but some of it is of lepidolite intimately mixed with small amounts of quartz and cleavelandite. Apparently only a small tonnage is available. The mass in the most westerly open-cut in the swamp is 6½ feet wide. It is composed chiefly of an intimate mixture of lepidolite and cleavelandite in approximately equal amounts. Within the middle part of this mixture and grading into it are a few masses of pure lepidolite measuring up to 1 foot by 3 feet. Here the dyke apparently dips south and the lepidolite-bearing rock probably continues to a considerable depth. A much larger tonnage of lepidolite may be present beneath the swamp which covers the major portion of the

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[1] Spence, H. S.: "Investigations of Mineral Resources and the Mining Industry, 1926"; Mines Branch, Dept. of Mines, Canada, p. 16.

deposit. An analysis of pure lepidolite from the deposit shows the following percentages of various constituents: Li_2O, 3·39; Fe_2O_3, 0·24; MnO, 0·90; Cs_2O, 0·21; F_2, 4·30. Rubidium and germanium are also present. Much of the lepidolite rock is pure or almost pure and may be expected to have about this composition. When lepidolite is mixed with cleavelandite or quartz the percentage of its constitutents as given above would be proportionately decreased. Several analyses of lepidolite ore have been made with the following results:

—	I	II	III	IV	V	VI
Li_2O	3·87	3·98	4·02	2·9	3·5	
Fe_2O_3	0·10	0·64	....	0·3	0·4	0·25
Iron oxide	....	....	....	....	....	
Manganese	....	....	....	0·3	0·9	0·5
Fluorine	4·10	....	4·21	3·6	3·1	
AlF_3	....	8·40	....	....	....	

I. "Sample of compact crystalline lepidolite. M. F. Connor, analyst." Wright, J. F.: Geol. Surv., Canada, Sum. Rept. 1024, pt. B, p. 103.

II. "Analysis, furnished by Silver Leaf Syndicate, of lepidolite. Analysis by Daniel C. Griffith and Co., London, England." Cole, L. H., and Eardley-Wilmot, V. L.: "Investigations of Mineral Resources and the Mining Industry, 1925"; Mines Branch, Dept. of Mines, Canada, p. 72.

III. "General sample of lepidolite mineral from the deposit. E. A. Thompson, analyst, Mines Branch, Ottawa." Cole and Eardley-Wilmot: Op. cit., p. 72.

IV. "Run of mine, lepidolite ore, Silver Leaf mine. Analysis furnished by Corning Glass Works, Corning, N.Y." Spence, H. S.: "Investigations of Mineral Resources and the Mining Industry, 1926"; Mines Branch, Dept. of Mines, Canada, p. 16.

V. "Run of mine, lepidolite ore, Silver Leaf mine. Analysis by E. A. Thompson and A. Sadler, Mines Branch." Spence, H. S.: Op. cit., p. 16.

VI. Spence, H. S.: Op. cit., p. 16.

The lithia content of the lepidolite compares favourably with the lithia content of lepidolites from California[1] and New Mexico[2] and the fluorine content is generally higher so far as known. The iron and manganese content is rather high, however, which may make the lepidolite objectionable for use in glass-making.[3] Should the lepidolite be used for extraction of lithia compounds the cæsium, rubidium, and germanium which it contains may possibly be valuable by-products, but it is doubtful if lithia compounds could be profitably extracted from material with such a low lithia content.

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[1] Schaller, W. T.: U.S.G.S. Mineral Resources of the United States, pt. 2, 1916, p. 12.

[2] Roos, Alford: Eng. and Min. Jour., vol. 121, pp. 1037-1042 (1926).

[3] Spence, H. S.: Op. cit., p. 16.
Myers, W. M.: U. S. Bureau of Mines, Information Circular 6206, p. 31, states that the iron content should not exceed 0·05 per cent of ferric oxide.

The following information regarding various minerals occurring in the deposit has been taken from a manuscript article by E. Poitevin, R.J.C.Fabry, and C.H.Stockwell. The minerals described were collected chiefly by J.F.Wright, C.H.Stockwell, H.S. Spence and H.D.Cole but material had been accumulating since 1923 when specimens from the district were first sent in for identification.

Spodumene. Occurs as greyish to white cleavable masses. Carefully selected mineral freed from impurities as much as possible, has been analysed (for analysis, see page..).

The spodumene is low in iron and manganese, fairly high in lithium oxide, and unusually fresh. It would appear, therefore, tobe the most valuable lithium mineral present in the deposit, as well as being the most abundant.

Amblygonite. (var Montebrasite) .This mineral, occurring in greyish white masses with polysynthetic twinning, was at first mistaken for feldspar. The indices of refraction $\alpha = 1,600, \beta = 1,611, \gamma = 1.620$ (E.Poitevin) are higher than normal amblygonite and correspond to the variety montebrasite.

For analyses of the pure material, see page......

MICAS

Several varieties of mica occur in the deposit. Besides the true lepidolite there are other varieties more or less resembling the lepidolite in appearance, but which contain very little lithium.This would indicate that it may be necessary to exercise caution in selecting the lepidolite for ore purposes if the lithium content is to be kept as high as possible.

Lepidolite. The typical lepidolite occurs as a massive, deep lilac-coloured rock composed almost entirely of small scales less than one-quarter inch in diameter, the majority being scarcely more than one-sixteenth inch in diameter. For an analyses of purified flakes (see page...

Curved Muscovite. This peculiar mica is characterized by curved faces, being sometimes almost hemispherical about the C axis. The structure may be called curvilaminar. There are two colour varieties: one is silvery or pearly grey, the other is faint lilac. It occurs as nodules, sometimes several inches in diameter, in pinkish albite. The indices of refraction, =1.555, = 1.592, = 1.596, 2V =38, agree with those commonly given for muscovite. The laminae, however, are brittle and it is not so easily cleavable as ordinary muscovite. It is fusible only with difficulty and in thin splinters before the blowpipe, agreeing in this respect with normal muscovite. For an analyses of the grey variety from the Annie mining claim, see page....

Except in colour the lilac variety resembles in physical appearance the grey variety. However, it differs a good deal in chemical composition and in its refractive indices. The indices of refraction are =1.542, =1.571, =1.573, 2V =40 degrees. For an analysis of the pink variety, see page .....

Muscovite (light lilac). This forms a massive rock composed of minute scales mostly one millimetre or less in diameter and is distinguishable from the lepidolite only by its lighter colour and finer grain size. It is much like the fine-grained, light-coloured lepidolite from Pala, San Diego, California. Although it resembles lepidolite in appearance, it contains very little lithium and the refractive indices, chemical composition, and fusibility seem to indicate that it is more nearly related to muscovite. In the blowpipe flame on charcoal a small fragment expands to several times its original volume, turns white, and sinters more or less but does not melt down to a glassy globule, whereas a fragment of lepidolite of equal size fuses easily with intumescence to a vesicular glassy globule. Indices of refraction, $\alpha = 1.555$, $\beta = 1.588$, $\gamma = 1.595$, $2V = 46$ degrees. A chemical analysis of pure flakes is given on page..

Drab-coloured Radiating Mica (Low Lithium Lepidolite?). This mica occurs as veinlets an inch or more in width in albite and as borders surrounding large spodumene crystals between the spodumene and the enclosing albite.[1] The mica has a radiating, narrow fan-shaped structure normal to the vein walls, and cleavage surfaces show a fine, radiating wrinkling parallel to the long direction of the fans. In any given specimen the points of all the fans appear to originate from one wall only. The mica, also, sometimes occurs as rosettes with fine wrinkling radiating from the centres. The colour is a purplish silvery grey. When ground this mica has exactly the same colour as the ground

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[1] Spence, H.S.: Personal communication.

lepidolite. The mineral fuses somewhat more difficulty than the lepidolite and without intumescence to a white opaque glass at about 3. The indices are = 1.533, =1.578, = 1.581, 2V =41 degrees. An analysis of pure flakes is given on page ... The analysis shows that this mica is unusually low in lithia for lepidolite and rather high in manganese. Nevertheless it appears to be more nearly related to lepidolite than to muscovite or zinnwaldite.

Lithiophillite. This mineral occurs as compact cleavable masses varying in colour from salmon to orange, and as a rule is very fresh, but sometimes the surrounding feldspar shows dark stains of manganese oxide derived from alteration of the lithiophillite. An analysis of the mineral is given on page .....

Beryl. A few small crystals of milky white, greenish to colourless, transparent beryl have been found in the dyke, but this mineral is not abundant. The largest individuals were about 6 inches long. Very few crystals are terminated.An analysis of the greenish beryl is given on page.....

Topaz. Crude, long, pyramidal crystals and crystalline masses of topaz as much as 3 inches or more in diameter and a foot or more long have been collected in some quantity by H.S.Spence, who states, however, that the mineral is localized and is not really abundant. This topaz is whitish or faintly blue-green in colour and shows well-developed basal cleavages. Prof. J.Papish[1] of Cornell University has

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[1] Occurrence of Germanium in Topaz;Science, Oct. 12, 1928.

examined this topaz, as well as many others, spectroscopically and has discovered that the very rare element germanium is present in small amounts in this material as also in all of the topaz from 27 different localities examined by him. Although the crystals of topaz appear to be quite fresh, they are without doubt somewhat altered at their periphery.

Optical Properties: Biaxial positive, indices =1.614, =1.617, =1.624, - =0.010, 2V =63°30'. An analysis of carefully selected material is given on page .....

Columbite-tantalite. A few small masses an inch or so in diameter have been found.

Cassiterite. A few small grains and one or two masses the size of a fist have been found.

Tourmaline of a blue colour, spessarite and apatite have been collected by C.H.Stockwell.

Reference: Stockwell, C.H.: Geol.Surv.,Canada, "Lithium Deposits in Memoir 169,Geology and Mineral Deposits of a part of southeastern Manitoba, by J.F.Wright (1932).

Reference: Stockwell, C.H.: Geol. Surv. Canada, " Lithium Deposits", in Memoir ..., Geology and Mineral Deposits of a part of southeastern Manitoba, by J.F.Wright (1932).

ANNIE MINERAL CLAIM

The lithium-bearing body on the Annie mineral claim is in rocks of the albite granite group $\frac{3}{8}$ of a mile northeast of the dyke on the Bear claim. On the Annie claim lithium-bearing pegmatite mixed with granite and aplite occurs chiefly over an area measuring 50 feet across and was also observed easterly of this locality at distances of 60 and 300 feet. The lithium-bearing pegmatite contains scattered flakes of lilac lithia mica, lilac curvilamellar lithia mica, and grey curvilamellar lithia mica. A small amount of beryl occurs in crystals up to 1 inch across. The grey, curvilamellar, lithia mica contains only 0·90 per cent of lithia. The deposit is of no economic value.

GRAY MINERAL CLAIM

The lithium-bearing body on the Gray mineral claim is in rocks of the albite granite group $\frac{1}{4}$ of a mile northwest of the dyke on the Bear claim. On the Gray claim a small amount of grey curvilamellar lithia mica similar to that on the Annie claim is scattered through pegmatite and aplite over an area measuring 75 feet by 50 feet. A small amount of beryl is also present. The deposit is of no economic value.

CAPTAIN GROUP OF CLAIMS

The lithium-bearing body on the Captain group of claims is a dyke cutting rocks of the oligoclase granite group in the southern portion of sec. 14, tp. 16, range 16, 3 miles slightly south of east of the dyke on the Bear mineral claim. The deposit may be reached from Winnipeg river by a trail about a mile long. The dyke strikes north 20 degrees east, dips 35 degrees to the southeast, and is exposed for 200 feet along the strike. At its southwest end it is 24 feet wide and at its northeast end is 3 feet wide. Scattered flakes of lepidolite occur in small amount in the middle of the southwest portion of the dyke. A small amount of beryl is also present. The deposit is of no economic value.

BERNIC LAKE DEPOSITS

Nine lithium-bearing dykes occur over an area 500 feet wide and 3,000 feet long near the east end of Bernic lake. The deposits may be most easily reached from Lac du Bonnet, Man., by canoe along Oiseau river at Bernic lake, a distance of 36 miles. An ungraded road 4 miles long extends southward from the south shore of Bernic lake, 3 miles from the east end of the lake, to Winnipeg river about 2 miles west of Lamprey falls. From the end of the road on Winnipeg river it is 5 miles along the river to Pointe du Bois, Manitoba.

Two claims, the Buck and the Coe, were staked by K. E. Miller in 1926, the former on May 10 and the latter on July 9, and a third, the Brillant mineral claim, was staked on July 10 of the same year by P. Osis. The deposits have been prospected to a limited extent by stripping operations, small open-cuts, and trenches. The dykes have intruded volcanics which contain a few narrow belts of sediments. Dykes Nos. 1, 2, and 4 are fairly large and the others are small.

Dyke No. 1 is well exposed on the southern face of a small cliff into which it dips at an angle of 20 to 30 degrees. It is exposed along the strike, which is northeasterly for a length of 120 feet and at its eastern end is covered by a swamp which continues along the base of the cliff and covers the foot-wall of the dyke so that its thickness is unknown. The thickest exposed portion, measured normal to the dip, is about 15 feet. A zone 1 to 4 feet thick, extending along the hanging-wall of the dyke for a distance of 75 feet from the east end of the exposure, is composed, in its upper part, chiefly of large, black, tourmaline crystals mixed with albite and in its lower part is chiefly a coarse, granitic mixture of albite, quartz, and muscovite. The west end of the dyke over a length of 35 feet is chiefly of large microcline crystals. Albite aplite occurs in small amount in association with the microcline and also occurs along the lowest exposed portion of the dyke midway along its length. Lithium minerals occur in a middle zone, lying beneath the hanging-wall zone. The middle zone has a maximum exposed thickness of 7 feet and for the most part its thickness is unknown, for it is partly covered by swamp. The lithium minerals present are spodumene and montebrasite. The spodumene is intimately mixed with quartz, the mixture forming quartz-spodumene crystals generally from 6 inches to a foot long and about half as wide. Only twelve such crystals were noted distributed over a distance of 50 feet along the strike of the zone. Only three rounded masses of montebrasite from 6 inches to 1 foot across were noted. Both the quartz-spodumene crystals and the montebrasite masses lie in quartz which constitutes the major portion of the middle zone. Near the top of the dyke at its west end a quartz area measuring 6 feet by 3 feet contains fifteen or twenty scattered beryl crystals from 2 to 10 inches in basal section. A few crystals of beryl from 1 inch or less to 8 inches in basal section are scattered through the quartz of the middle zone, and a few an inch across occur in the coarse, granitic material of the hanging-wall zone.

Dyke No. 2 strikes north and has been traced intermittently along the strike for 220 feet. It is exposed on a cliff face across its southern end where it has a horizontal width of 45 feet. Here it dips 25 degrees to the east at its east side and is apparently horizontal at its west side. The maximum exposed thickness normal to the dip is about 9 feet. The easterly dipping hanging-wall of the dyke is well exposed on a dip slope for a distance of 150 feet from the south end. Midway along the strike the dyke outcrops in a few, small, natural exposures and is exposed in some trenches over a length of 45 feet and a width of about 25 feet. At the north end it is exposed on a low cliff face into which it dips at an angle of 55 degrees to the east. A hanging-wall zone of the dyke is about 3 feet thick and is composed chiefly of tourmaline and albite in its upper part and of a coarse, granitic mixture of quartz, albite, and muscovite in its lower part. Nowhere is the foot-wall of the dyke exposed, but in the most westerly part of the trenches, apparently close to the foot-wall, the pegmatite, across a width of 10 feet, is composed chiefly of large microcline crystals. Lithium minerals are exposed chiefly in the trenches over a length of 45 feet and a width of 4 to 6 feet between the hanging-wall zone and the microcline. Here, the lithium minerals are spodumene and montebrasite. The spodumene is intimately mixed with quartz, the mixture forming spodumene-quartz crystals about 1 foot across and constituting about 60 per cent of the area in the trenches. The montebrasite forms masses 1 to 2 feet across and constitutes about 10 per cent of the area. The remaining 30 per cent of the area is chiefly of quartz. Lithium minerals are also exposed on the cliff face at the south end of the dyke west of the hanging-wall zone. Here, a few scattered flakes of lepidolite are scattered through cleavelandite and two or three masses of montebrasite up to a foot across occur in a large, open cavity. Beryl forms a few, small crystals in the trenches in association with the lithium minerals.

Dyke No. 4 strikes slightly north of east. Its south wall dips vertically and its north wall is not exposed. At its east end the dyke is in irregular contact with broken blocks of the country rock, holds a few inclusions of the country rock, and breaks up sending many small branch dykes into the country rock. Near the east end the dyke is well exposed on a flat surface for a length along the south wall of 7 feet and over a width of 9 feet. At a distance of 20 feet to the west of this exposure the dyke has been uncovered in a cross trench over a width of 20 feet. At a distance of 30 feet farther to the west a small open-cut on the strike of the dyke shows country rock cut by small pegmatite stringers. A band of quartz-muscovite rock 1 inch to 1 foot wide lies along the south wall and a narrow band of granitic pegmatite occurs along the east end. The flat surface near the east end of the dyke covers about 50 square feet and is composed almost entirely of closely packed quartz-spodumene crystals mostly from 1 to 2 feet long and with a maximum observed size of 2½ feet by 10 inches. Over a width of 19 feet in the trench the dyke is composed chiefly of a coarse-grained mixture of quartz-spodumene crystals, quartz, and a small amount of montebrasite.

In dykes Nos. 3, 5, 6, and 7 a few scattered masses of montebrasite lie in quartz. They are generally 6 inches to a foot across, but in dyke No. 7 one mass is 3 feet across. In dykes Nos. 3, 6, 8, and 9 there are small amounts of spodumene. In dyke No. 3 there is a 1-foot mass of massive lepidolite similar to the lepidolite on the Bear mineral claim. In dykes Nos. 3, 5, and 7 there are a few scattered beryl crystals, the largest of which is 6 inches in basal section.

Of chief economic interest in the Bernic Lake deposits are spodumene, montebrasite, and beryl. The spodumene is intimately intergrown with quartz, the mixture forming quartz-spodumene crystals similar to those on the Bear mineral claim and only about half spodumene. The quartz-spodumene crystals could be hand-sorted from other materials where necessary, but the spodumene could not be separated by this means from the intergrown quartz. Unless some cheap method of bringing about this separation is developed the spodumene is probably of too low a grade to be profitably used for the extraction of lithium compounds and even if such a method were developed a considerably larger tonnage would have to be proved before mining could be considered advisable. No analyses of the montebrasite have been made, but it is similar to that on the Bear mineral claim which is of commercial grade. There is more montebrasite in the Bernic Lake deposits than anywhere else in Canada as far as known. An

Reference: Stockwell, C.H.: Geol.Surv.,Canada, " Lithium Deposits" in Memoir ....,Geology and Mineral Deposits of a part of southeastern Manitoba, by J.F.Wright (1932)

amount large enough to warrant mining operations has not yet been proved, but the indications are encouraging enough to make a further search worth while. The beryl of the deposits is generally slightly turbid, but is transparent and all the crystals are minutely fractured. They are colourless to very pale sea green and pale yellowish, but the pale colouring and fracturing makes the material of no value as gem stone. The quantity, as indicated at present, is not large enough to be profitably mined for other purposes. The beryllium content (12·74 per cent BeO) of a specimen from dyke No. 1 is sufficient, however, for commercial purposes.

CAT LAKE DEPOSITS

Cat lake is in the central part of township 19, range 15, 12 miles north of the Bernic Lake deposits. At the time of the writer's visit it was rather difficult to reach. The first part of the trip was made by motor boat from Lac du Bonnet, Manitoba, to Peterson's farm on Oiseau river, a distance of 22 miles. From there a trail, about 13 miles long, was followed to a small cabin at the southern end of a lake in the northeast corner of township 18, range 14, supplies being taken in by horse and buckboard which were hired locally. The remainder of the journey is by way of a little travelled route, 6 to 8 miles long, over a chain of small lakes and long portages without well-defined trails. Dug-out canoes and boats were available on the lakes, but it would be preferable to take along a small, light-weight canoe. Five lithium-bearing dykes are present in the vicinity of the lake. They cut granodiorite and volcanics. One of the dykes, on the Irgan mineral claim, is about 1,500 feet north of the lake and another, on the Cat Lake mineral claim, is 1,000 feet south of the lake. Two are in an area of volcanics 500 feet south of the lake and ½ mile east of the dyke on the Cat Lake claim. The fifth is north of the lake and 1,400 feet slightly east of south of the east end of the dyke on the Irgan claim.

The dyke on the Irgan claim is well exposed on a glaciated surface. The dyke strikes north 80 degrees west and dips 87 degrees to the south. At its east end it is about 40 feet wide and strikes into a swamp. Toward the west it widens to a maximum width of 60 feet at a point 200 feet from the east end. Farther west it gradually narrows and, finally, apparently pinches out. Its total exposed length is 1,450 feet and its average thickness is about 20 feet.

Near the middle of its widest part over an area measuring 45 feet along the strike and 12 feet wide, the dyke is composed of large microcline crystals, from 6 inches to 2 feet along their edges, lying in a finer grained groundmass of a mixture of quartz and spodumene. The spodumene is in crystals usually about ¼ inch or less in length and diversely oriented in the quartz. The two minerals are present in about equal proportions. The microcline crystals constitute about one-third and the quartz-spodumene mixture about two-thirds of the area. The quartz spodumene mixture could be hand-sorted from the microcline, but the spodumene could not be separated from the quartz by this means. Elsewhere the dyke has a well-developed, banded structure parallel to the strike of the dyke. The banding is due chiefly to an alternation of bands or long lenses of

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spodumene-quartz mixture, with bands of coarse, granitic rock or albite aplite. The lenses vary from small ones 1 foot long and 1 inch to 6 inches wide to large ones 10 feet long and 6 inches wide. The bands vary in width from 1 inch to 2 feet. The coarse, granitic rock is composed of a mixture of albite, microcline, muscovite, and quartz with accessory garnet and apatite and is estimated to constitute over half of the dyke material. The albite aplite is much less abundant than the granitic rock. The spodumene of the spodumene-quartz mixture forms plates usually less than ¼ inch long and with a maximum observed length of 1 inch. They are usually diversely oriented in the quartz and constitute about one-half of the mixture.

A rough estimate in the field indicates that, across the strike of different parts of the dyke, the quantity of quartz-spodumene rock varies from 20 per cent to 50 per cent of the whole and the richest portion is estimated to contain 70 per cent of the quartz-spodumene rock over an area of about 500 square feet. Similar percentages are likely to continue to a great depth. It has been calculated that there are about 50,000 tons of quartz-spodumene rock or about 25,000 tons of spodumene in each 100 feet of depth. About half of this tonnage of spodumene is in rock composed of from about 15 per cent to about 30 per cent spodumene and about half is in rock composed of about 10 per cent spodumene. In the part of the dyke composed of large, microcline crystals in a ground of quartz-spodumene rock, the quartz-spodumene rock could be hand-sorted from the microcline, and in some parts of the banded part of the dyke the quartz-spodumene rock could be hand-sorted from the granitic material and aplite and a product of about 50 per cent spodumene obtained. In most of the dyke, however, the quartz-spodumene rock could not be separated from the granitic material and aplite by this means. All the spodumene is so intimately mixed with quartz that the two could not be separated by hand-picking.

The dyke on the Cat Lake claim is exposed along the face of a cliff into which it dips to the southwest at angles varying from 13 degrees to 25 degrees. It strikes north 25 degrees west and has been traced along the strike for 200 feet. It is covered by swamp at the southeast end and apparently breaks up at the northwest end. The hanging-wall contact with country rock is well exposed, but the foot-wall contact is covered. The maximum exposed thickness measured normal to the dip is about 15 feet. Albite granite forms a band from 1 to 2 inches thick along the hanging-wall contact and is underlain by a band of quartz-muscovite rock from 1 to 3 inches thick. A few beryl crystals occur in the quartz-muscovite rock. A band of albite aplite 3 to 5 feet thick constitutes the lowest exposed portion of the dyke. A lithium-bearing zone 10 feet thick occurs along the middle of the dyke and is exposed for a length of 160 feet along the strike. It is composed of large microcline crystals scattered through a groundmass of albite aplite and quartz-spodumene rock. The spodumene of the quartz-spodumene rock is in plates averaging from 1 to 2 inches long, which have a maximum observed size of 1 foot by 6 inches by ½ inch. They generally lie with diverse orientations in the quartz and constitute about half of the quartz-spodumene rock.

Reference: Stockwell, C.H.: Geol. Surv., Canada, "Lithium Deposits" in Memoir ..., Geology and Mineral Deposits of a part of southeastern Manitoba by J.F.Wright (1932)

The percentage of quartz-spodumene rock varies greatly in different parts of the dyke. Rough estimates in the field indicate that, in some sections across the strike of the lithium-bearing zone of the dyke, the quartz-spodumene rock forms as much as 75 per cent of the whole. In other sections it forms only about 5 per cent of the whole. On the average the lithium-bearing zone consists of approximately 50 per cent quartz-spodumene rock, most of which could be hand-picked from the associated microcline and aplite. The spodumene could not be separated from the quartz-spodumene rock by this means.

Unless some cheap method of concentration of the spodumene on the Irgan and Cat Lake claims is developed the spodumene is too low grade, taking transportation and other factors into consideration, to be profitably used for the extraction of lithium compounds, and even if such a method were developed it is improbable that these deposits could be mined profitably under present conditions.

The three other dykes at Cat lake contain only small amounts of spodumene or beryl and are of no economic value.

WEST HAWK LAKE DEPOSITS

Of the three lithium-bearing dykes in the West Hawk Lake district, the largest is on the Deer mineral claim in the centre of sec. 16, tp. 19, range 17, 1,000 feet from the southwest shore of West Hawk lake. The two other dykes are small. One is 4,400 feet north 25 degrees west of the dyke on the Deer claim and the other is 1,200 feet south 30 degrees east of the same dyke. All three cut volcanics. West Hawk lake is easily reached from Ingolf, Ontario, on the Canadian Pacific railway. Ingolf is on Longpine lake and a portage trail, 44 chains long, leads from the west end of Longpine lake to West Hawk lake.

The dyke on the Deer mineral claim strikes north 30 degrees west and is exposed by natural exposures, stripping, and open-cuts at two localities, a southeast locality and a northwest locality. At the southeast locality it dips 75 degrees to the southwest and varies from 5 to 10 feet in thickness. At the northwest locality it varies from 2 to 8 feet wide, is in irregular contact with the country rock, sends a branch dyke into the country rock, and holds a large inclusion of the country rock. The length of the dyke, as indicated by the two exposures, is 260 feet. The dyke is composed chiefly of an intimate mixture of quartz, albite, lepidolite, and spodumene. A few small crystals of pink tourmaline are also present. They are somewhat turbid and are not of gem quality. The deposit is of no ecomonic value at the present time.

The two other dykes are only from 6 inches to 1 foot wide. They are composed of albite and quartz with a small amount of lepidolite and, in one of them, a small amount of pink tourmaline which is not of gem quality. The dykes are of no economic value.

Reference: Stockwell, C.H.: Geol. Surv., Canada, "Beryllium Deposits" in Memoir ...., Geology and Mineral Deposits of a part of southeastern Manitoba, by J.F.Wright (1932).

BERYLLIUM DEPOSITS

By C. H. Stockwell

A description and an account of the economic possibilities of beryl which occurs in lithium-bearing bodies has already been given. In lithium-bearing bodies it is most abundantly present in the Bernic Lake deposits, but also occurs in the Cat Lake deposits and on the Bear, Annie, and Gray mineral claims and on the Captain group of claims.

Beryl was also noted by the writer in eleven non-lithium-bearing bodies. Three of these are at Cat lake and consist chiefly of albite aplite in which are patches of quartz-muscovite rock. A few beryl crystals up to 1 inch in basal section are scattered through portions of each type of rock. On the Captain group of claims a dyke striking parallel to the lithium-bearing dyke is composed chiefly of microcline, but portions are of albite pegmatite which contains a few small beryl crystals and one large, milky white beryl crystal measuring 8 inches in basal section. Another dyke ¼ of a mile northeast of the lithium-bearing dyke on the Captain group of claims is composed chiefly of albite aplite, microcline pegmatite, and quartz-muscovite rock. Both the aplite and the microcline pegmatite contain pockets of quartz. Yellowish green beryl crystals up to 2 inches in basal section occur in some of the quartz pockets, but are chiefly present in the aplite close to quartz pockets. The beryl crystals are numerous over a length of 50 feet along the strike of the dyke; in one place fifteen beryl crystals were counted in an area of 1 square foot. Much smaller amounts of beryl were noted in a dyke 2 miles southwest of the Captain group of claims. On the south shore of Winnipeg river 3 miles east of Lamprey falls an albite pegmatite dyke contains a few green beryl crystals, about an inch in basal section, scattered through quartz-rich parts of the dyke. Two microcline pegmatite dykes in the northeast and northwest corners, respectively, of sec. 1, tp. 15, range 15, 6 miles slightly north of east from Pointe du Bois, Manitoba, contain a few small crystals of beryl. In Ontario, a few similar crystals were noted in a large pegmatite dyke cutting volcanics on the east shore of English river 2 miles northwest of Separation rapids and in a small dyke cutting sediments 3 miles west of Oneman lake. In none of these deposits is the beryl of gem quality, nor is it present in large enough quantity to be profitably mined for other purposes.

The outstanding discovery of beryl in the region is in a pegmatite dyke on the Huron claim[1] owned by the Winnipeg River Tin Company. This claim is about a half-mile inland from a point on the southeast shore of Winnipeg river, 9 or 10 miles above Pointe du Bois and in the immediate vicinity of the lithium-bearing dyke on the Bear mineral claim. The deposit has not been visited by the writer, but is described by J. S. DeLury[2] as follows:

> "The pegmatite outcrops on the vertical face of small cliffs of andesite on either side of a narrow swamp. The attitude of the pegmatite, wherever seen, strongly suggests an anticlinal structure. On either side of the swamp the pegmatite dips away at low angles.

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[2] "Beryl in Manitoba"; Can. Min. Jour., vol. LI, 1930, p. 1017.

[1] See also further accounts, page "Huron claims".

> The main constituent of the dyke is coarse feldspar. It is present in massive form with little or no quartz except in two or three places where masses of quartz resembling veins occupy thicknesses of 2 to 7 feet. In the trenches quartz is seen to be associated with beryl and the two appear to be in about equal quantity. Beryl is conspicuous in two places, one on either side of the swamp. On the north side beryl is exposed over a width of 15 feet. It occurs here in distinct crystals and crystalline masses. The more irregular masses have been fractured and the fractures are filled with veinlets of feldspar. The beryl is both green and golden in colour.
>
> Across the swamp about 140 feet away is the other conspicuous beryl showing. The beryl is similar but less massive and with more good crystal outlines apparent. The mineral is closely associated with feldspar and quartz. The zone carrying beryl is about 20 feet wide and the richer portion with more massive beryl is 8 feet wide. Much of the beryl shows distinct alteration. Other interesting mineral occurrences in the same workings are tantalite, monazite, and pitch blende."

The same author in the same report mentions other beryl occurrences in the district as follows:

> "The Winnipeg River Tin Company also has a pegmatite on the Annie claim (north of Huron) showing a small concentration of beryl, cassiterite, and lepidolite. The same company, on the Top of the World claim about ½ mile southeast of Greer lake, has a wide dyke of pegmatite showing zones of different composition more or less parallel to the walls. In one zone about 3 feet wide, small and well-formed beryl crystals are conspicuous. Other zones show less beryl and some of them lepidolite, the lithium mica.
>
> Another interesting occurrence of beryl on the south side of Winnipeg river should be mentioned. At the water's edge on a claim about 9 miles above Pointe du Bois and owned by F. B. Evans, a pegmatite outcrops for a length of 60 feet along the shore. A 12-foot width is exposed in one place. Besides the usual minerals of pegmatites, this one shows rose-tinted and opalescent quartz and green and colourless beryl crystals. Some of the beryl is fairly transparent and in pleasing tints and has been used in a small way for gem material.
>
> Beryl in small crystals and veinlets is also reported from a number of pegmatites near the shore of Winnipeg river, on the south side about 2½ miles above Pointe du Bois and on the north side 1½ and 4 miles above that place."

Other deposits of beryl occur at Shatford lake, at several places near Bernic lake, and at other localities. Regarding the deposits, J. F. Wright contributes the following account. "By hand-sorting perhaps several tons of beryllium ore could be mined from these pegmatites, but probably it would not be profitable to undertake to quarry and to market the beryl unless larger and higher grade deposits are found nearby". Regarding the economic possibilities of the deposits in Manitoba, DeLury says: "A great deal must be done still to prove that large tonnages of beryl can be shipped from Manitoba, but there is one deposit at least, and perhaps several more to be proved or found, that give high hopes that the province may be a producer when the time arrives for a large consumption of the metal beryllium."

Two beryl occurrences are in pegmatitic bodies on a point on the south shore of Shatford lake, 3,500 feet from the east end of the lake. These pegmatites are controlled by Manitoba Tin Company, Limited. A prospect pit in one pegmatite mass exposed an area 2½ feet across carrying beryl crystals up to 24 inches long. In a nearby pegmatite, small beryl crystals are estimated to form half the area exposed in a pit 2 feet deep, 3 feet long, and 2 feet wide. Pink soda feldspar, white muscovite, and quartz are the only minerals noted with the beryl in the pegmatite. In June, 1929,

in single

sufficient work had not yet been done on these pegmatite bodies to determine the size of the beryl-bearing deposits that might be present, but apparently the beryl is localized within erratically distributed pockets.

Crystals of beryl are also present in the pegmatites opened up by Jack Nutt Mines, Limited, on the north shore of Bernic lake, and in the pegmatite in the Rush group. At these localities, however, beryl forms only a minor constituent of the pegmatite. A few tons of beryl perhaps could be obtained from the deposits south of Shatford lake.

FUCHSITE-BEARING ROCK SUITABLE FOR STUCCO MATERIAL

By C. H. Stockwell

Fuchsite (chromium mica) occurs in quartzite on the Vernon mineral claim in the southwest part of section 13, township 16, range 15. A road, ¾ mile long, has been constructed from the property to a point on Winnipeg river 1 mile south of Lamprey falls. From the end of the road it is 6½ miles southwest along the river to Pointe du Bois where railway connexions are made. In 1926 the Silver Leaf Mining Syndicate mined about 150 tons of fuchsite-bearing rock and shipped it to Winnipeg for use as stucco dash.[1]

The fuchsite is in a narrow band of quartzite that strikes east and dips at an angle of 70 degrees to the north. The quartzite is bordered on its south side by grey oligoclase granite and on its north side by basaltic lava. The deposit is exposed on the side of a hill in an open-cut about 20 feet wide and extending 50 feet along the strike. The quartzite is locally known as pearl rock. Pale green pearl rock composed chiefly of quartz with a few disseminated flakes of fuchsite occurs as a bed 3 feet wide along the middle of the open-cut. This bed is bordered on its south side by grey pearl rock and on its north side by white pearl rock containing a few narrow layers of fuchsite. In the bed of pale green pearl rock are about half a dozen lenses of fuchsite rock measuring up to 3 feet by 1 foot. The fuchsite rock has a bright green colour, is schistose, and is composed chiefly of fuchsite with small amounts of quartz and a black opaque mineral in microscopic grains. A larger proportion of fuchsite rock is said to have been present in the material mined. The fuchsite rock and pearl rock are cut by a few dykes and stringers of pegmatite. Analyses of "fuchsite ore" and of "a hard, green, compact material," probably the pearl rock, are given by Spence in the article referred to above. The fuchsite has probably been formed by metamorphism of original constituents of the quartzite. The pearl rock is exposed at intervals over a distance of 800 feet along the strike to the east. Over this distance the bedrock is largely covered and no fuchsite-bearing rock was seen, but it may be present.

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[1] Spence, Hugh S.: "Investigation of the Mineral Resources and the Mining Industry, 1926"; Mines Branch, Dept. of Mines, Ottawa. p. 18.

HURON CLAIM, OISEAU RIVER AREA

Reference: DeLury, J.S. "Beryl in Manitoba". Can.Min. Jour., vol.LI, 1930, p. 1017.

DeLury, J.S. and Ellsworth, H.V.: Uraninite from the Huron claim, Winnipeg River Area, S.E.Manitoba: The Amer Mineralogist, vol.16, No.12, pp. 569-575, (1931).

Walker, T.L.: Contributions to Canadian Mineralogy, 1931, pp. 9-13.

The Huron claim is about a half mile inland from a point on the southeast shore of Winnipeg river, 9 or 10 miles above Pointe du Bois. The claim is one of a large group of claims staked by the Winnipeg River Tin Company.

Uraninite was discovered during the summer of 1930 in a pegmatite body on the Huron claim. The pegmatite lies in andesite schist about 1500 feet south of an intrusive body of granite. There are 7 or 8 outcrops of the pegmatite in a depression largely filled with drift. Contacts of pegmatite and schist are exposed on either side of the depression.

In two or three outcrops of the pegmatite, notable segregation of beryl were encountered. Further work lead to the finding of columbite-tantalite and, finally, of monazite and uraninite in one of the outcrops. The most prominent mineral in the pegmatite is a reddish feldspar. Quartz is also abundant and tends to occur in more or less p pure masses. Beryl is prominent and is associated with both quartz and feldspar (see further description, on page...). In the one outcrop which so far has yielded uraninite, this mineral together with monazite and columbite occurs as crystals and grains embedded in feldspar. Monazite is more abundant than uraninite.

In addition to the minerals just mentioned T.L.Walker (loc.cit.) has recently described topaz and triphyllite from the Huron pegmatite or other nearby dykes. Analyses of triphyllite and columbite given by Walker are quoted on page .....

The uraninite in the specimens of the pegmatite received for examination and analysis, occurs in small crystals of cubic habit from one-eight to one quarter inch diameter embedded in feldspar. Some of the crystals were hard, greyish steely black, and had an uneven fracture. Others were more altered, some to the pitch-black stage of uraninite alteration, and some showing outer rims and cracks with yellowish alteration products.

The better crystals of uraninite were separated from the specimens, crushed, picked over and panned in water, yielding a heavy fraction with sp.gr. 8.082. This is the material represented by analysis I, page.... The material remaining from the panning was further panned using as wash liquid 17 per cent hydrochloric acid. The heavy product of this panning is represented by analyses II, page...

The Huron claim uraninite is remarkable for its high content of lead and thorium and its very high lead ratio (0.260) which make it possibly the oldest uraninite known, so far as the writer is aware. The question immediately arises as to whether the age indications can be accepted as reliable. So far as the quality of the material analyzed is concerned, it appeared to be fully as good as that of some other Canadian Precambrian uraninites previously analyzed which have yielded lead ratios of 0.15 to 0.16. Further the high percentage of ThO_2 in the Manitoba uraninite is not altogether exceptional, as the Wilberforce, Ontario uraninite has nearly the same Th content and yet yields a lead ratio between 0.15 and 0.16. The high lead ratio of the Huron claim uraninite is closely approached by that of only one other known uraninite, that from the Ingersoll claim, South Dakota, analyzed by C.W.Davis, the essential figures for which are reproduced in the third column of analyses above. It is significant that both uraninites occur in the same general region in pegmatites of a very similar, one might say, identical, type, characterized by the presence of large amounts of albite and lithium and beryllium minerals. It has been claimed by Hess and Schaller that the albite in such pegmatites is a replacement on a large scale of earlier formed minerals during the later phase of magmatic activity. If earlier formed minerals including possibly uraninite have been reworked in this way, one might wonder what is the effect of such alteration and replacement on the uraninite. Schaller and Hess, however, believe that uraninite and other rare element minerals occurring in albite pegmatites do not belong to the first generation of minerals but were formed during the albitization process. That uraninites occurring in albite pegmatites do not on that account yield abnormal lead ratios is supported by the fact that uraninites of the albitic, lithium-bearing New

England pegmatites yield comparatively small lead ratios in complete accord with the age as determined by ordinary geological methods. Thus there seems to be no reason to doubt the age indications of the Dakota and Manitoba uraninites on the ground that a special sort of alteration or replacement associated with albitization has increased the lead content. The only other doubts which may enter results from the lack of exact knowledge as to the origin of actinium and the possibility of the existence in the early stages of the earth's history of short-lived isotopes of uranium. The older idea of physicists that ordinary lead occurs in uraninites has been pretty well exploded by recent work, and has always seemed most improbable to mineralogists.

In comparing the Manitoba and Dakota uraninites it may be noticed that the lead percentages are much the same in both also the total U and Th of the Manitoba uraninite is about the same as the U of the Dakota. It may be only a remarkable coincidence, but possibly there is some significance attached to the fact that if the Th of the Huron claim uraninite be calculated as U replacing it in molecular proportions, i.e. 12.25 Th= 12.56 U the resulting lead ratio of the Manitoba uraninite becomes 0.227, very close to that (0.221) of the S. Dakota uraninite, calculated in a similar way.

ONTARIO

INTRODUCTION

Precambrian rocks cover the greater part of Ontario, except in the extreme south and around Hudson bay and James bay, where Palaeozoic sediments occur. The more southerly parts of the

Precambrian in Ontario being easily accessible have been much prospected for feldspar and muscovite and many pegmatite dykes have been opened up, so that much more is known regarding the mineralogy of the pegmatites in this area than elsewhere. Numerous occurrences of rare minerals have been encountered in the course of mining for feldspar or mica, but in the majority of instances the quantities obtained have been too small to be of other than scientific interest. In one or two instances, however, several tons of material were produced which would have made commercial ore if it had been saved. A good deal of the rare mineral material produced in Ontario has found its way into the hands of mineral dealers and collectors, the prices received by producers being often more than the minerals would bring if sold on an ore basis.

Rare element minerals have been found in Ontario, so far, only in pegmatites. In view of the rapidly increasing number of metalliferous deposits being discovered and developed, the occasional occurrence of uranium ores in depositsof this type may be recalled. Thus in Colorado, pitchblende was produced in commercial quantities from a gold-quartz mine, whereas in Cornwall pitchblende occurs with copper-tin ores, in Bohemia with silver and cobalt-nickel ores, and in the Belgian Congo with copper ores.

The Precambrian of southeastern Ontario and the adjoining part of Quebec north of Ottawa river, is particularly rich in pegmatites. These are typically composed of pink to red microcline feldspar and white to smoky quartz with varying amounts of accessory minerals such as muscovite, biotite, hornblende, pyroxene, garnet, tourmaline, titanite, ilmenite, magnetite, pyrite, pyrrhotite, etc., with, occasionally, various rare-element minerals. Albite or plagioclase feldspar is usually present in only minor amounts but the microcline quite often contains minute perthitic intergrowths of albite. The dykes vary in size from mere stringers an inch or less in width to huge bodies 100 feet or more wide and 1,000 feet or more long. The country rock is often penetrated by complex networks of pegmatitic material and in face pegmatite is so often seen and so abundant that it might be considered to form a considerable portion of the total mass of the rocks exposed in this area. Much pegmatitic material occurs as lit-par-lit injections in the older gneisses, and many originally sedimentary gneisses have been much altered by such injections. The larger pegmatite bodies commonly occur in the older gneisses rather than in the parent granite itself, though occasionally pegmatitic areas are found in granite. In such cases the pegmatite mass is seldom well-defined or sharply differentiated but passes gradually into normal granite. The highly segregated type of pegmatit containing large masses of crystal microcline and white quartz, the kind sought by the feldspar miner, is rarely if ever found in granite The largest pegmatitic masses are normally of the so-called "graphic granite" type. These sometimes appear to be the feeders of the segregated type or they may contain somewhere within their own mass areas of more coarsely crystallized material, but such dykes are rarely if ever of economic value as sources of high-grade feldspar nor do they commonly contain more than traces of rare-element minerals, although allanite is sometimes present. The coarsely crystallized pegmatites containing large masses of white quartz and crystal microcline appear to be the most favourable for the occurrence of rare-element minerals. Allanite and members of the euxenite-polycrase group appear to be the most common rare-element minerals in Ontario pegmatites.

Rare mineral material mostly in small amounts has been obtained from a large number of localities in Ontario, but it has been found practicable to study in detail only a comparatively small fraction of the material collected. In the descriptions that follow many small occurrences of allanite and other as yet unidentified rare minerals, noted by the writer, are not mentioned.

MAMAINSE, ALGOMA DISTRICT: CORACITE (ALTERED URANINITE OR PITCHBLEND

References: Le Conte, J.: "On Coracite, a new ore of uranium"; Am. Jour. Sci., 1847, p. 173.
Whitney, J.D.: Am. Jour. Sci., 1849, p. 434.
Genth, : Am. Jour. Sci., 1857, p. 421
Geol. Surv., Canada, Rept. of Prog. from its commencement to 1863, pp. 504, 702 .

This occurrence represents the first discovery of uranium minerals in Canada and, possibly in America. The exact location of th occurrence is unknown though several attempts have been made to rediscover it. The earliest published account states that the material cam from "the north shore of Lake Superior, about seventy miles from the Sault Ste Marie, at the junction of trap and sienite; the vein in which it is found is about two inches in width ... on the face of an almost perpendicular cliff." A later statement by the original reporter (Le Conte) of the discovery is that the locality is "about 90 miles above Sault Ste Marie on the north side of Lake Superior." In the "1863 report" the locality is said to be Mamainse promontory but which is only about 40 miles north of Sault Ste Marie.

The mineral is probably either uraninite or pitchblende much altered. A 2-inch width of pitchblende occurring as a true vein filling and if of sufficient length and continuity would present possibilities for production on a commercial scale. Whether this mineral was uraninite or pitchblende is, therefore, of some interest, because if it were the latter it would be more at home in a vein as described and one might expect it to occur in greater quantities and to have more continuity than if it were an occurrence of uraninite in pegmatite. At the time the mineral was described, however, pegmatite dykes were commonly referred to as veins, so that the fact that it was said to occur in a vein does not necessarily imply that it was a vein in the modern sense of the word. If it were definitely known whether the mineral contained appreciable amounts of thoria and rare earths, the question would be settled, but Le Conte reported thoria present, while Whitney and Genth do not mention thoria or rare earths.

If Genth and Whitney were right in regard to the absence of thoria the mineral must have been pitchblende and this might well have occurred in a true vein as stated.

TURTLE LAKE, RAINY RIVER DISTRICT:BERYL

Reference: Tanton, T.L.: Geol. Surv.,Canada, Sum. Rept. 1925, pt.C, p. 10 (1927).

Beryl occurs in a pegmatite dyke on an island in Turtle lake 2 miles east of the west end of the lake and near the headland of Portage bay. The dyke is largely made up of quartz,microperthite, and dark mica; red garnets are also present. The beryl crystals are unevenly distributed; they are abundant in one area of 4 square feet. The beryl crystals are translucent,yellowish green, and prismatic; some are 2 inches long and ½ inch in diameter. No crystals of gem quality were seen.

(Insert Figure 4)

DILL TOWNSHIP,SUDBURY DISTRICT: TODDITE

Reference:Ellsworth, H.V.: Amer. Mineralogist, December, 1926.

Within recent years a number of pegmatite dykes have been opened up in Sudbury district for the production of commercial feldspar. From each of several of these dykes a few grains of radioactive minerals have been collected but in only one instance (the Dill Township occurrence) in amounts sufficient to permit making detailed studies of the material.

In Dill township, in the northwest corner of lot 4,con.3, an opening has been made in a pegmatite dyke from which one carload of feldspar was shipped. The dyke cuts biotite-garnet gneiss. It is 30 to 40 feet wide and is exposed for a length of 100 feet. The pegmatite consists of pale pink microcline in crystals not usually over 1 foot in diameter, white quartz, some much cracked muscovite in thin plates and "books" up to 4 X 6 inches in diameter, a little decomposed biotite, a little smoky quartz, a few garnets and a little plagioclase feldspar. Columbite occurs sparingly in crystals and grains usually not over ½ inch in diameter. Probably two or more different radioactive minerals occur. These form small, rounded, elongated masses 1 to 3 inches in length and which have caused well marked radial fracturing in the enclosing rock. For instance, one mass of toddite about 1½ X ½ inches has given rise to fractures 5 inches long in the quartz and feldspar matrix. The outer part of this mass had a dull lustre and had been altered; the inner part waspitchblack and had a brilliant, submetallic lustre. An analysis of the mineral is given on page *****

From the analysis it is evident that the mineral conforms in a general way to the columbite formula and may be considered as columbite in which some manganese and iron is replaced by uranium, which is present in sufficiently important amount to justify making it a new species.

The mineral was named in honour of E.W.Todd, formerly of the Ontario Department of Mines.

Some specimens were also obtained from this dyke in which a radioactive mineral (possibly toddite) is intermingled with a black carbon mineral (see thucholite) in such a way as to suggest that the whole may be an intergrowth of the two minerals.

HENVEY TOWNSHIP, PARRY SOUND DISTRICT: URANINITE

References: Spence, H.S.: Amer. Mineralogist, Vol. 15, No.11 (1930).
Ellsworth, H.V.: Amer. Mineralogist, vol. 16, No.12 (1931).

A dyke worked for feldspar on lot 5, con.B, Conger township, Parry Sound district, has furnished the finest, largest, most abundant specimens of thucholite yet found in Canadian pegmatits. Uraninite is intimately associated with the thucholite and the pegmatite also carries allanite, beryl, and cyrtolite as well as other minerals.

The width of the dyke is about 70 feet and the body is vertical. The enclosing country rock is porphyritic granite-gneiss. The pegmatite consists of large crystal masses of pink perthitic microcline separated by zones of massive, white quartz. Plagioclase feldspar, possibly albite, occurs in places along one wall over a width of 2 to 3 feet. Large thin flakes of biotite, largely altered to chlorite are scattered throughout much of the dyke. Muscovite and garnet occur in comparatively small amounts. The thucholite, uraninite, etc. are chiefly present along the borders of the pegmatite although some of them, notably cyrtolite and allanite, occasionally occur in small amount in the feldspar and quartz of the main body of the dyke.

Most of the thucholite found occurred near the dyke walls at or near the surface. Only minor traces were noted in the lower part of the pit. It occurs associated with radiated groups of an altered green mineral, now principally chlorite but which Spence thinks may have been a variety of allanite. The thucholite is present both in and along side this chloritized mineral. The thucholite occurs in: (1) irregular, massive, form filling crevices and cavities; (2) in small, bean-like nodules in the chlorite mineral and in titanite, biotite and feldspar; (3) in rough, cubic crystals in massive thucholite or partly embedded in chlorite or titanite; (4) in more perfect cubic crystals in feldspar; and (5) in thin films and minute veinlets in the feldspar and other minerals closely associated with the chlorite. Most of the thucholite cubes are small, from ¼ to ½ inch in diameter, the largest perfect cube found, measured 1 inch. The larger single masses of thucholite measured 4½ X 2½ X 1 inch and larger. The nodules range from ½ to 1 inch in length.

The massive thucholite is jet black when fresh, has a conchoidal fracture and is brittle. The nodular thucholite is duller;. Most of the cubes have a dull, earthy appearance and are evidently non-homogeneous; many have a core that may make up half or more of their mass and is probably uraninite. Crystals of uraninite of similar form occur with all types of the thucholite.

Two samples of the thucholite have been analyzed; one, No. 1 was of crystals and the other, No. 2 of massive thucholite. The results of these analyses are given below; Analyst, R.A.Rogers, Ore Dressing Division, Mines Branch, Dept. of Mines, Ottawa.

	No.I	No.2
Moisture at 110°C	2.00	1.60
Volatile hydrocarbon (possibly includes some water).....	20.19	19.96
Fixed carbon	50.82	61.56
Ash	26.86	16.63
	99.37	99.75
Sp.gr.	1.82	1.67

When tested in the electroscope, the ash from both samples was found to be strongly radioactive and comparisons with a standard of carnotite indicated that the content of U_3O_8 in the ash of No. 1 sample might be as high as 9.05 per cent, and in the case of No. 2 sample, 54.37 per cent.

Uraninite occurs intimately associated with thucholite and was not observed elsewhere in the pegmatite. The thucholite has, apparently, partly replaced the uraninite in some instances. It occurs rarely in small cubic crystals, seldom more than ½ inch diameter, enclosed in the thucholite. Considerable massive uraninite is also present inthe form of small veins some of which are as much as ½ inch wide. Both the crystals and the massive uraninite are usually bordered by a shell of thucholite.

Two samples (Nos. I and II page ...) were obtained by panning and otherwise treating material derived from five or six specimens. A third sample (No. III, page...) was panned material derived from a single crystal. The three samples were analyzed, the results obtained are given on page....

Allanite is fairly common in the neighbourhood of the thucholite. Most of it is massive. A few specimens of massive greenish-blue beryl and several small crystals of the same mineral were found. Cyrtolite occurs almost invariably with the thucholite in small masses up to a pound or more in weight. Occasional small masses also occur in the main body of the dyke enclosed in feldspar and unaccompanied by thucholite. An oil substance is also present. It is confined, as far as observed, to two parallel fracture zones crossing the dyke at right angles. The zones are about 1 foot wide and 40 feet apart. Both zones are heavily saturated with a heavy, yellow oil in appearance resembling a thin vaseline. In addition to the thin oil, there are present in the cavities and crevices of the shattered rock, numerous small, pea-like balls of hardened oil.

Ambeau Mine. Small quantities of radioactive minerals, probably euxenite, were found also in the Ambeau feldspar mine, about 10 minutes walk northwest of Britt station. This is a smaller dyke and a smaller working than the Besner mine and nothing particularly noteworthy was seen.

CARTER TOWNSHIP, SUDBURY DISTRICT: RADIOACTIVE MINERAL OCCURRENC

Two or three small grains of a brown to black complex columbate mineral, probably euxenite, were sent in for identification by Robert A. Ramsay, Sudbury, from what was said to be the Leach and Johns property near mile 98 on the Canadian National Railway northwest of Sudbury.

W.H.Collins, who subsequently visited the occurrence, has contributed the following notes. The mineral is found in a prospect pit in pegmatite, 150 feet west of the railway and about 100 feet south of mile-post 98 from Capreol and quite close to a small creek. Mile 98 is near Bethel station. The pegmatite is mostly a coarse mixture of quartz and feldspar, with some pure feldspar crystals reaching a diameter of 10 inches. Considerable chlorite, magnetite, and dark red garnets are present along with occasional grains not over one-quarter inch diameter of the dark radioactive mineral mentioned. Some of these grains have borders of yellow alteration products.

Only a few grains of the radioactive mineral were obtained and they have been held in the hope of obtaining larger quantities suitable for a detailed study. This represents the most westerly known occurrence of radioactive minerals in Ontario, outside of the lost coracite deposit on lake Superior.

CONGER TOWNSHIP,PARRY SOUND DISTRICT:URANINITE OCCURRENCE

Reference: Ellsworth, H.V.: Geol. Surv.,Canada, Sum. Rept. 1921, pt.D,
pp. 58-62.
Am.Jour. Sci.,Vol.IX, February, 1925.
Am. Min.,Feb. 1928, pp. 66-68.

Uraninite was discovered in 1921[1] in a dyke on the line between lots 9 and 10, con.IX,Conger, near a bay of Blactstone lake. At one time small crystals of uraninite were sufficiently abundant in places in the dyke to encourage the discoverers in the hope of producing commercial quantities, but further work did not justify the earlier

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[1] Ellsworth, H.V.: Geol. Surv.,Canada, Sum.Rept.,1921, pt.D.

expectations. The few hundred pounds of quite rich uraninite-bearing rock obtained was distributed as samples and specimens to mineral collectors, museums, and others.

In this part of Conger township, fine-grained,reddish granite carrying small red garnets, cuts garnetiferous, hornblende-biotite gneisses. Long, dyke-like masses occur that consist, typically, of a medium-grained, granular groundmass of microcline and quartz carrying rounded crystals or "augen" of microcline up to 4 inches in diameter. The rock has a well-marked flow structure parallel to the elongation of the masses. A little mica in small flakes and red garnet is usually present. The rocks of these masses seem to represent a variety intermediate between the granite and the pegmatites and may be referred to as the augen pegmatites. The pegmatites in which the rare minerals have been found appear to be later than augen pegmatites. In one case a mass of the augen pegmatite seems to grade laterally into a pure feldspathic phase that was mined for feldspar on lot 7,con.9. In one or two cases it appeared as though small bodies of pegmatite were connected with augen pegmatite masses though the connexion could not be traced with certainty. The pegmatites contain segregated masses of quartz and of microcline and other feldspars. Massive, basic rocks, having the composition of charnockite, occur in relative small amount and often outcrop near to or in contact with masses of the augen pegmatite. Similar intrusions of massive pyroxenic rocks have been seen by the writer at various points between Parry Sound and the western boundary of of Algonquin Park. They sometimes contain small nickeliferous sulphide segregations.

The pegmatite body carrying the uraninite, as seen by the writer, was exposed for 70 feet along the north side of a small hill on the shore of Blackstone lake. The contact with the country rock was not exposed except at the eastern end and, therefore, it was not possible to ascertain the dip and strike, and the true width. However, the exposed width was 60 feet or more and the probable strike about north 60 degrees east. The body may be a comparatively narrow dyke dipping north.

About one-half of the exposed area was massive white quartz and the remainder consisted of mixed quartz, feldspar, and mica. The areas of white quartz held occasional crystals of microcline up to a foot or more in diameter, and large crystals of muscovite, some of which reached a diameter of 18 inches but were rarely if ever over an inch or 2 thick,(along the c axis). These large muscovite crystals usually occurred at the boundaries between the areas of massive white quartz and those consisting more largely of feldspar, sometimes parallel to the boundary, sometimes normal to it, in which latter case one-half the diameter of the mica book would be embedded in quartz, the other half in feldspar. Sheets of bent and crumpled very black biotite, as much as 2 feet in diameter, were seen at the contact of the massive quartz with the granular quartz-feldspar-mica mixture. A few small flakes of molybdenite were found, but this mineral is rare.

The feldspathic parts of the surface consisted mainly of a granular mixture of smoky quartz, pink to red feldspar in which more or less polysynthetic twinning could usually be seen, and small, thin crystals of muscovite and biotite, chiefly the former. Some patches of crystals of microcline up to 3 feet indiameter and other patches in which muscovite, and to a less extent biobite, occurred in irregular clusters and fan-shaped aggregates of thin crystals, were also included in these areas.

Uraninite occurs as scattered crystals in the feldspathic parts of the dyke, particularly in association with stringers and aggregates of thin muscovite crystals, sometimes embedded in the mica, sometimes in quartz or feldspar, usually near the mica. The uraninite crystals very from 1/8 inch to a rare maximum of 1 inch in diameter, the averag being ¼ inch or less. The crystals are cubic in habit showing usually only a small development of the octahedron.

A mineral that appears to be a variety of samarskite high in lime, and hence called for convenience calciosamarskite, occurs in much less quantity than uraninite though under the same conditions, except that it seems to be more closely associated with the biotite. Associated with both uraninite and calciosamarskite are occasional occurrences of a black carbon mineral, which has been called thucholi[1]

by the writer, and which might easily be mistaken for uraninite

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[1] Thucholite, A Remarkable Primary Carbon Mineral from the Vicinity of Parry Sound, Ontario, H.V.Ellsworth:Amer. Mineralogist,vol.13, No.8,(August, 1928)

when embedded in the rock, except that it does not show much if any indication of crystal form. The thucholite occurs in exactly the same way as the uraninite, embedded in feldspar, quartz, or mica, or in a mixture of all three, and is certainly just as much a primary mineral as are any of those just mentioned. It takes the form of irregular, rounded nodules or more or less roughly globular masses from 1 millimetre to 1 inch in diameter. In the form of small, round grains, 1 to 3 millimetres in diameter, it is rather abundant in some of the finer-grained parts of the granular mixture of smoky quartz feldspar, and small mica where uraninite does not occur. Occasionally a uraninite crystal is completely embedded inthucholite and the calcio-samarskite also is sometimes in contact with it. The majority of the larger thucholite nodules are outwardly more or less intergrown with radiating intergrowths of cyrtolite and an unidentified mineral, probably a rare earth phosphate. Small radiating masses of rough crystals of cyrtolite also occur independently. Allanite was found only near the side of the dyke in small crystals almost completely altered to the characteristic dull reddish brown decomposition product. Small radiating masses, usually less than 1 inch in diameter, of a mixture of unidentified minerals with feldspar, quartz, and mica, also occur.

Practically all the uraninite found in this dyke is in the form of more or less well-developed crystals predominantly cubic in habit, with small octahedral faces. Some quite perfect crystals were collected, the largest being an inch in greatest dimension and weighing about an ounce. The uraninite is often very fresh, unusually hard and heavy, and almost a steel grey in colour with metallic lustre. It breaks with an uneven rather than a conchoidal fracture. Uraninites that are black with submetallic lustre and conchoidal fracture appear to have undergone the first stage of alteration from the type just described. Uraninite being the richest uranium mineral, with a large content of uranium and lead and composed almost wholly of oxides with comparatively few interfering elements, yields analytical results of higher accuracythan most other radioactive minerals, and, therefore, is the best possible material for age determinations by the lead-uranium ratio method. The unusually fresh Conger township uraninite is ideal for this purpose and as a fain amount of this most excellent material was obtained, thanks to Mr. H.F. McQuire of Parry Sound, the owner of the property, it was possible to make some experiments with the idea of testing the consistency of results afforded by the radioactive disintegration method of age determination. Several experiments in this connexion suggested themselves, viz.:

(1) The variation, if any, of results yielded by individual unaltered crystals might be investigated.

(2) The effect of natural alteration on the lead ratio - i.e., altered individuals might be found to give more or less consistently, higher or lower results than fresh crystals.

(3) The effect of averaging by taking a large number of crystals as a

sample for analysis.

The program of experiments just mentioned has not been completed, owing to the time required and the desirability of first investigating other rare minerals in a preliminary way at least. However, experiment (3) has been completed and a beginning made on the others. The first sample for analysis consisted of thirty crystals, each carefully selected for freshness, as evidenced by physical characters such as: high density, hardness, steely colour, and metallic lustre. The faces of each crystal where they had been in contact with rock were ground on a wet carborundum stone and all traces of foreign matter as well as any altered portions were eliminated so far as could be ascertained under a binocular microscope. The sample was crushed, ground, and well mixed for analysis. Several complete analyses were made by different methods with closely agreeing results, the best of which is given on page ....

Another similar sample of thirty crystals was prepared with the same precautions as before and analysed. The material was judged to be only slightly, if at all, inferior to the first lot and this was confirmed by the figures for UO_2 obtained. Analyses of this sample yield exactly the same lead ratio as the earlier sample, though the analytical figures are slightly different. This very satisfactory agreement seems to indicate that perfectly consistent results may be obtained by taking a considerable number of specimens for the analytical sample. The results of the analyses of this lot of thirty crystals is given on page .....

A single crystal weighing between 6 and 7 grams and considerably altered to the black stage was analysed; the results are given on page..

Subsequent work has shown that altered uraninite crystals usually yield higher lead ratios than unaltered uraninite from the same dyke, though alteration to the black stage only, as in this case, apparently affects the ratio only slightly in the third decimal place. This crystal is thus an apparent exception, but as no analyses of single unaltered crystals from this occurrence have yet been made, it may be that fresh individual crystals may vary to this extent from the average.

Calciosamarskite is much less abundant than uraninite, being in fact rare in the part of the dyke exposed, though what appears to be the same mineral occurs much more abundantly in another dyke a few hundred feet distant in which uraninite is apparently absent or at least was not seen. The calciosamarskite from the uraninite-bearing dyke was, however, particularly interesting because it afforded an opportunity to compare the lead ratios of the two minerals occurring only a few inches apart under identical conditions inthe same dyke. The complex columbate minerals frequently yield a low lead ratio, compared with uraninites from rocks of apparently identical age and the writer has ascribed this to alteration, but as the two minerals rarely occur together there was, of course, always the possibility that the complex minerals really were younger than the uraninites.

The calciosamarskite is black en masse, brownish and isotropic in thin grains or sections under the microscope. Other properties are: powder, brownish grey; cleavage none; fracture irregular; lustre submetallic; hardness 6.5; sp.gr. = 4.485. It occurs occasionally as rough, square prisms up to ½ inch in diameter by 1 inch in length. It is often associated with thucholite and cyrtolite-phosphate intergrowths. Usually it occurs in feldspar near or with clusters of biotite.

The material selected for analysis was the best available, but was slightly contaminated by thucholite and cyrtolite-phosphate. The results of the analysis are given on page....

The deficiency in the summation of the analysis is largely due to the presence of carbon (from thucholite) which was not determined. The carbon also rendered it impossible to determine UO_2 and FeO with certainty. The very low lead ratio compared with that of uraninite[1] from the same dyke was so startling that several determinations were made, all of which yielded practically the same result, the latest and most careful work yielding merely a trifle less lead and slightly more uranium than the earlier determinations.

The proper classification of this mineral is somewhat uncertain, but it seems to be rather closely related to a mineral from Hybla, Ontario, described under the same name.

This mineral was studied chiefly in order to ascertain if it would yield the same lead ratio as the uraninite, with which it is closely associated. The analysis of this particular complex columbate

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[1] Am. Jour. Sci. vol. ix, Feb. 1925.

shows conclusively that such minerals may sometimes be of no value whatever as geological age indicators. The writer's experience with Canadian minerals of this type indicates that when they contain more than a very small amount of SiO_2 the age ratio must be regarded with suspicion as being probably too low.

The black carbon-rare-element mineral that has been called thucholite occurs typically as rounded nodules, but sometimes exhibits a squarish cross-section with rounded corners, almost suggesting a tendency to crystallize in the forms of the isometric system,or that the thucholite replaces a uraninite crystal originally present,though when uraninite occurs in the centre of thucholite masses, the outline of the thucholite is usually roughly circular. A few of the nodules collected were clean, lustrous, and homogeneous throughout from centre to outside, some have an irregular cavity in the centre containing crumbly decomposed highly uraniferous material which appears to have been originally uraninite, and one or two collected which still contained a core of fairly well preserved uraninite. The majority, however, though consisting internally of pure lustrous thucholite were outwardly more or less intergrown with the cyrtolite intergrowth. The outer surface of thucholite nodules usually also contains minute embedded scales of white and black mica. The latter is very black and opaque except in the thinnest possible cleavages. It is biaxial with 2E=50 degrees, approximately. Such chemical tests as it was possible to make on the small quantities available did not indicate that it was different from ordinary biotite. One might suspect it to contain uranium and vanadium but the possibility of contamination from its associates would in any case render results on such small quantities dubious. Associated with the cyrtolite and black mica on some of the thucholite nodules are small patches of a powdery white mineral apparently a decomposition product, which so far as it has been examined appears to be a new mineral, a hydrous phosphate or silico-phosphate of calcium and yttrium earths. As this mineral can only be isolated in the most minute quantities much more work will have to be done before it can be fully described.

It appears likely that the thucholite varies considerably in composition. Nodules which are intimately in contact with uraninite naturally would be likely to carry more uranium than usual, and the ash of such specimens in fact is sometimes almost black and highly uraniferous, whereas the ash at other times may be cream coloured, greenish (from presence of V), or yellowish. Thucholite was first identified by the writer in 1921 but it was not until some years later that enough of the material was obtained to justify undertaking quantitative studies. Finally, about 10 grams was assembled and from this lot small fragments of the most lustrous material free from any visible impurities were carefully selected for the tests under a binocular microscope equipped with a Silverman Illuminator.

Thucholite is jet black with brilliant lustre and perfect conchoidal fracture. Cleavage none. Very brittle. Hardness 3.5 to nearly 4. It is absolutely opaque even in the smallest grains with arc illumination. Sp.gr.= 1.777 at 17.74 degrees. In the closed tube yields much water but no hydrocarbons.[1] Fragments if quickly heated may explode intoppwder with considerable violence, the particles being projected in all directions. It evolves gas copiously if immersed in water and heated. Digestion with 10 per cent HCl removes the greater part of the rare-element constituents, and the solution if filtered and evaporated shows the yellowish green colour due to uranium (yellow) and vanadium (green). Concentrated nitric acid at the boiling temperature slowly attacks the thucholite, the acid becoming brown coloured. The carbon can be completely destroyed by heating with concentrated H_2SO_4 and KNO_3. Concentrated cold H_2SO_4 seems to have little or no effect on the carbon, with long heating, however, the acid becomes brown coloured. Strong hydrochloric acid (33 per cent HCl) can be boiled with the mineral for hours without becoming coloured in the slightest degree of carbon compounds. Of course any of the mineral acids dissolve out the rare element compounds. The mineral burns slowly in air when maintained at a red heat yielding a light, pulverulent, ashy residue. The ash retains to a great extent the shape of the original fragments, but with some reduction in size, though it crumbles to fine powder at the slightest touch. Under the binocular microscope it very closely resembles fragments of dried bentonite. The prevailing

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[1] The mineral of course shows considerable radioactivity easily detectable in the electroscope and it produces the same radial fracturing in feldspar or quartz enclosing it as do other radioactive minerals.

colour of the ash fragments is a creamy-yellow but almost an equal number are greenish, and occasional minute black specks may be seen may be seen where no doubt there was a concentration of uranium. Some fragments may be in part greenish, in part yellowish. As obtained by ignition it shows no sign of fusion at a high red or nearly white heat in a platinum crucible heated over a large Meker burner.

Attempts to make sections thin enough to transmit light were unsuccessful, but a very good polished surface was obtained by first embedding a nodule in dentist's phosphate cement, grinding and polishing as usual. When examined by reflected light, this surface appeared to be entirely homogeneous, even under the highest powers, except for a few minute hair-like lines near the outer edge, which stood in slightly higher relief. These lines looked much like extremely minute cracks which had been filled with some harder material of the same nature. The proportion of this harder material would be much less than 1 per cent of the surface examined.

Three different samples of approximately 0.1 gram gave by combustion in oxygen; carbon = 45.18, 42.24, 50.48 per cent. No precautions were taken to ensure complete combustion of CO and probably these results are low.

Three different samples (not corresponding to above) yielded results as follows:

	I	II	III
H_2O at 110°	7.64	8.63	8.40
H_2O total, dir ct	13.20	13.02	12.86
Ash	24.48	24.20	23.06

The purpose of the foregoing experiments was to find out whether the substance has a constant composition. Unfortunately it was not practicable to obtain each sample from one nugget only, so that possibly all the samples represented more or less of an average of the lot from which they were selected.

The ash of various determinations was combined and analysed with results given on page....

If a larger quantity of ash had been available it would doubtless have been possible to attain a more satisfactory summation. As it was, all the constituents had to be sought for and determined in the one small lot, and as nearly half of the ash was thorium oxide all the other constituents together amounted to only about 0.2 gram. The low total is believed to be due to slight losses incident to the necessarily complicated analytical procedure rather than to failure to determine some constituent or constituents actually present. A review of the analytical notes indicates that possibly much of the deficiency was due to slight losses of lime occasioned by repeated operations on other substances from which the lime was supposed to be completely separated but actually was not. Thus it seems likely that most of the missing 3 per cent should be credited to CaO, especially as this amount was subsequently found on another sample in 1927. Owing to the presence of phosphorus, vanadium, and zirconium, numerous operations and exceptional precautions were necessary to ensure pure precipitates, especially in the case of uranium and thorium, hence thes are probably slightly low. With the exception of the ZrO_2, which, being small in amount, was not especially purified, the analytical results as given represent minimum percentages of the constituents present, and as thus defined are believed to be trustworthy. Vanadium was separated with certainty from uranium by cupferron. The thorium weighed was free from zirconium.

Previous to the analysis, the radioactivity of the ash was compared with that of standard analysed carnotite in a United States Bureau of Mines type α-ray electroscope. Equal weights and surface areas of ash and 1.55 per cent U_3O_8 carnotite were compared, with the result that the ash was found to be 13.6 times as active as the carnotite, indicating an activity equivalent to 21.08 per cent U_3O_8, which agrees quite well with the analytical results (24.9 per cent U_3O_8 equivalent), considering that radon and thoron were doubtless driven off by the ignition and that the test was made before they had again reached equilibrium. In view of the small amount of lead found it would have been interesting to have determined radium and mesothorium accurately by the emanation method to see whether these were present inamounts corresponding to the normal equilibrium ratio, or in other words, to see whether lead only is being removed faster than it is formed, or whether not only lead but also radium and mesothorium are being leached away.

At attempt to determine the gas content by weight was carried out as follows. The sample in fragments was introduced into a small silica tube closed at one end, which was weighed before and after. C Crushed and sifted, freshly ignited, transparent, fused silica was then inserted on top of the mineral to prevent loss by decrepitation and a plug of dry glass wool was inserted to hold down the fused silica powder. The whole was then weighed and attached to a mercury vapour vacuum pump. After exhausting until long after all air had been removed the mineral was gradually heated to a white heat with a gas blast lamp, the heating being continued until tests with the McLeod gauge attached to the pump indicated that only unweighable quantities of gas were coming off. The tube was allowed to cool, was detached from the pump and weighed. The results are hiven below:

	Per cent
Loss by vacuum ignition	26.08
H_2O — direct same sample	(12.96)
Gas by difference	(13.12)
Ash — same sample	28.06)
Fixed carbon, by difference	45.86
	100.00

Occurrences of diamonds in pegmatites have been reported[1] and it was thought to be worth while to look for them in the thucholite ash, but none was found.[2] During the washing of the silica of the analysis some very minute, almost perfectly spherical balls attracted attention by rolling around in the platinum dish. These had withstood the action c

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[1] According to Mellow, A Comprehensive Treatise on Inorganic and Theoretical Chemistry, vol.V, p. 737 -"M.Chaper found diamonds in the pegmatites of Bellary, Madras".

[2] After treatment with HF and H_2SO_4 any small residue of lead sulphate, etc., is completely soluble in HCl leaving not the slightest trace of insoluble material.

concentrated H_2SO_4 over night at the fuming temperature. Three were secured for examination. Two measured a little less than 0.1 mm. in diameter, the largest nearly 0.4 mm. across. Immersed in oilsunder the microscope the large ball was absolutely isotropic with index = 1.518 and contained numerous minute bubbles or inclusions. The colour of the balls varied from colourless to greenish. It was suspected that these balls might have been produced by fusion of ash around concentration of material rich in alkalis or phosphates, but if that were so their resistance to fuming sulphuric acid is rather surprising. About 0.2 gram of the thucholite in small fragments was destroyed by heatin with concentrated H_2SO_4 and KNO_3 and no balls or insoluble residue were seen in this solution. Since, however, only a half dozen balls were seen in 0.4 gram of ash they might exist in the original material and still be missed by the wet test on the small quantity.

The foregoing work was performed some years ago by the writer. More recently Dr. A.L.Day, Director of the Geophysical Laboratory, Washington, very kindly enlisted the services of Dr. E.S.Shepherd, the noted authority on volcanic gases and gas analysis, for an investigati of the gas content of thucholite. By permission of Dr. Day the report of Dr. Shepherd covering his analysis of the gases of thucholite, is reproduced below.

THE VOLATILES IN THUCHOLITE

E.S.Shepherd

"Dr. H.E.Mervin with the aid of the binocular microscope kindly selected from the better sample submitted some three decigrams of the most homogeneous seen.

Methods. A slight variation of the regular procedure was thought advisable. The mineral was placed in a small platinum capsule equipped with a fiarly tight lid, which was wired on. This capsule was then placed ina Lawrence Smith Alkali tube containing pure CaO. The tube was capped and the cap secured. The combined tubes were then placed in the silica tube in the furnace and the exhaustion carried out as described in my paper on Methods.[1] Of course the platinum, silica, and CAO had all been previously exhausted at 1100 degrees before the mineral was introduced.

The lime used was intended to stop sulphur, halogens, and phosphorus, but at the temperature of evacuation would not hold CO_2 nor H_2O. At the close of the run there was no evidence of carbon deposited in the lime as one might have expected had there been heavy hydrocarbons or tar present, nor did any such deposit appear when the lime was later dissolved for analysis. This fact combined with the results from the combustion indicates the absence of heavy hydrocarbons.

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[1] The Analysis of Gases Obtained from Volcanoes and from Rocks, E.S. Shepherd, Journal of Geology, vol. XXXIII. Supplement to Number 3, 1925, (H.V.E.)

Temperature of Evacuation 1000-1100°C., Time about 20 Hours.

Material taken	0.3310	Ash =3.48 per cent
After	0.1909	Carbon (by difference) =54.20 per cent
Loss	0.1401 or 42.3 per cent	
Weight of volatiles recovered	0.1395 or 42.1 per cent #	

#Note. The agreement implies an unusual series of compensating errors since the methods claim no such precision.

Total volume of "fixed gases" at 0°, 760 mm. = 173.4 cc.

Total volume volatiles at 1200°, 760 mm. = 1016.5 cc.

Volume per cent at 1200°, 760 mm.

CO_2	6.444
CO	35.827
CH_4	1.500
H_2	44.498
N_2	3.562
A	0.010
S_2	0.063
Cl_2	0.033
F_2	0.167
H_2O	7.357

cc/ gm = 3071

All rare gases are lumped as argon because there was too little to justify an attempt to separate them. The value A/A N x 100 =1.5 is but little above the argon ratio for atmospheric nitrogen. Phosphorus was detectable in the lime but not enough to bother with.

H_2O was 3.59 per cent by weight, thus lower than obtained by Ellsworth, but the total volatiles runs much higher. From the nature of the material no very definite ratio was to be expected. The ash varies greatly in colour. Some pieces are white and some green, indicating irregular distribution of metallic oxides. "

The great discrepancies in regard to ash, gas, and H_2O content between Dr. Shepherd's results and the writer's can only be explained by supposing that specimens of thucholite from different parts of the dyke vary greatly in quantitative composition. The specimens examined by the writer had been derived mainly from one particular small area of the dyke and evidently all had much the same composition. Since the time of the writer's work, however, various additional specimens were assembled in one tray along with what was left of the original lot. The lot sent Dr. Shepherd later on was thus taken at random from a mixed assemblage representing more widely separated parts of the dyke. The differences in our results apparently mean simply that thucholite is not nearly so constant in quantitative composition over the whole dyke as was indicated by the writer's results for specimens from a small, restricted area. In another occurrence of thucholite[1] it will be seen that not only the amount of ash but also its percentage composition is quite variable, though the same constituents are present in both cases.

The work of Dr. Shepherd adds much to the interest of this remarkable mineral. It was surprising enough to find a carbon containing 25 to 28 per cent of rare-element compounds and yet yielding no visible evidence of their presence, but when in addition to this we find an enormous gas content in which hydrocarbons are practically absent, one cannot but feel that we have in thucholite a priceless scientific key mineral, which if carefully studied might yield important

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[1] Thucholite and Uraninite from the Wallingford mine, near Buckingham, Quebec.

new information in the fields of both chemistry and geology. A full discussion of the possible significance of thucholite would occupy too much space here but a few important points might be briefly noted. The occurrence of carbon as a magmatic mineral is established, and it looks as it we have absorbed in thucholite a sample preserved through some 1,000 million years, of the final gases of a Precambrian granite magma, with the exception of helium which is not appreciably retained by carbon. It becomes evident also that uraninite is formed under strongly reducing conditions in the presence of carbon, carbon monoxide, and hydrogen and, therefore, we can be practically sure of its essentially UO_2 initial composition. The foundation for the autoxidation process in uraninite, as suggested by the writer thus becomes secure. Further, one might speculate as to whether the noteworthy differences between uraninite, which occurs in crystals, and the always amorphous pitchblende, may not be due to differences in the reducing effect of the magmatic vapours or solutions at the time they were formed.

Under highly reducing conditions such as prevailed when thucholite was formed uranium would appear as the lowest oxide (UO_2) which has a strong tendency to crystallize, so much so that artifical crystals can be easily prepared. Isomorphous oxides as ThO_2 (which is definitely known to be isomorphous with UO_2) and rare earth oxides (about which less is known at present) would be likely, if present, to crystallize with the UO_2 as uraninite. On the other hand, under less completely reducing conditions and probably at lower temperatures, representing a later stage of the magmatic vapours, uranium would probabl precipitate as U_3O_8 with which ThO_2 and rare earths are not isomorphous, and which has little if any tendency to crystallise. Thus we have a rather plausible explanation for the remarkable fact that uraninite always contains thorium and rare earths besides relatively large amounts of UO_2, often greatly exceeding the ratio of UO_2 in U_3O_8, and is always crystallized, whereas pitchblende contains only traces, if any, of thorium and rare earths and has a UO_2 content not greater in amount than is required for U_3O_8 and is never crystallized. The fact that carbon occurs in various forms in nickel-iron meteorites, as diamond in the blue groun pipes, etc., is sufficient evidence that it can be a primary constituent of deep-seated rocks. In the case of the Parry Sound thucholite there seems to be little or no immediate ground for suspicion that the carbon may have come from limestones assimilated by the magma, the time-worn explanation usually advanced for all occurrences of calcite, graphite, or other carbonaceous materials in igneous rocks, but unfortunately it cannot be said that the possibility of a limestone origin can be entirely ignored even here. There is comparatively little limestone in the Precambrian region bordering Georgian bay and none in the immediate vicinity of the thucholite occurrence so far as the writer is aware, the nearest outcrop seen being a band perhaps a 100 feet wide which crosses the junction of the concession road between McKellar and McDougall township and the road leading to McKellar and Dunchurch, about

16 miles from the thucholite dyke. This band seems to strike about north 25 degrees east magnetic and probably continues with increasing volume through Limestone lake, Fairholme post office and past Dunchurch The strike of this band apparently would carry it no closer than about 10 or 12 miles northwest of the thucholite locality. The absence of contact pyroxenites (consisting largely of sahlite and calcite) formed by the action of granite on limestone, which are so characteristic of regions such as the Gatineau and Lievre river, where limestone is abundant, is further evidence that such action has not occurred in the neighbourhood of the thucholite dyke.

During the present year the writer performed some further experiments on thucholite. It was thought for one thing, that possibly lead had been lost by volatilization during the combustion of the mineral, and that perhaps a greater percentage could be obtained by acid extraction. As material a single nodule was selected, which for apparent purity and homogeneity was the best of the whole collection. This was a solid nodule showing under the binocular only a few very sma patches of decomposed cyrtolite intergrowth confined to the outer surface. The cyrtolite was cut away and the outer surface filed until no further impurities could be seen. The nodule was then broken into fragments and about 0.4 g. of apparently pure fragments were selected. Of this 0.1100g. was burned in a platinum crucible yielding 0.0243 g. of ash equal to 22.09 per cent. The remainder, 0.3065 g. in weight, was leached with acids and the acid extract with the washings evaporate

In a small platinum dish, ignited to oxide, and weighed, the extracts of chlorides of course being first converted to nitrates before ignition.

			Grams.
Extracted by	H_2O only	3 hrs. on hot water bath	0.0005
"	" 10% HCl	3 " " " " "	0.0239
"	" 10% "	3 " " " " "	0.0087
"	" 10% "	6 " " " " "	0.0072
"	" 35% "	16 " " " " "	0.0068
"	2-[1]HF.H_2SO_4 and final 35 per cent HCl		0.0038
			0.0609

It has been observed inthe earlier work that there was a slight amount of water-soluble substance. Microchemical and spectroscopic test indicated that the water-soluble material is mainly sulphate and chloride of sodium. A Nessler's test for ammonia gave positive indications also, but the ammonia may have come from the laboratory air or water.

The appearance of the thucholite fragments viewed under the binocular microscope was not noticeably changed after the severe acid treatment, except that some pieces developed ordinary fractures due to internal strain, and in some fragments very minute fissures, apparently resulting from solution, were visible. It has been mentioned previously that a polished surface examined by reflected light appeared to be entirely homogeneous, except for the presence of a few very minute

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[1] This extraction was first by HF only, followed by 3 hours with concentrated H_2SO_4 at the fuming temperature, and after washing by final treatment with 35 per cent HCl overnight on hot water bath, followed by a long treatment with hot water. All these separate extracts being small were combined and the total weighed 0.0038 as oxides. The long treatment with hot concentrated H_2SO_4 attacked the mineral somewhat, the acid becoming dark brown, and on evaporation a small amount of a yellowish organic compound appeared in the dish.

lines of harder material standing in relief. The solution fissures just mentioned have exactly the appearance that would result if these lines of harder material had been dissolved out. Otherwise the leached grains seemed to have retained their original brilliant lustre.

The specific gravity of the acid leached thucholite dried at 120 degrees was determined after thorough boiling in a silica pyknometer, to be 1.75. This value, which is nearly that (1.777) obtained on the unleached material of the earlier experiments, is perhaps due to the leached mineral being more readily penetrated by water. It is reasonable to suppose that there is a constant gaseous tension within the unleached mineral by reason of which water would be more or less prevented from completely penetrating internally, and hence low results for specific gravity would be obtained.

The oxides obtained by acid leaching amount to 90.09 per cent of the total obtained by combustion, and as probably much of the silica was retained by the carbon and volatilized by the HF treatment, it was concluded that the extraction was nearly complete. A 0.0969 gram portion of the original material dried at 120 degrees was brought to a red heat in a covered platinum crucible, not more than one minute being required, and the material on weighing was found to have lost 0.0338 gram, so that there appears to be about 30 per cent of volatile matter present. About 15 minutes ignition with the crucible open in a large Meker flame was required to burn the remainder. The ash remaining weighed 0.0004 gram or about 4 per cent. Thus it appears probable that the ash could be entirely removed by acid leaching if the material were ground fine and given a sufficiently prolonged treatment.

The 0.0604 gram of extracted oxides were united and as a certain amount of silica had been extracted, along with the other substances, this was removed by HF and H_2SO_4. A few of the main constituents were then determined, with minimum results for the carefully purified oxides as follows:

	Grams	Per cent
PbO	0.0002	0.3
CaO	0.0018	3
ThO_2	0.0224	37
R.E	0.0087	14
1 ThO_2+ R.E	0.0025	4

1 Slightly impure recoveries not further treated.

There was a comparatively large amount of uranium present, but owing to an accident it could not be determined. V, P_2O_5, Fe, etc., were present as usual. This analysis confirms the suspicion that the Ca of the earlier, more complete analysis was low. No more lead was obtained than in the first analysis. Nickel and cobalt were sought in the 0.0243 of ask from the combustion of this lot, but no trace of either was found.

When the author in 1921 first identified the mineral here referred to as thucholite he was inclined to regard it with some justification as something entirely new and unheard of. As a matter of fact there appears to be no reference to any such mineral in the recognized works on mineralogy, though as it subsequently turned out this mineral had been found and superficially described long ago in both Sweden and Canada. It has also been found recently in some pegmatites in northern Russia.

As has been noted the thucholite nodules almost invariably carry on their outer surfaces more or less embedded or intergrown cyrtolite. This is generally without definite crystal form, but occasionally shows a development of typical zircon-like square prisms with curved faces characteristic of cyrtolite. Usually also it is considerably altered. No detailed optical study of the mineral was made, but it was seen that there are at least three substances present, viz. the zircon-like prisms, a massive material which is more altered than the crystals, and small amounts of thucholite. Most of the grains had n greater than 1.75, but some were lower. All grains had indices greater than 1.65. From the analysis it appears that the constituent with the lower index is probably a phosphate which may be closely related to, or identical with, the material mentioned under thucholite as being possibly a new silico-phosphate of calcium and the yttrium earths.

Some typical examples of the cyrtolite intergrowth were selected and ground for analysis. A little thucholite was unavoidably present in the sample analysed but not enough to appreciably affect the results which are given on page.... Small cyrtolite crystals also occur independently in the dyke, but only in very small amount.

Allanite occurs in only small quantity and is badly weathered. Alpha ray tests indicate that it carries but little uranium or thorium. The specimens collected were not considered particularly favourable material for lead ratio determination and, therefore, no analysis has been made up to the present.

MINERALS IN OTHER DYKES

A few small crystals or grains of uraninite and thucholite have also been found in other neighbouring dykes in Conger township. The mineral described as calciosamarskite also occurred in small amounts in a dyke on lot 10, concession 9. Columbite-tantalite occurred in some quantity in the feldspar working on the north half of lot 7, concession 10. This feldspar working was in a large pegmatite mass at a point where the mass was locally more feldspathic than usual and freer from garnets, mica, etc. The material mined contained some disseminated quartz and a little pale yellowish muscovite in stringers composed of small scales. The columbite-tantalite occurred as scattered crude crystals and masses up to 2 inches or more in diameter in a zone less than 1 foot wide but several feet long. An analysis of the columbite-tantalite by the Union Carbide and Carbon Research Laboratories gave: columbium 20 per cent, tantalum 22 per cent. A fine specimen of this mineral presented by Mr. H.F.McQuire, may be seen in the National Museum, Ottawa. A few grains of particularly well-preserved uraninite were also found in this dyke.

At a dyke just west of the Canadian National Railway right of way on lot 4, con.IX, Conger tp., which was worked many years ago for quartz and feldspar, well-formed, long, flat-prismatic crystals of allanite were found. Some of these still visible in part or of whic impressions remain, were 3 or more inches wide, an inch thick, and, according to local statements, as much as a yard long. Fragments of these crystals collected by the writer are much altered and show very little radioactivity.

BUTT TOWNSHIP,NIPISSING DISTRICT: URANINITE

Reference: Knight, C.W.: Can. Min. Jour.,Oct. 14, 1919.
Ellsworth, H.V.: Geol. Surv.,Canada, Sum. Rept.,1921, pt.D, pp. 62-66.

Uraninite was discovered in 1919 by Wm Elliot in a dyke worked for muscovite, situated on the south half of lot 13, con.VII, Butt tp. The occurrence was described soon afterwards by C.W.Knight. The dyke was exposed by stripping on the side of a small hill forming a peninsula about 20 or 30 feet above Mica lake. At the time of the writer's visit the dyke was exposed for a length of 90 feet and a widt of 10 feet, with strike north 30 degrees east magmatic and dip uncertain. At one point a cross trench showed a width of 18 feet of pegmatite on the slope. The dyke is a granite pegmatite of the segregated type carrying a considerably quantity of muscovite. Masses of white quartz and pink feldspar occur up to 3 feet in diameter. Most of the feldspar carries white mica. In addition, there are areas of a granular mixture of deep red spar, smoky quartz, and small books of white mica just as in the uraninite dykes at Parry Sound. In this mixture small brownish allanite(?) crystals are fairly common and a few scattered grains of uraninite up to ½ inch in diameter were seen. Uraninite also occurs sparingly in the feldspar and mica. Books of dark-coloured muscovite up to 5 or 6 inches in diameter occur plentifully in the more feldspathic areas. Black mica in minor amount is also present and in some cases intergrowths of both occur in which muscovite has continued to grow around a core of black mica. The feldspar varies from microcline to oligoclase. This mine produced altogether only a few ounces of uraninite, but the mineral was of great scientific interest as material for age determination by the radioactive disintegration method. The writer did not obtain enough of the uraninite to permit making analyses on fairly large average samples containing a considerable number of crystals, as was possible in the case of the Parry Sound uraninite. However, two analyses of mixed fragments and two of individual crystals were made. The results are given on pages...

It may be noted that all the Butt uraninites yield slightly lower lead ratios than the Parry Sound uraninite.

The discovery of uraninite in the Elliot dyke aroused considerabl interest and hopes that commercially valuable deposits might be found. Quite a number of claims were staked by private individuals and one of the large mining companies took up claims and did considerable trenching and exploration work. No deposits of commercial value were found however, though small amounts of allanite, euxenite, and columbite were found in several of the dykes opened up at this time in the neighbourhood of the Elliot claim.

The Butt township occurrences were reached by a road from Kearney on the Grand Trunk railway, 6 miles east of Scotia junction. The area is just west of the western boundary of Algonquin park. The road can be traversed by automobile as far as the Fish shacks on Maganatawan river (lot 28, concession VI, Proudfoot). From there a winter log road leads to what is called No. 2 camp, an old logging camp on lot 1, con.VI, Butt tp. From No. 2 camp trails have been made to the various claims.

CALVIN TOWNSHIP, NIPISSING DISTRICT; BERYL

Reference: Géol. Surv., Canada, Ann. Rept. n.s., vol.XI, 1898, p.14R

"Large but for the most part very imperfect crystals of a yellow variety of beryl have been found by Mr. C.W.Willimott, associated with black tourmaline and spessartite, in a coarse granite vein on the thirteenth lot of the fourth concession of the township of Calvin, in the district of Nipissing, province of Ontario. One of the finest specimens obtained from this vein is in the form of a rough hexagonal prism measuring 6 by 6½ centimetres in its diameters, consisting of a slightly altered beryl of a straw yellow, in parts honey yellow, colour, subtranslucent, and having a waxy lustre, in large part replaced by a light, at times somewhat dark, greyish white quart

This occurrence was visited by the writer in 1923. It is 50 feet south of the main highway from Mattawa east of Eau Claire and 100 feet from the lot line between lots 12 and 13. The dyke is 6 to 10 feet wide and can be traced for 200 feet, following a curving course with general strike 30 to 40 degrees east of north magnetic. It consists chiefly of pink microcline and white quartz with some white plagioclase. On the dump were seen; some small white mica, red garnets, black tourmaline, and a few pieces of cleavelandite containing yellow beryl. One rough crystal fragment of beryl was 3 inches by 4 inches in diameter and 7 inches long. Apparently there was a local segregation of beryl in cleavelandite at the spot where the pit was sunk. No beryl can now be seen anywhere in the dyke.

The dyke cuts what appeared in the field to be a somewhat micaceous plagioclasite or anorthosite. Both the dyke and anorthosite are cut off at the east end by a somewhat garnetiferous granite-gneiss.

The dyke was worked over thirty years ago by a Mr. Picher.

CALVIN TOWNSHIP,NIPISSING DISTRICT:EUXENITE AND POLYCRASE

Reference: Geol. Surv., Canada, Ann. Rept.,n.s.,vol.XI, pt.R, p.14

"Fine examples, of what on examination by Mr. R.A.A.Johnston pro ed to be polycrase .... have been found by Mr. C.W.Willimott, on th nineteenth lot of the ninth concession of the township of Calvin, district of Nipissing, ... where it occurs in ..... crystalline masses -- one of which weighed rather more than 700 grams -- associated with xenotime, a highly altered, cleavable, massive form of magnetite, and small quantities of a brownish red spessartite, in a coarse granite vein ...... The mineral has a pitch-black colour; an uneven, in parts subconchoidal, fracture; a resinous lustre; is brittle; and affords a greyish-brown streak. Its specific gravity, at 15.5°C, is 4.842" .

In 1923 the writer visited this locality and found two old workings, the only ones in the neighbourhood, in about the position given, but more probably on the northwest corner of lot 20, con.9, as rather than lot 19. The location is about 1 mile northwest of Eau Claire station, Canadian pacific railway. The opening farthest west is 4 by 6 feet by 10 feet deep, with water to within 5 feet of the top, in a dyke reaching a maximum visible width of 15 feet, with strike about north 60 degrees magnetic. The dyke is not well exposed but can be traced for about 200 feet. It appears to peter out at the east, and at the west end it either peters out or diappears under a sand-plain. It consists chiefly of pink microcline and white quartz with some dark red plagioclase, probably oligoclase. Crystal masses of microcline up to 1 foot diameter occur and some good-sized masses of quartz occupy the middle of the dyke. There is also present a certain amount of fine-grained mixture of dark red plagioclase (oligoclas carrying "fish scale" biotite. Small books of white mica up to 3 inches diameter occur very sparingly. A very few nodules up to ½ inch diameter, apparently euxenite, were found.

About 300 feet east of this pit is another opening 4 by 6 feet by perhaps 8 feet deep, also nearly full of water. This is in a dyke 8 feet wide of massive, white quartz and rusty pink feldspar with much black mica in patches up to 18 inches in diameter. No white mica was seen. One piece of euxenite ½ inch by 1 inch by ½ inch, and of allanite ½ inch diameter by 3 inches long, were found. This dyke also seems to strike about north 60 degrees east magnetic. and peters out about 50 feet east of the pit. To the west of the pit the ground is overgrown and the dyke cannot be traced.

The dykes were worked by Mr. Andrew Ryan of Eau Claire about thirty years ago.

MATTAWAN TOWNSHIP, NIPISSING DISTRICT: EUXENITE-POLYCRASE

REFERENCE: Ellsworth, H.V.: Am. Min. Dec., 1926.

Euxenite-polycrase and allanite have been found in small amounts in the last few years in several dykes which have been prospected for feldspar in the area between Eau Claire and Mattawa. The dykes in this region are generally comparatively small and seem likely to carry considerable iron and black minerals, so that feldspar mining in this district has not been very successful, so far. In the case of the occurrence described below, where considerable mining was done for feldspar, quite a little euxenite was encountered, though none was visible on the surface, so that it seems probable that euxenite-polycrase and allanite might be expected to occur in almost any of the dykes of this area.

The euxenite-polycrase here described occurs on lot 29, con.3, Mattawan tp., about 5 miles west of the village of Mattawa, in a pegmatite dyke which was opened up for feldspar during the winter of 1926 by M.J.O'Brien, Limited. The writer had seen the dyke before mining began, but is indebted to N.B.Davis of Ottawa for specimens of the mineral and for the description of its occurrence.

The dyke is 18 to 25 feet wide and is exposed for a length of about 300 feet, following a straight course a little west of north up a high hill which faces south of Lac Plein Chant, an expansion of Mattawa river. The dyke dips about 80 degrees to the west, cutting syenite-gneiss. The hanging-wall is closely frozen to the gneiss whereas the foot-wall is separated from it by about one-half inch of gouge consisting of rusty, scaly, decomposed, micaceous material. In composition the dyke is of the coarsely crystallized, segregated type. The middle portion is composed of crystals of microcline and massive white quartz; the quartz masses occurring in some cases in the middle with microcline on both sides, in other cases mostly on one side or the other. Along the sides next the wall-rock there is a varying width of soda feldspar, up to 2 feet wide along the hanging-wall, less along the foot-wall. This arrangement is typical of Ontario pegmatites and would probably be interpreted by most observers as indicating that the soda feldspar crystallized first, the microcline next, and finally the quartz.

The chief euxenite occurrence is on the top of the hill. It was first encountered within 6 feet of the surface. The euxenite is found in masses varying from pea size up to a diameter of 4 to 5 inches, principally in the microcline about 2 feet from the hanging-wall, but now and then a mass may be found in the middle of the dyke. Though no complete crystals have been seen so far, the masses of euxenite have a tendency toward a tabular form tapering to sharp edges and may have some roughly formed crystal faces. The feldspar around the euxenite masses is coloured red and is radially fractured, a characteristic effect of radioactive minerals in Canadian Precambrian rocks.

The pegmatite is compact and fresh looking with no evidence of weathering on the hanging-wall side, but there are slight indications of weathering on the foot-wall side near the seam of gouge. Minerals other than those mentioned are not prominent. No tourmaline and only a little black mica has been encountered.

The euxenite is black, unusually brilliant and fresh looking, and seems to be quite unaltered by the normal weathering agencies. Hardness 6.5; cleavage none; fracture subconchoidal; powder yellowish brown; under the microscope brown and isotropic. It appeared to be exceptionally good material for Pb-U age determination. The pieces selected for analysis were examined under the microscope and appeared to be perfectly homogeneous and absolutely free from included impurities An analysis yielded the results given on page ....

W.E.Brogger has suggested that the name euxenite be applied to those minerals with $Cb_2O_5 : TiO_2$ between 1:2 and 1:3 and polycrase to those with ratio less than 1:4. This mineral with $Cb_2O_5 + Ta_2O_5$:

TiO_2 =1 : 3.3 is on the border-line between euxenite and polycrase and, therefore, may be called euxenite-polycrase. This complex columbate mineral is noteworthy in that it yields age results in entire accord with those derived from the Ontario uraninites whereas other complex uranium minerals of Ontario commonly give much lower figures. The very small amount of SiO_2 present is, in the writer's opinion, highly significant as indicating that this particular mineral has not suffered appreciable leaching, alteration, or replacement by circulating waters, whereas those complex Ontario mineral which give low age figures invariably contain very appreciable amounts of silica, in some cases 2 per cent or more. It is not likely that silica is an original constituent of such minerals and it seems probable that in cases where a mineral contains considerable silica (not due to inclusions of quartz, feldspar, etc.) it is present as a result of secondary replacement of some of the normal constituents, notably lead. Thus, if this theory is correct we have a method of judging the probable value of age results from the complex titano-tantalo-columbate minerals. If the mineral contains little or no silica we may attach considerable weight to the age result; if an appreciable amount of silica is present we can be almost certain that the age result is lower — often very much lower — than the true value.

FRY LAKE, MONTEITH TOWNSHIP, PARRY SOUND DISTRICT: ALLANITE

Reference: Walker... and Parsons ... ; University of Toronto Studies, No. 16, pp. 29-30, 1923.

Allanite occurs rather abundantly in exposures around Fry lake, a small lake just south of Seguin Falls station on the Ottawa-Parry Sound line of the Canadian National railway. The location is lot 21, con. B, Monteith tp., Parry Sound dist. The allanite occurs as well-developed crystals from 1/8-inch to ¾ inch in diameter, which, however, as a rule are short, rarely over 2 inches long. They occur in irregular pegmatitic bodies of pink to red feldspar and quartz which appear to be pegmatitic phases of a fine-grained garnetiferous granite resembling the granite found at the Parry Sound uraninite occurrence. The pegmatites cut banded hornblende-biotite gneiss that has been profusely injected lit-par-lit by the garnetiferous granite and so altered as to be now practically granite-gneisses. Some of the pegmatites are as much as 15 to 20 feet wide in places, but they are irregular and not well defined as to strike and dip. For the most past they are rather fine-grained with but little large feldspar or quartz showing. Magnetite or ilmenite and a little black mica also occur.

The allanite has been described by Walker and Parsons with an analysis by E.W.Todd as follows:

"The crystals are rhomboidal .... The crystals appear to have been the first to form from the magma as they are frequently broken across and the parts while still in approximate position cemented by the quartz and feldspar. The crystals are dull brownish black on the outer surface, while the central core is jet black and of brilliant adamantine lustre. When the powdered mineral is examined with the microscope, it is seen to be doubtly refracting, brownish green in colour, and pleochroic in varying tints of olive green to brown green. The general index of refraction is about 1.735 -0.005. Birefringence 0.01. A sample carefully prepared from the central parts of the crystal was analysed." The analysis is given on page.....

A few shots have been put in dykes at three places around the north shore of the lake where allanite was most abundant. Of the two most promising dykes one showed a total exposed area of about 18 square yards. Of this the part richest in allanite constituted about 5 square yards, averaging 1 to 2 square inches of exposed allanite surfaces per square foot. The opening farthest west showed a pit 4 feet in diameter and 3 feet deep, at a point where small allanite crystals 1/8 to ½ inch diameter were abundant over an area of 4 square yards. The bottom of the hole was out of the allanite area and showed barren rock. This dyke showed a surface exposure of about 150 square yards, of which about 10 square yards contained allanite to the extent of 1 square inch or more per square foot. Of the 10 square yards perhaps 5 averaged 4 square inches allanite per square foot. At this point there is a good deal of magnetite or ilmenite in grains up to ½ inch diameter in the pegmatite.

From these and other observations it does not appear that the allanite exists in any great quantity suitable for profitable commercial operations, though small supplies could be obtained if needed. The allanite, of course, would need to be concentrated from the rock as the crystals are too small for economical hand cobbing.

AYLEN LAKE, DICKENS TOWNSHIP, NIPISSING DISTRICT; MONAZITE

Reference: Ellsworth, H.V.: Am. Min., Jan., 1932

Some years ago there was considerable prospecting for feldspar and mica in the neighbourhood of Aylen lake and along the Parry Sound-Ottawa railway between Barrys Bay and Madawaska. The rocks are typically garnetiferous granite-gneiss, biotite and hornblende schists, and basic intrusives resembling those noted in the Parry Sound and Butt townships areas. Pegmatites are numerous and several have been opened up, at least two of which produced feldspar for some time and one dyke on Aylen lake is said to have yielded some 60 tons of muscovite. Radioactive minerals in small quantities frequently occur in this region, almost all the numerous dykes examined by the writer showing some indications of their presence. The monazite described here was obtained from a dyke on the claim of F.G.Armstrong of Pembroke, lot 9, con. 13, Dickens tp., probably on the north half of the lot. The dyke strikes about north 60 degrees east magnetic along the side of a hill and is exposed for a length of 200 feet. The true width was not definitely ascertainable, but the surface exposure reaches a maximum of 50 feet or more. To a large extent it consists of graphic intergrowths of quartz and microcline but patches of coarsely crystalline microcline and massive white quartz occur. Some good-sized crystals of muscovite and biotite in less quantity occur, but as a rule the mica is so crumpled and cracked as to be valueless. Red garnets up to 1 inch in diameter are rather common in the feldspar and a 2-inch crystal of molybdenite was seen. Small, brilliant, black crystals of a mineral resembling euxenite or samarskite are quite abundant in the feldspar in places and occasional, flat reddish brown crystals of monazite were seen .

The largest monazite specimen collected measured about 3 inches in one direction.The wide end of the tapering mass bears well-develope crystal faces and is more or less transparent for a distance of about an inch back from the faces. The remainder becomes dark coloured, in places almost black, toward the thin edge of the wedge-shaped mass. The dark colour has been found to be due to the presence of carbon in a state of very minute dissemination. In thin sections under the microscope the dark material does not appear to be different in any way from the transparent parts except for the presence of some very minute, dust-like inclusions visible under high powers. There is reason to believe that the normal reddish brown colour of the transparent portions is also due to carbon present as particles of such small size as to be invisible under the microscope.

The association of carbon and hydrocarbons with radioactive minerals is not unusual in the pegmatites of Ontario and Quebec studied by the writer. The present case, however, is interesting in that we have here a transparent mineral which is definitely proved to be coloured by carbon.

Both the transparent and dark-coloured portions of the crystal were examined in representative thin sections to discover if possible evidences of alteration or the presence of inclusions. If, as has sometimes been supposed, the thorium is present in the form of thorite as inclusions or intergrowths the thorite should make up 9.09 per cent of the whole material (7.32 ThO_2 + 1.77 SiO_2) if the full amount of silica were present. Actually, however, only 1.54 per cent of silica was found by analysis. Thorite is always isotropic and should be easily detected between crossed nicols, but no indications of isotropic inclusions could be seen .A prominent cleavage or parting is well shown in all the sections as a series of roughly parallel rather closely spaced lines or cracks. Along the edges of these major fractures the clear monazite has altered to a cloudy whitish material, scarcely noticeable, with strong illumination but very distinctly visible when the right conditions are obtained. Just as in the case of many titano-columbate minerals examined by the writer this alteration could easily account for the silica present without assuming the presence of thorite. The mineral also shows a rather definite parting/or rough cleavage across the major cleavages and in addition a still more minute system of irregular minor fractures may be seen under high powers with certain conditions of illumination. The alteration seems to vary directly with the size of the cleavage cracks or fractures being scarcely apparent along the more minute fractures. Apart from the whitish alteration product visible chiefly along the major fractures the only indication of a possible lack of homogeneity is a variation in the interference colours producing a mottle effect of red and blue. It appears certain, however, that thorite is not present and that the silica can be accounted for by the alteration along the major cleavage cracks.

A sample for analysis was carefully selected from the best transparent material. The results of the analysis are given on page.....

Monazite is a particularly interesting mineral considered as a geological age indicator and in connexion with the theories of radioactive disintegration, because according to most of the published analyses it contains thorium but no uranium. Minerals in which thorium is present unaccompanied by uranium are rare, if indeed any such exist. It seems likely that in the older analyses of monazite small amount of uranium actually present may have been overlooked or at least not determined. Thorium minerals compared with uranium minerals usually yield low age results and various theories have been proposed to account for this. At one time it was thought that possibly the lead is unstable or that there may be another end product besides lead, but the tendency at present is to ascribe the low lead ratios of thorium minerals to loss of lead due to alteration and leaching. Holmes has advanced a plausible explanation of the discrepancies by supposing that the lead of uraninite is present in the mineral as uranate, whereas in thorium minerals it must be present as oxide or other compound, and that the lead uranate is less soluble and less liable to be leached away than the lead compound occurring in thorium minerals. The writer has shown that complex uranium, thorium, titano-columbate minerals which contain appreciable silica due to alteration yield low lead ratios, whereas those with little or none are in accord with uraninite. It is interesting to note that almost all monazite analyses show a silica content of one per cent or more and it has been supposed that the silica could be accounted for along with the thorium content by assuming thorite to be present as inclusions or intergrowths. But, as thin sections of the Dickens township monazite containing 7 per cent ThO_2 failed to yield any evidence of the presence of thorite, it seems more reasonable to believe that the silica found in monazite is due to replacement involving loss of lead just as appears to be the case with the titano-columbate minerals. There is also, of course, in all cases where the lead ratio is too low the possibility that leaching may have removed nor only lead but also radium and mesothorium or other members of the radio-elements. If this were so it could be detected by determining radium and mesothorium by the emanation method and calculating whether they were present in amounts required by the normal equilibrium ratios to correspond with the amount of uranium and thorium found by analysis.

Uranium as a rule has not been reported in the earlier analyses of monazite, probably because of the difficulties connected with the detection and determination of minute amounts in the presence of phosphoric acid.

Neighbouring Occurrences. Thanks to the interest of Mr. F.G.Armstrong the writer was enabled to examine a large number of pegmatites in this area with a minimum of time and trouble. Small monazite crystals were noticed in several other dykes, and small crystals and grains of what appeared to be minerals of the euxenite group and allanite were frequently seen, but in no case were they present in quantities of other than scientific interest.

SABINE TOWNSHIP,NIPISSING DISTRICT,ONTARIO: EUXENITE

Reference: Ellsworth, H.V.: Amer. Miner.,vol. 13, No. 9, Sept.,1928.

Euxenite, next to allanite, is the commonest rare-element mineral in Canadian pegmatites. This particular occurrence was studied because it represents a new area in central Ontario, consists of unusually fine material, and was obtained in considerable quantity. It occurs in a pegmatite worked for feldspar, on lot 28, con.I, Sabine tp.,Nipissing dist. The property is reached by a mine road which connects with the Trenton-Bancroft line of the Canadian National railways near mile 113, which is about 3 or 4 miles north of Lake St. Peter station.

The dyke in which the euxenite occurs is 12 to 20 feet wide and outcrops at intervals for a distance of 1,000 feet or more, extending into lot 29. The strike is about north 60 degrees east magnetic and it probably dips to the north. The feldspar working is on lot 28. The is nothing particularly noteworthy about the dyke. It is the ordinary microcline-quartz type common in Ontario, consisting for the most part of a coarse graphic intergrowth of quartz and microcline, with occasional patches of microcline crystals, not usually over 1 by 3 feet, from which commercial feldspar was obtained at the expense of considerable hand cobbing. Very little plagioclase was seen in the working. Biotite was abundant, muscovite was not seen. Nodules, up to 1 inch diameter, of martite were common. It is non-magnetic, has a reddish streak, and contains by a rough qualitative test not over 1 per cent TiO_2. On reducing it to a powder occasional grains present impart a blackish hue to the predominant hematite colour and are feebly magnetic. It seems likely that this material was originally magnetite which has been transformed to hematite. In some specimens what appears to be the magnetite cleavage is retained.

The euxenite occurs chiefly as masses up to 4 inches in diameter, often associated with biotite, in microcline which is considerably fractured and reddened by iron rust for a radius of a foot or more from the euxenite. The euxenite masses consist of the pure solid mineral uncontaminated by intergrowths of other minerals and are really aggregates of large crystals grown together, the outer surfaces often bearing good crystal faces. Some small individual crystals were also seen. Sometimes a martite nodule may be in contact with the outer surface of the euxenite masses. The feldspar surrounding the euxenite, though badly fractured and stained red, presumably by iron, appears to be typical microcline. When crushed and examined in oil under the microscope practically all grains show the microcline twinning and all have indices less than 1.530, but when examined as hand specimens under the binocular microscope a few, scattered, minute, perthitic intergrowths of plagioclase were seen, which it was estimated would constitute not more than one per cent of the whole.

No large masses of quartz were exposed. There is some smoky quartz but it is not deeply coloured. At the time of the writer's visit a cut 4 to 5 feet deep had been made over a length of 30 feet and four carloads of feldspar had been shipped. The small amount of silica present indicates that the mineral has suffered but little normal alteration and the lead ratio is only slightly lower than that (0.15) of the best uraninites of the Ontario Precambrian.

As the ratio of $Cb_2 O_3 + Ta_2O_5 : TiO_2 = 1:2.5$ the mineral is to be classed as euxenite, following the suggestion of W.E.Brogger that the name euxenite be applied to those minerals with $Cb_2O_5:TiO_2$ between 1.2 and 1.3, and polycrase to those with ratio less than 1:4.

HALIBURTON AND HASTINGS COUNTIES

In this area there are several occurrences worthy of note, viz., uranium minerals near Hybla station, 10 miles north of Bancroft, uraninite occurrences in Cardiff township a couple of miles east of Wilberfor and an ellsworthite occurrence south of Wilberforce in Cardiff township.

The district has long been noted for the number and variety of its mineral species. Within a radius of 25 miles from Bancroft, most of the common minerals and many rather rare species have been found. Gold, iron ores, graphite, molybdenite, galena, corundum, feldspar, garnet, sodalite, marble, talc, apatite, fluorite, have been mined at one time or another. Minerals such as apatite, phlogopite, graphite, scapolite, titanite, molybdenite, pyroxenes and amphiboles of various kinds, pyrite, pyrrhotite, garnet, zircon -- the assemblage characteristic of limestone-granite contact metamorphism -- are common. The pegmatites are now beginning to yield their store of minerals of the rare elements as feldspar mining proceeds.

The most complete account of the geology of the area is contained in the report[1] and geological map (No. 770) of Adams and Barlow.

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[1] Adams, F.D., and Barlow, A.E.: "Geology of the Haliburton and Bancroft Areas"; Geol. Surv., Canada, Mem. 6, (1908).

The area is located near the southern margin of the Canadian Shield. It includes an unusually complex assemblage of gneissoid igneous rocks ranging in composition from granites to gabbros, ancient altered sediments, among which crystalline limestone is prominent, and a series of rocks such as hornblende, pyroxene, and garnet gneisses, and nepheline-bearing rocks which appear to have resulted from the action of granite on limestone. According to Adams and Barlow the dominant geological feature of the district has been the intrusion and partial assimilation of ancient sediments -- largely limestone -- by great granite batholiths, resulting in the production of amphibolites, nepheline rocks, and other rocks of various types which occupy large areas.

In a general way, four types of pegmatites may be distinguished on a basis of mineral composition: (1) Ordinary granite pegmatite; consisting chiefly of quartz and potash feldspar, with plagioclase feldspars in minor proportion. These pegmatites range in texture from graphic granite to very coarsely crystallized types containing great masses of quartz and microcline crystals up to 10 feet in length. The common accessory minerals are hornblende, pyroxene, black mica, black tourmaline, pyrite, pyrrhotite, titanite, titaniferous magnetite or ilmenite, garnets, allanite, and hematite as a decomposition product of pyrite or pyrrhotite. White mica occurs, but is not as a rule prominent; some fluorite, beryl, zircon, and cyrtolite are found, and some of the larger dykes which have been extensively worked for feldspar have yielded unusually large amounts of rare minerals containing uranium, thorium, titanium, columbium, and the rare-earth elements. These dykes vary in size from that of mere stringers to more than 100 feet in width. The larger masses are apt to be of the graphic granite type. A remarkable feature of some of the dykes is their content of coarsely crystallized calcite, one mass of which probably weighed over 100 tons.

(2) Syenite pegmatites. These consist essentially of potash feldspar and plagioclase, with little or no quartz. Accessory minerals maybe corundum, hornblende, pyroxene, black mica, black tourmaline,

ilmenite or titaniferous magnetite, pyrite, molybdenite, garnet, allanite, and other rare-earth minerals in small amounts only. Examples of such dykes may be seen in the old corundum workings at Craigmont and Burgess mine. Uraninite seems to have occurred in small amount at Craigmont.

(3) Nepheline-Soda feldspar pegmatites. The essential constituents are coarse nepheline and soda feldspar. Quartz is absent. Some white, brown, or black mica in plates up to an inch in diameter may be present; some hornblende and garnets occur; and grains of calcite seem to be an almost invariable constituent. Calcite, in fact, can be found without much trouble in almost all exposures of nepheline rocks, its presence being readily detected by the fact that it dissolves more readily than nepheline and hence leaves pits in weathered surfaces of the latter mineral. The nepheline itself dissolves faster than the feldspars, which consequently stand in high relief. Some of the nepheline pegmatites show patches of almost solid, pure nepheline that may reach a diameter of 2 feet or more. These dykes would be valuable if a commercial use were found for nepheline for they appear to contain as much as 75 per cent of that mineral. Examples of such dykes, which seldom exceed 10 feet in width, may be seen along a wagon road which leaves the public road on concession XI, Dungannon township, and runs north over the hills to the east of York river in concessions XII and XIII. Radio-active minerals have not been found in this type of dyke up to the present.

(4) Calcite-Fluorite-Apatite Pegmatites. A number of rather unusual pegmatitic vein-dykes have been opened up at various times for fluorite or radioactive minerals in the Harcourt-Wilberforce area. They are in general more or less vein-like bodies of widths usually not more than 8 feet, and they have an easterly or northeasterly trend, as have the majority of the ordinary granite pegmatite dykes. They are composed chiefly of interbanded white to pinkish calcite and dark purple fluorite, with in some cases abundant apatite, hornblende or pyroxene of various kinds, sometimes in parallel growths, usually considerable magnetite or ilmenite, sometimes a little titanite, molybdenite, zircon, allanite, ellsworthite or uraninite. There is generally, if not always, a relatively narrow border of feldspar next the wall rock carrying inwardly projecting feldspar crystals. These crystals generally show more or less polysynthetic twinning and are probably mainly soda-lime feldspar but often there seems to be some microcline present also. The crystals may be intergrowths or they may have been originally microcline which was subsequently replaced by plagioclase. The uraninite occurrences of the Ontario Radium Corporation and adjacent properties are in deposits of this general type.

The radioactive minerals apparently occur most often in the acid pegmatites, that is, those containing abundant quartz and potash feldspar. The greatest quantity of such minerals so far turned out from any one dyke was undoubtedly the ellsworthite at the MacDonald dyke at Hybla, a granite pegmatite containing large masses of calcite-quartz intergrowth. Radioactive minerals are apparently less abundant in the syenite types and have not yet been found in the nepheline pegmatites in the very few instances where these have been opened up. The calcite-fluorite-apatite type though usually barren, in one instance, the deposit of the Ontario Radium Corporation in Cardiff township, has produced the largest quantity of uraninite so far found in one deposit in this country.

A characteristic feature of many of the pegmatites in this area is the occurrence, sometimes in large quantities, of coarsely crystallized calcite, having apparently the relationship of a normal primary mineral such as the quartz or feldspar. Particularly large calcite masses were present in the MacDonald and Woodcox dykes (q.v.) and smaller quantities have been seen by the writer in the majority of the dykes that have been opened up in this district. The calcite is in some cases associated with quartz, as at the MacDonald mine; in some cases with pyrrhotite, and pyrite; often with dark purple fluorite, particularly in the area east and south of Wilberforce; and many occurrences are simply very pure white or pinkish calcite containing no other minerals. Some of the calcite, calcite-quartz, or calcite-fluorite intergrowths carry radioactive minerals (uraninite, ellsworthite and allanite), Zircon or cyrtolite, titanite, pyrrhotite, pyrite, apatite. The calcite masses usually occur near the middle of the dykes in the same way as the latest quartz of the dykes and the calcite appears to be in part more or less contemporaneous with the latest quartz, and also possibly slightly later.

The writer has seen no evidence to indicate that the calcite masses might be recrystallized limestone inclusions. Pyroxenic limestone inclusions do occur in the MacDonald dyke, but they have not been converted even in part to coarse calcite nor do they carry the minerals mentioned as occurring in the calcite. Lack of space forbids description here of the numerous calcite pegmatites examined, though they are worthy of detailed consideration because of their scientific interest and because of the present controversy as to the origin of calcite in igneous rocks. Brogger[1] and his school believe that calcite in the igneous rocks of the Fen area in Telemark, Norway, must be considered as a primary igneous rock mineral, a view which is opposed by Bowen,[2] and associates of the Geophysical Laboratory on the grounds of results obtained in laboratory experiments by Smith and Adams and observations of thin sections of the Norwegian calcite-bearing rocks in which Bowen sees evidence that the calcite replaces other normal minerals originally present. Bowen believes that the calcite was brough in by hot circulating waters following the consolidation of the rock. Schaller, Hess, Bowen, and other advocates of the theory of wholesale replacement processes in rocks, undoubtedly would ascribe the calcite present in these Ontario pegmatites to the action of such replacement processes. Other investigators have attacked the problem by seeking to find physical differences between ordinary low temperature calcite and that found in the igneous rocks. Thus Walker and Parsons [1]

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[1] Brogger, W.C.: Vid. Selsk. Skrifter I, M.N.Kl, No.9 (1920)

[2] Bowen, N.L.: Am. Jour. Sci., vol.VIII, No.43, p.1, (1924, July)

find evidence in the presence of an unusual cleavage and anomalous optical behaviour such as biaxial character and incomplete extinction that Grenville crystalline limestone and the calcite of Ontario pegmatites and apatite deposits "has originated from the inversion of alpha calcite which was formed from igneous fusion at temperatures above 970°." One of the calcites studied by these authors was said to be "from a feldspar quarry near Hybla, Ont." On the other hand it has been shown by J.L.Gillson[2] and M.J.Burrger that such optical anomalies can be produced in normal low temperature calcite by stress or deformation, and Smith and Adams could not verify the existence of a high temperature modification of calcite (lot.Cit.) The nepheline rocks of the area also carry considerable calcite as grains, which appear to be as much a primary constituent as any of the others. Adams and Barlow[3] believed that the calcite grains were merely undigested particles of crystalline limestone included in the intrusive rocks. The writer's observations[4] favour the view that the calcite is as much a magmatic mineral as any of the others, though the magma doubtless obtained its calcite content by solution of crystalline limestone. The limestone taken up by the magma must have been completely dissolved,

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[1] Walker, T.L., and Parsons, A.L.: University of Toronto Studies, No.20, 1925, pp. 14-17.
Boeke, H.E.: N.J.Min.,1912, p, pp. 91-121.
Smyth, F.H., and Adams, L.H.: Jour. Am.Chem.Soc.,vol.XLV, 1923,pp. 1167-1184.
Fersman, H.E.: Bull.Acad.Sci.,Russ.,1926, pp. 231-273.
Grubenmann, U., and Niggli, P.: Die Gesteinmetamorphose, Bd.I, 1924, pp. 121-122.

[2] Gillson: Biaxial Calcite, Am. Min. Oct., 1927, pp. 357-360

[3] Geology of the Haliburton and Bancroft Areas, p. 233

[4] Geol. Surv., Canada, Sum. Rept., 1923, pt.Cl,pp. 17-19.

so that the considerable quantities of impurities present in the original limestone were absorbed by reaction with other constituents of the silicate melt leaving an excess of practically pure calcite to appear as grains and masses in the consolidated rocks, a rebirth of calcite under truly magmatic conditions.

MACDONALD AND WOODCOX MINES, MONTEAGLE TOWNSHIP, HASTINGS COUNTY

References: Walker, T.L. and Parsons A.L.: University of Toronto Studies
No. 16, 1923.
Ellsworth, H.V.: Geol. Surv., Canada, Sum. Rept. 1923, pt. CI
Am. Min. Oct., 1927, Feb., 1928.

The occurrences described are in granite pegmatite dykes worked for feldspar near Hybla, 10 miles north of Bancroft on the Canadian National railway. The feldspar mines for the casual visitor are most conceniently reached by automobile from Bancroft.

The country around Hybla is 1,300 to 1,500 feet above sea-level. Large, gently-rounded, broad-topper, drift-covered hills modify the usual rugged aspect of the central Ontario highland. Differences of elevation between hilltops and valleys rarely exceed 200 feet. Much of the drift-covered upland has been cleared for farming and shows only a few, small, scattered rock exposures. The drift is mostly unstratified bouldery sand or clay, sand predominating. It reaches a considerable thickness in depressions, and even on hilltops may be 3 to 6 feet deep, which hampers prospecting and increases the cost of mining. A number of dykes have been worked intermittently for feldspar by different companies. The largest operation was at the MacDonald mine which produced a large amount of feldspar but now appears to be about worked out, work having ceased in 1920.

MACDONALD MINE

The property known as the MacDonald mine, owned by Peter MacDonald, Hybla, Ont., has yielded the largest quantity of radio-active minerals so far obtained from a pegmatite dyke in Canada and if these minerals had been saved there might be some justification for the assertion that they were produced in commercial quantities. The operators, however, regarded them merely as an expensive nuisance detrimental to the production of feldspar, and the material was dumped with the waste rock from the pit. The local practice of granting mining leases for feldspar only, naturally influenced operators who encountered other minerals.

The MacDonald mine (See Figures 5 and 6) is on the southeastern slope of a drift-covered hill on lots 18 and 19, con.VII, Monteagle tp. The hill is one of the highest for miles around. The dyke strikes east, has an average width of 40 to 50 feet, and the upper portion dips 60 or 70 degrees to the north. It has been exposed, mostly by stripping, and opened up for a length of 600 feet or more. Since the plan represented in Figure 6 was made, the workings have been considerably extended down the hill on the east end and also to much greater depth. In order to work the lower levels two parallel adits side by side were driven fro low down on the eastern slope and stopes were carried up until they brok through into the old open-cut. With increasing depth the dip to the

(Insert Figures 5 and 6)

north increases and the dyke tends to flatten out in the bottom. At the west end on top of the hill the dyke is only 5 feet wide, but it widens rapidly to the eastward and with depth. It seems probable that the dyke never extended far above the present top of the hill, that is, that there is here represented an almost complete section of the upper part of the dyke. The workings from the present lowest point to the extreme top represent probably the greatest vertical depth to which a pegmatite dyke has been explored in this country. Assuming the usual roughly lens-shaped form from this dyke, probably much of the thickest central part of the lens has been removed. In view of the unique character of the dyke, this evident loss due to erosion is particularly unfortunate.

Crystallization in the dyke is in many places on a gigantic scale. Great masses of solid white quartz up to 30 feet in diameter extend from side to side, and huge, well-defined pale pink microcline feldspar crystals may still be seen outlined in the walls. Crystals of pyroxene and allanite reach a diameter of a foot or more in places. Crystals of titanite are common, some reaching a diameter of 3 inches. Brown lime-iron garnet occurred rather plentifully as irregular masses several inches in diameter near the walls. One of the most interesting constituents of the dyke is calcite which, mixed with quartz occurs in masses of considerable size. The largest, which has now been mined out, weighed, probably 100 tons or more. Some of the calcite is white, some pink, or salmon colour, and it is as a rule associated with a good deal of white, nearly colourless, or smoky,quartz. Some parts of the calcite-quartz mixture contains numerous zircon or crytolite crystals, averaging one-quarter inch in diameter, embedded in both calcite and quartz. Where they occur in quartz they are invariably surrounded by very well-marked, radiating fractures. Possible causes of such fracturing have been discussed by Walker and Parsons.[1]

Patches and nodules of ellsworthite, a radioactive mineral, usually associated with abundant cyrtolite crystals, occurred plentifully in parts of the calcite-quartz intergrowth. A few large blocks of this material, the largest perhaps three quarters of a cubic yard in volume and containing possibly 5 per cent or more of ellsworthite, were still to be seen on the dump in 1928. This material when mined was piled on the dump along with the waste rock. Much of it was thus lost, but some of the larger pieces were subsequently picked out and considerable quantities were disposed of to mineral dealers, collectors, museums etc. Mr.MacDonald generously presented a considerable quantity of this material to be used for scientific purposes and for exchange with foreign museums and the thanks of the Department are hereby tendered for the gift. The writer estimated that possibly one ton of pure ellsworthite was contained in the large calcite mass. The position occupied by this large calcite mass was immediately above and partly below the point where the pond is shown on Figure 6. The writer saw only a part of it in

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[1] *University of Toronto Studies*, No. 16, 1923.

the summer of 1922, when work was suspended. Most of the mining below the 160-foot contour line has been done since that date. The calcite as seen at that time occupied the middle part of the dyke, having no apparent connexion with the wall-rock, and it seemed to be as much a primary constituent of the dyke as the quartz and feldspar. In October, 1923, when the writer again visited the mine, the mass had been entirely removed and no traces of it were to be seen in the dyke itself.

Besides the minerals already mentioned, several others of interest occurred. A few pounds of uranothorite were collected by the writer from the dump. It is not known exactly how or where this occurred in the dyke beyond the evident fact that it is embedded in feldspar and quartz and hence did not come from the calcite mass. During 1923 another interesting mineral association was encountered. Masses consisting chiefly of pyrrhotite with minor amounts of pyrite, nodules of dark quartz, zircon crystals, feldspar, and radioactive minerals apparently ellsworthite, dark purple fluorite which emits a foetid odour when struck, a little chalcopyrite, and occasionally a crystal of molybdenite, seem to have been mined in considerable quantity. Fragments, 2 feet in diameter, of this mixture, were seen on the dump. Probably several tons of this sulphide mixture were mined. There were no good exposures of this association in place at the time of the writer's visit, waste rock having covered the floor of the pit. At one point exploration with a pick revealed a mass of the sulphide mixture about

3 feet in diameter, set in white quartz and blackened, pale greenish feldspar. Similar material was found at two or three other points nearby, but the size of the masses was not ascertained. At a somewhat later date Mr. MacDonald gave the writer a few ounces of galena occurring in association with the assemblage of minerals just mentioned. This is the first and only instance of galena or any other common lead mineral being found in Canadian pegmatites, and as it seems possible that the lead might have been derived from the radioactive minerals, it would be interesting to have its atomic weight determined.

Ellsworthite. The radioactive mineral found most abundantly at the MacDonald mine was described by Walker and Parsons[1] as a new mineral under the name of ellsworthite with analyses by E.W.Todd which are given on page.... It occurs as nodular masses of yellow or brown colour without cleavage or crystal faces, in calcite, quartz, or mixtures of the two, and also in the sulphide association previously described. Zircon (or cyrtolite) and titanite crystals are in many places associated with it in the calcite-quartz gangue, the zircon being often abundant. Both ellsworthite and zircon when in quartz are surrounded by well-marked radiating fractures, when in calcite by fracturing which is less apparent, probably due to the softness of the mineral. The calcite immediately surrounding ellsworthite is a paler colour than it is elsewhere, the general mass of the calcite being generally a bright salmon colour, whereas around ellsworthite nodules, it is

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[1] University of Toronto Studies No. 16, 1923, pp. 13-17

bleached to a cream colour. The ellsworthite occurs in two varieties, one amber yellow, the other dark brown to almost black. The yellow type is more common in the calcite; the darker type is more likely to be found in quartz or the sulphide association. Some nodules consist almost entirely of one or the other variety; others have the dark type in the centre with a border of the yellow variety. Under the microscope both are isotropic,the one pale and transparent, the other brownish and transparent only in thin grains. The indices of both are higher than 1.74. Hardness about 4; streak pale brownish yellow to pale chocolate. "Both types give up considerable water at 100 degrees. At 176 degrees the dark type has given off 5.92 per cent of water. At 200 degrees it gains in weight and changes in colour from black to yellow brown,so as to resemble the powder from the yellow type. At 225 degrees it is still heavier than at 176 degrees. This gain in weight accompanied by the change in colour probably indicates the oxidation of the uranium from the dioxide to the trioxide.The gain in weight, though not known exactly, owing to the simultaneous evolution of water and oxidation, seems to be about the amount of the oxygen necessary to convert all the uranium to the higher state of oxidation as shown by the titration of the dissolved mineral with permanganate. The question as to whether the uranium or iron is in the lower state of oxidation may be decided in favour of the former since the gain in weight is marked by the mineral becoming lighter in colour rather than the reverse, as is characteristic for iron compounds" (Walker and Parsons: Loc.cit.)

It is evident from the analytical results and from the occurrence of the dark variety as cores surrounded by the yellow type, that the latter is simply a more altered phase of the dark type. UO_2 produces a black colour in minerals and UO_3 yellow, orange, or red colours.

The low lead ratio is noteworthy, being for the dark variety only about one-seventh the normal ratio found in uraninites from Ontario pegmatites cutting the Grenville series. This will be referred to again (page).

URANOTHORITE AND SULPHATIC ALTERATION PRODUCTS

Among the specimens collected from the dump of the MacDonald mine was one which proved to be uranothorite, the first known occurrence of this mineral in Canada. Subsequently several pounds more were obtained, some of which appears fresher than the original material analysed.

The specimen consists of aggregates of black crystals set in a mixture of quartz and somewhat decomposed and rusty feldspar. Both qua quartz and feldspar surrounding thorite are severely fractured, the fractures radiating generally in a direction normal to crystal surface The crystals are typically elongated square prisms varying from one-eighth to one-half inch in cross-section, and terminated in many cases by the basal pinnacoid. They are very brittle and cannot be extracted intact from the rock. Most of the thorite crystals in contact with feldspar are superficially altered for a depth of one-

one-quarter millimetre or less to a soft, pearly white mineral of about the colour and lustre of porcelain. Where thorite is in contact with quartz there is generally little or no alteration product, and the thorite is black and fresh right up to the contact. In some cases part of a single thorite crystal is altered where in contact with feldspar, fresh where enclosed by quartz. On close inspection under the binocular microscope patches of a paper-thin coating of more or less altered pyrite may be seen lining the feldspar in cavities from which thorite crystals have been broken out and also in fractures in the feldspar, whereas there is little or no pyrite at quartz-thorite contacts. Occasional minute grains of pyrite also occur embedded in the thorite crystals themselves. These have not oxidized. It seems very probable that originally there was a film of pyrite enveloping nearly all the thorite surface in contact with feldspar and that the thin layer of thorite alteration products is due to the action of sulphuric acid resulting from the oxidation of the pyrite. Where the alteration has been most intense there is a second alteration product, between the feldspar and the white material. This also occurs only in extremely thin films and minute patches, never over one-quarter millimetre thick, and where a crystal has broken out this mineral usually remains attached to the feldspar, whereas the white mineral is more likely to remain attached to the thorite. This alteration product is transparent to translucent, of a yellowish colour and resinous lustre, resembling some varieties of allophane in appearance.

That many of the thorite crystals are quite perfectly formed is indicated by various sections exposed where the feldspar with its contained crystals has broken in suitable directions. Nearly all the crystals, however, appear to connect with others at some point, so that the whole might almost be described as a "graphic intergrowth" of thorite with feldspar and quartz.

The thorite is black en masse, in thin sections brownish and isotropic; powder brownish grey; lustre sub-vitreous to pitchy; cleavage not apparent; fracture subconchoidal; very brittle; hardness 4.5 to 5. Sp.Gr.=4.414, n = 1.710

The results of an analysis of carefully selected crystal fragments free from alteration products are given on page....

The mineral is evidently a high uranium, high calcium thorite, with apparently a greater content of both U and Ca than any previously known.

In view of the very evident alteration of this mineral it is not surprising that the lead should be low and the apparent age only a small fraction of that indicated by the Ontario uraninites. The lead ratio is about the same as that determined by Todd[1] for ellsworthite from the same mine. Nevertheless, it is rather remarkable that the two minerals -- i.e., thorite and ellsworthite -- so different in composition, should ever agree as well as they do, granted that both have been

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[1] Walker and Parsons: University of Toronto Studies (1923)

greatly altered and leached. There is no geological evidence, however, (in the writer's opinion), to indicate that the MacDonald dyke is younger than other dykes of the Ontario Precambrian. For instance, uraninite from a somewhat similar calcite-bearing pegmatite on lot 4, con. XXI, Cardiff tp., Haliburton co., Ont. (the Richardson property), about 20 miles distant yields the normal ratio 0.15. Geologically, the occurrence of considerable quantities of calcite and dark purple fluorite in both dykes, as well as in many other pegmatites of the Bancroft area, seems to indicate a close relationship of all of them to one period of intrusion, so that in spite of the low age indications of the ellsworthite and thorite, the writer believes that the MacDonald dyke cannot be younger than the Richardson pegmatite just mentioned.

The two minerals resulting from sulphatic alteration of the thorit occur in such minute amounts that it was impossible to isolate sufficien quantities for quantitative analysis. Careful qualitative microchemical tests indicated that thorium is the most prominent constituents of both, with uranium apparently next in importance. Iron and small amounts of lead are present, with SO_3 and SiO_2 as acids. Carbon dioxide was not detected. As only the most minute quantities could be obtained in approximately pure condition it was impossible to do more than identify the main constituents. Thorium was positively identified in both cases by the formation of the oxalate with oxalic acid in hydrochloric acid solution and by the formation of the peroxynitrate precipitate in a neutral nitrate solution. Relatively large Th precipitates were obtained.

Both minerals appear to be hydrous basic sulpho-silicates of thorium chiefly, with minor uranium, iron, and lead, and quite likely some aluminium and calcium. There does not appear to be an abnormal amount of lead present -- i.e., no more than would roughly correspond to the amount present in the thorite itself. These alteration products were examined in the first instance with the idea that they might represent a concentration of lead compounds derived from the thorite, but no evidence was obtained that would indicate the presence of lead in increased amounts. The sulphate reactions obtained may of course be due solely to lead sulphate, though there appeared to be more SO_3 than would correspond to the lead present. The yellow-brown alteration product in particular might be expected to contain aluminium derived from the feldspar, which also appears to have been considerably attacked by the decomposing pyrite.

The white mineral will be referred to here as alpha-hyblite, the yellow-brown one as beta-hyblite.

Although alpha-hyblite appears opaque, pearly white, or porcelainic under the binocular, minute grains when immersed in oils under fairly high power are brownish, transparent to cloudy, isotropic and without visible definite cleavage, though it may have a scaly cleavage or parting. With high power many extremely minute bubbles are visible which perhaps are aggregations of entrapped helium. These bubbles probably contribute largely toward producing the brownish colour at lower magnifications, but even with high powers the mineral itself still appears yellowish. The great majority of grains selected at random from different crystals have indices between 1.540 and 1.545 which seems to indicate that most of the material is one fairly definite compound. A few grains which go as high as 1.580 are perhaps transitional to beta-hyblite.

Beta-hyblite under the binocular appears yellowish brown with resinous lustre and conchoidal fracture and is transparent to translucent. It is very brittle and easily scratched by a needle point, but is harder than alpha-hyblite. In oils under the microscope it is yellowish to brownish, isotropic and definitely granular, whereas alpha-hyblite is powdery or scaly. The beta-hyblite is without bubbles and it also shows no cleavage. The great majority of the grains taken at random have indices between 1.605 and 1.610, not exceeding the latter value.

As the most completely altered yellow thorites listed by Larsen do not go below n =1.68 it is evident that these two materials are very different in every way from the usual alteration product of thorite.

Allanite. Allanite occurred as very large masses, some 100 pounds or more in weight, in some cases completely embedded in feldspar and quartz, in others in proximity to the sulphide association. The allanite contains inclusions of radioactive minerals. The detailed study of the allanite has not yet been completed, an exact determination of the lead ratio being particularly desirable in this case for comparison with the ratios of ellsworthite and uranothorite.

Zircon or Cyrtolite. The mineral which has been referred to as zircon or cyrtolite has not been analysed. Numerous small crystals probably nearer zircon than cyrtolite occur in the calcite-quartz-ellsworthite masses. The crystal faces are seldom if ever absolutely plane surfaces and probably a small amount of rare earths, U, Th, etc., will be found to be present.

At other points in the normal feldspar and quartz of the dyke, lumps consisting of aggregations of crystals, with radiating structure and more noticeably curved faces are found quite abundantly. These are more altered also than the individual crystals from the calcite association, are slightly radioactive, and doubtless will prove to be cyrtolite.

Zircon or cyrtolite also occurs as previously mentioned, in the sulphide association with pyrite, pyrrhotite, chalcopyrite, molybdenite, ellsworthite, allanite, fluorite, and rarely a little galena.

RADIOACTIVE, RARE-EARTH BEARING GARNET

A dark brown mineral occurring near the walls of the dyke as rounded masses or rough crystals, some several inches across, has been identified by qualitative tests as probably iron-lime garnet

— andradite. All specimens so far examined are quite noticeably radioactive. The mineral is isotropic with specific gravity around 3.73 and index greater than 1.80. Uranium and thorium were not identified with certainty on a 1-gram sample, but a content of 1.14 per cent of rare earths was found. No inclusions of other minerals could be seen under the binocular in the material used for the test, but very careful optical examination would be necessary to eliminate this possibility. Nevertheless, it is possible (to the writer it seems probable) that the rare earths are really a constituent of the garnet, probably replacing lime. This is a point of some mineralogical interest which the writer hopes to investigate as opportunity permits.

CALCITE

The calcite that carries most of the ellsworthite has been studie by Walker and Parsons (loc.cit.) with an analysis by E.W.Todd. It is a deep salmon pink in colour and of a coarse crystalline texture, with cleavage parallel to r $(01\bar{1}1)$ and sometimes to e $(01\bar{1}2)$. An analysis by E.W.Todd follows:

MACDONALD MINE

	Percentages	Molecular parts
CaO	55.43	990
CO_2	43.86	995
FeO	0.28	004
MnO	0.21	003
SiO_2	0.03	001
Moisture	0.10	005
Total	99.91	

No traces of Nb_2O_5, Ta_2O_5, TiO_2, ZrO_2, WO_3, SnO_2, rare earths, Fe_2O_3, Al_2O_3, U_3O_8, MgO, ZnO, F, S, SO_3, or P_2O_5 were found. The colour is due to manganese and possibly ferrous iron, as is clearly shown by the decoloration of the calcite near the contact with the ellsworthite, where secondary hematite has been formed in cleavage cracks, together with a black mineral which is possibly pyrolusite, though in too minute a quantity to be identified with satisfaction.

ANTOZONITE (FOETID FLUORITE)

The foetid fluorite of the MacDonald mine has been studied by F.L.Sine (Antozonite from Monteagle Township, Hastings county, Ontario, University of Toronto Studies, No. 20, 1925, pages 22-24), who describes it in part as follows:"This fluorite is characterised by a strong odour suggestive of ozone, when crushed, a loss of the blue colour on heating, and a lack of the power to phosphoresce. During the crushing of the mineral a gas is evolved and oxidation of any readily oxidizable substance which may be present takes place. The liberation of the gas may be readily seen by immersing a fragment of the mineral in a liquid and crushing it in the field of a low-power objective. Ordinary fluorite does not free a gas during crushing." From his oxidation experiments Mr. Sine concluded that the fluorite contains free fluorine to the extent of 4.55 parts by weight in 10,000 parts of the mineral, or eight volumes of fluorine per ten volumes of mineral.

NORTH DYKE, MACDONALD MINE

Two smaller dykes on the MacDonald property were also mined. The one nearer the main dyke is of no particular interest. The other is 20 to 25 feet wide and dips 30 degrees to the north. The country rock is the same highly deformed gneiss as seen at the main dyke, a rock consisting chiefly of pyroxene, calcite, and feldspar, evidently a contact product of granite acting on crystalline limestone. The cut is 10 to 15 feet deep with a level floor. The quartz and feldspar are very coarsely crystallized here also. Masses of white quartz 10 by 20 feet occur with large crystals of microcline; Crude allanite crystals a foot or more wide, 2 feet long, and 3 inches thick form groups set in red radially shattered crystal microcline. Large, rounded pyroxene crystals attain a diameter of 2 feet or more. Zircon or cyrtolite crystals are associated sparingly with the allanite and they also occur in bunches the size of a man's fist in radially fractured quartz or microcline. Titanite and elmenite are abundant. A few small crystals of white and black mica may be seen. Pyrite, smoky quartz, and a little plagioclase feldspar complete the list of minerals observed.

WOODCOX MINE

This mine, on the property of Mr. H Woodcox, lot 17, con. VIII, Monteagle tp. (See Figure 5) about 1 mile northeast of the MacDonald dyke was worked for several years by the Feldspar Mines Corporation, a mining subsidiary of the Pennsylvania Pulverizing Company, Lewiston, Pa. The dyke averages 60 feet in width and has been exposed by strippin for a length of 350 feet. From 3 to 6 feet of bouldery drift was removed. The dyke strikes northeasterly along a low hill which slopes gently the same way. The dip is uncertain, probably nearly vertical or slightly to the north. One or two small exposures of country rockin the stripping at the contact are of reddish granite-gneiss. The workings are 20 to 30 feet deep and are not everywhere the full width of the dyke. Part of the pit is at present filled with waste rock. This dyke contained a considerable amount of good, coarsely-crystallized, pink microcline with massive white quartz, but some parts were rather "dirty" from the feldspar miners' point of view, containing in abundanc minerals such as hornblende, pyroxene, black mica, titanite, pyrite, and hematite, resulting from the decomposition of the pyrite. Some red garnets, dark purple fluorite, and black tourmaline were found. Allanite in crystals an inch long are abundant in some of the fine-grained parts. Many rusty cavities containing either massive red hematite or reddish hematite mud were encountered. The titanite crystals are in places almost completely altered to a yellowish powder. The whole appearance of the dyke is suggestive of considerable alteration by downward descending waters, which penetrated through fractures caused by the expansion of masses of radioactive minerals.

Nodular masses of brown to black radioactive minerals, commonly associated with crystals or masses of greyish cyrolite, a variety of zircon, and with columbite, were of not unusual occurrence. Such masses in places reached a weight of 100 pounds and they invariably produced marked disintegrative effects on the surrounding quartz and feldspar, the rock within a radius of a yard or two being in some instances completely shattered by fractures radiating from the central mass. The

Feldspar surrounding the radioactive minerals is unusually red and apparently softened and more or less altered for a distance of 1 to 3 feet from such a mass, the effect being the greater the nearer the feldspar is to the radio active minerals. These phenomena (the invariably shattered condition of rock enclosing radioactive minerals and the red coloration of neighbouring feldspar) have been noted in a large number of varied occurrences. The common pegmatite minerals do not apparently produce shattering in quartz and feldspar. For magnitude and intensity of such effects the Woodcox dyke is unique, for nowhere else in Canada have such large individual masses of radioactive minerals been found in quartz and feldspar.

Near the middle of the dyke toward the west end, several tons (it is said even carloads) of beautiful amazon stone (a green variety of microcline) were mined and shipped. Since the end of 1923 mining operations have ceased.

Mr. R.H.Thompson, superintendent of the mine, stated that during the summer of 1923 a large mass of calcite was encountered at a point in the bottom of the working near the west end. Work there was stopped and the depression allowed to fill with water, forming a pool several feet deep. Not much of the calcite was removed, but fragments seen on the dump were white to pinkish, very pure, coarsely crystallized, cleavable material resembling that of the MacDonald mine. To the north of the calcite mass is a cavern which perhaps was originally occupied by calcite. An investigation of this calcite mass would be extremely interesting in view of the radioactive mineral content of the MacDonald mine calcite. It may be significant that the radioactive minerals found in this dyke occurred in the eastern part, little or none being found in the western half where the calcite is situated. The calcite may, therefore, serve as the storehouse for radioactive minerals in this part of the dyke.

Hatchettolite, cyrtolite, and columbite from this dyke have been described by Walker and Parsons[1] with analyses by E.W.Todd, Which are reproduced on page....

HATCHETTOLITE[2]

This mineral appears in two slightly different types, one black, the other somewhat amber-tinted in thin splinters. They are both conchoidal in fracture, and about 4 in hardness. The hatchettolite occurs without crystal form in irregular masses closely associated with reddish feldspar and cyrtolite. Both types are nearly isotropic and possess refractive indices higher than 1.74 . The two types were analysed by E.W.Todd, See page ....

These two types, light and dark, bear a relationship to one another analagous to that shown by the two types of ellsworthite, In both cases the light variety carries more water, and less lead, contains its uranium in a higher state of oxidation, and is somewhat lower in density. For hatchettolite and ellsworthite the light

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[1] University of Toronto Studies, No. 16, 1923.

[2] Walker and Parsons, Loc.cit.

coloured types are probably secondary, derived from the dark types by hydration and oxidation. Being younger, the lead content, resulting from the break-up of the uranium, is also lower. The density of mineral is somewhat lower than that of the hatchettolite from the type locality, but this may be readily accounted for by the fact that our mineral contains less tantalum and more titanium than is found in the mineral from the type locality. This is the first reported occurrence of hatchettolite in Canada.

ZIRCON, VARIETY CYRTOLITE[1]

This mineral occurs along with hatchettolite, and makes up about half the mass in some of our specimens. It is for the most part quite massive, grey in colour, and fine-grained. It has a pitchy lustre and sometimes constitutes irregular stringers half an inch wide and 2 inches long. On the outer surfaces, where the mineral is in contact with the feldspar, imperfect crystallization may be seen. All the crystal surfaces are much more curved as in the type of this variety. The pyramid is the most prominent form. This mineral was analysed by E.W.Todd. The analyses are given on page.....

The niobium and uranium were probably derived from hatchettolite, which could not be completely separated from the cyrtolite. This variety of zircon in general contains considerable water and an excess of zirconia over silica. In the present example the specific gravity is somewhat lower than for zircon. It can hardly be regarded as an alteration from the normal zircon, ~~for~~ as its massive form and

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[1] Walker and Parsons: Loc.Cit.

curved crystal surfaces appear to be primary characteristics.

COLUMBITE [1]

[1] Walker and Parsons: Loc.cit.

The specimen of columbite studied was massive and fine grained. Examination of a thin section shows the presence of a small amount of rutile, the presence of which is confirmed by the chemical analysis (See page...) from which it may be observed that no simple columbite formula can be derived if the TiO_2 be included with the Nb_2O_5 and Ta_2O_5. The general complexity is indicated by the presence of not inconsiderable amounts of titanic acid, water, zirconia, tin, and rare earths.

CALCIOSAMARSKITE [2]

[2] Ellsworth H.V.: [illegible] Am. Min., Feb., 1928.

The writer examined a mineral from the Woodcox mine which appears to be related to samarskite. The material examined was part of a large mass which originally must have weighed at least 100 pounds. It consisted chiefly of a brown complex columbate with some black miner which was the substance analysed. The brown mineral appears to be a mor altered phase of the black one. The latter was analysed (for analyses see page...) because it presumably would represent more nearly the original composition of the mineral and might be expected to be more favourable material for determining the radioactive age ratio. The samples selected for analysis on microscopic examination appeared to be homogeneous and free from inclusions of any kind. The mineral is [illegible] brilliant jet black en masse, brownish and isotropic in grains on sections under the microscope. The powder is greyish brown and lustre is brilliant submetallic. Cleavage none, fracture subconchoidal. H=6.5, Sp. gr. =4.738, and massive.

The analysis yields a very low lead ratio in agreement with Todd's results for hatchettolite from this mine. The high silica content is noteworthy and is unquestionably the result of alteration. The whole of the dyke exposed by the workings has been more or less shattered apparently chiefly, if not wholly, by the radioactive mineral masses and has been subjected to considerable alteration by surface waters. This mineral furnishes another instance of a Pre-cambrian mineral with an abnormally low lead ratio associated with a high silica content, a point to which the writer has given some attention in earlier pages.

The mineral seems to be most nearly related to samarskite though containing very much more lime than has been previously found in samarskite. All the radioactive minerals found in the calcite-bearing pegmatites of the Haliburton-Bancroft area tend to be high in lime, doubtless because of the universal presence of dissolved calcium carbonate in the magmas of that area. Thus this mineral perhaps represents the type of samarskite produced by a magma rich in lime. Considering the term samarskite as embracing a group of minerals in which considerable percentage variations of the constituents may conceivably occur, due to isomorphous replacement, the mineral here described seems to represent the case where iron is partly replaced by lime, and the name calciosamarskite is suggested as a suitable designation for this variety. A mineral similar to this in composition occurs with uraninite in Conger township, Parry Sound district (page...).

AGE OF THE MACDONALD AND WOODCOX DYKES

Ellsworthite and uranothorite from the MacDonald dyke and hatchettolite and calciosamarskite from the Woodcox mine all yield lead ratios from 0.02 to 0.04, in contrast with ratios of around 0.12 shown by uraninites from various parts of the Precambrian of southern Ontario and adjacent Quebec. To account for this inconsistency three explanations might be advanced.

(1) The age as indicated by the lead ratios is correct, from which it follows that these dykes might be of comparatively late geological age, perhaps late Devonian according to the radioactive time scale. To the writer it seems impossible that this explanation can be correct, as there is not the slightest geological evidence that intrusives younger than the Precambrian are present, and, further, uraninite from the Richardson dyke, Cardiff township, which also carries calcite and fluorite and appears to be genetically related to the Hybla dykes, gives a normal Precambrian ratio of 0.15.

(2[The minerals were formed initially in Precambrian time but were subjected to a later igneous action, by reason of which the accumulated radioactive lead was removed and only that which has been formed since is now present. This theory superficially seems almost as improbable as the first, since there is no geological evidence anywhere in this part of Ontario indicating igneous activity in Palaeozoic time. Nevertheless this theory may be worthy of some consideration, since intrusive igneous plugs penetrate Ordovician sediments at Montreal and vicinity about 200 miles to the eastward and inclusions of Lower Devonian limestone are found in the intruded rock of mount Royal. To the southward in New York state, peridotite dykes occur in Palaeozoic rocks near Syracuse[1] and Ithaca.[2]

(3) The minerals have undergone a selective leaching or replacement process by which lead was removed faster than uranium and thorium. If this be so, the close agreement between the lead ratios of ellsworthite and uranothorite is rather surprising, as they differ so greatly in composition, as well as in uranium and thorium content, that differences in the degree of differential leaching might be expected. Nevertheless, it is well to recall here, that samarskite occurring with uraninite at Parry Sound (page) yields a ratio of 0.03 while the uraninite ratio is 0.155. Uraninite is now known to yield the most consistent and reliable age results, whereas the complex columbate minerals and high thorium minerals have so far yielded rather irregular and inconsistent results, which, however, it must be admitted may be in some cases due to the difficulties of exact analysis.

Atomic weight determinations of the galena found at the MacDonald dyke might throw some light on the history of the dyke.

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[1] Williams, G.H.: Am. Jour. Sci.,Aug., 1887, p. 144.
[2] Kemp, J.F.:Am. Jour. Sci.,No. 251, 1891,p.410.

If the lead were found to be of radioactive origin it would be a point in favour of the theory of igneous action in Devonian time.

CARDIFF TOWNSHIP, HALIBURTON COUNTY: ELLSWORTHITE

Reference: Ellsworth, H.V.: Am. Min., Feb., 1927.

Crystals of ellsworthite were received from Mr. Charles G. Earle of Haliburton and stated by him to have been obtained from lot 10, con.XII, Cardiff township. The locality was visited but as work had ceased and the shaft was nearly full of water, not much could be seen. The opening consists of a shaft 8 feet square and said to be 30 feet deep, sunk on a vein of reddish calcite about 1½ feet wide at the top and said to be 3 to 5 feet wide deeper down. The shaft inclines slightly to the west. The calcite varies in colour from light pink to dark red and carries much black mica in books up to 3 inches in diameter and ½ inch thick, and apatite crystals with flat basal terminations, up to 3 inches long. The ellsworthite crystals occur embedded in calcite or sometimes weathered loose in cavities. The calcite veins in this part of Cardiff township and the calcite-fluorite-apatite deposits east of Wilberforce which carry uraninite, no doubt have a common igneous origin. The term vein-dyke as proposed by Spurr seems very appropriate for this type of deposit, representing the last residual material of a cooling magma.

The material received from Mr. Earle consisted of a few ouncesof small loose crystals varying from less than ¼ inch to ½ inch in diameter. Most of the crystals were more or less coated with a yellowish brown decomposition or resorption product. Some were entirely clear from any superficial coating or alteration. An analysis of carefully prepared material is given on page ....

LYNDOCK TOWNSHIP, RENFREW COUNTY: BERYL, LYNDOCHITE, ETC

References: Geol. Surv., Canada, N.S., vol. VIII, pt.R, p. 14.

Miller, Willer, G.: 7th Rept. Ont. Bur. of Mines, 1897, pt.III, p.234

Walker, T.L. and Parsons, A.L.: Cont. to Canadian Mineralogy, No. 16, 1923, p.34 and No. 24, 1927, p.12

Ellsworth, H.V.: Am. Min., May, 1927.

The occurrence of beryl and a euxenite-like mineral in a pegmatite dyke on lot 23, con.XV, Lyndoch tp., Renfrew co., has been known for many years, having been first described by Willet G. Millet in the 7th Report of the Ontario Bureau of Mines, 1897, pt.III, p.234.

The dyke was almost entirely covered by soil, brush, etc., only a few square yards being exposed, until the summer of 1926 when Mr T.B. Caldwell of Perth opened it up in the hope of obtaining beryl in commercial quantities. It is variously estimated that from 2 to 4 tons of beryl crystals were obtained. The dyke was more or less opened up over a length of 100 feet, a width of 5 to 10 feet, and a depth of 3 to 6 feet, but it is even yet not fully exposed. The strike in a general way appears to be about north 60 degrees east magnetic.

The openings show crystal masses up to 6 feet diameter of pink microcline and beautiful green amazon-stone, a moderate amount, perhaps not over 10 per cent of the whole, of white, smoky, and pale rose quartz: platy albite (variety cleavelandite), with some more or less albitized pink microcline. Accessory rare minerals that have been identified are: beryl, columbite, lyndochite, cyrtolite, monazite. A few red garnets in good crystals up to 2 inches in diameter occur and also a small amount of fluorite. Magnetite is abundant in the finer-grained parts of the dyke. Triangular black tourmaline crystals up to 6 inches in diameter are not uncommon, more especially in the albite. There is reason to believe that bismuthinite was also found, as this mineral is recorded [1] as occurring in a dyke with beryl in the same township, and Mr. John Sullivan, the discoverer of the dyke, some years ago informed the writer that he had found in earlier years a mineral answering to the description of bismuthinite.

BERYL

The beryl occurs as well-formed crystals usually from 1 to 3 inches in diameter, but in some cases as much as 6 or 8 inches in diameter and 3 feet or more long, most abundantly in association with the cleavelandite and also in massive microcline. A few crystals with well-developed terminations have been found, but they are exceptional. Terminated beryls from this locality have been described and figured by Walker and Parsons (loc.cit.)Some of the beryl crystals have been considerably bent without breaking, showing that the dyke has been subjected to severe stress. Occasional crystals may be in part clear and transparent and of gem quality except that the colour is not attractive, being a pale bluish or greenish tint or almost colourless. There is a very little beryl insight at the present time, all the richer areas

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[1] Geol. Surv., Canada, N.S., vol. VIII, pt. R p.14

having been mined out. Only an occasional small crystal can now be seen. An analysis of the pure material by H.C.Rickaby[1] is given on page .....

Lyndochite. Excellent crystals of a black columbate (lyndochite) collected at different times by A.T.McKinnon of this Department and the writer, have been in the Survey collection for several years. Owing to the roughness and distortion of the faces it has not been possible to make sufficiently exact measurements to be sure to what extent the interfacial angles differ from those of euxenite, but several fairly accurate contact measurements suggest a close similarity of forms and angles.

The mineral is brilliant black en masse, reddish brown and translucent by strong illumination of the thin edges or splinters or in a powder under the microscope. Powder pale yellow; lustre vitreous; perfect conchoidal fracture; cleavage none; hardness 6.5; Sp.Gr. 4.909 at 17.88 degrees; infusible.

Although a number of well-developed crystals and crystal fragments were available, the selection of a suitable sample for analysis was complicated by the discovery that all the material, including even the most perfectly formed crystals, contained scattered inclusions of an opaque black metallic looking mineral which proved to be columbite, easily distinguishable under the binocular microscope from the vitreous, semitransparent lyndochite. These inclusions fortunately are, for the most part, distributed in such a manner that was possible, by breaking up the material into small pieces a few millimetres in size, to select fragments showing under the binocular no visible inclusions. Nevertheless, thin sections of crystals showed that it would be impossible to obtain an absolutely pure sample as occasional microscopic inclusions exist in small amount even in the best material. These microscopic inclusions are plainly remnants of columbite in process of transformation to lyndochite. An analysis of the selected material is given on page ....

Columbite. Columbite occurs as thin, flat, disk-shaped masses with concentric markings on cleavages or partings of feldspar. The masses may vary in size from less than an inch in diameter to as much as a foot or more across. The large ones are comparatively thin, seldom more than ½ inch thick, whereas the smaller ones less than an inch in diameter may be almost hemispherical. The columbite was first analysed by Dr. W.L.Goodwin[1] and later a more complete analysis was made by E.W.Todd[2]. These analyses are given on page....

Cyrtolite. This mineral occurs in typical crystal masses up to the size of a fist, and of the usual greyish or yellowish colour. It has not been analysed.

Monazite. One rough wedge-shaped crystal about 2 inches square by ½ inch thick, and a few much smaller ones were found by the writer embedded in red microcline near a lyndochite crystal and a small

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[1] Miller, W.G.: Rept. Ont. Bureau of Mines, 1907.

[2] Walker, T.L. and Parsons, A.L.: Contributions to Canadian Mineralogy, No.16, 1923, p.34

cyrtolite mass. The monazite is a dull brown colour and has lost its transparency by alteration.

NEIGHBOURING OCCURRENCES

Specimens of radioactive minerals, as yet unidentified, and a few small beryl crystals up to 1 inch in diameter were obtained from a dyke on the farm of John Sullivan, south half lot 30, concession 15, Lyndoch. The exposures consist chiefly of large, solid masses of white to pale rose pegmatite quartz 20 to 40 feet in diameter, bordered in places by pure pink to red crystal microcline. At one point a width of 10 feet of crystal microcline is visible, but the dyke is nowhere completely exposed, the contacts being concealed by drift sand and gravel. The greater extension of the outcrop is in a direction about north 60-65 degrees east. Though at first sight the large quartz masses appear to be indicative of an unusually large dyke, it is possible that the dyke is lying nearly flat and that it is really the side of the quartz masses which is seen rather than a cross-section. Under such conditions a dyke only 25 or 30 feet wide might be cut down in such a way as to produce the exposures just described. A few shots had been put in by Mr. Sullivan and the radioactive mineral mentioned was found associated with fluorite and granular smoky quartz at the edge of the massive white quartz. The dyke no doubt would have been opened up for feldspar if it were not for difficulties in transportation.

The writer has been told of other alleged beryl occurrences in this area, but the exact locations were not stated. This region appears to be favourable for the occurrence of beryl and other pegmatitic rare minerals.

CRAIGMONT, RAGLAN TOWNSHIP, RENFREW COUNTY:

At Craigmont there are enormous open-cuts on the side of a large hill where corundum was formerly mined. Much the greater part of the corundum obtained came from red syenite pegmatite, but some was later obtained from corundum-bearing nepheline rock in the "Klondyke workings" northeast of the original cuttings. The geology of the corundum occurrences has been very fully discussed by Adams and Barlow[1].

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[1] Geology of the Haliburton and Bancroft Areas, Ontario: Geol. Surv., Canada, Mem. No. 6

Minerals seen on the dump or in situ were ; Magnetite, pyrite, pyroxene, black hornblende, common; black and white mica, occasional; molybdenite, occasional; in flakes up to 2 inches diameter. Calcite occurs moulded on inwardly projecting feldspar crystals and faces. Quartz occurs only rarely and in small amounts lining vugs and probably of secondary origin.

Euxenite or similar complex radioactive minerals and allanite can be found in small amount throughout the pegmatite workings without much trouble. Some years ago the old concentrating mill burned down and subsequently a quantity of concentrates that had been in the fire were put through the new mill. Among the heaviest materials coming off the tables was a mixture of lead pellets the size of No. 8 shot or smaller, along with fused sulphides, magnetite, etc., on which Mr.

Clarke, probably at the instance of Sir Stopford Brunton, had tests made for radioactivity, first at McGill University and later in the United States. In both cases the material was reported to be slightly radioactive. Mr.Clarke kindly presented the writer with a sample of this concentrate and examination under the binocular revealed a few small grains which chemical and alpha-ray tests proved to be unquestionably uraninite. Tests on some of these grains showed a high lead content corresponding to the 9 or 10 per cent PbO commonly found in Ontario uraninites, and it was evident that lead pellets were derived from the uraninite, as some of the grains of the latter were more or less fused and carried minute globules of lead on their surfaces. It is unfortunate that tests for radioactive minerals were not carried out in connexion with the concentration of the corundum when the mine was working, as it seems quite possible that it might have been practicable to recover a heavy radioactive concentrate in paying quantities at little or no extra expense. Mr. E.B.Clarke, former manager of the mine, informed the writer that there was, according to his estimate, 350,000 tons of tailings from the old operations, of which 200,000 tons still containing 3½ per cent corundum could be rehandled. It seems probable, however, that any uraninite originally present would be decomposed by this time, though minerals such as euxenite, etc., might still be recoverable.

BURGESS MINE, CARLOW TOWNSHIP, HASTINGS COUNTY

At the Burgess mine the corundum occurred in red syenite pegmatite as at Craigmont. Nodules of radioactive mineral were fairly abundant in some of the fragments on the dump, and some were also seen at the Grady Lake opening of the Burgess Company. These minerals and those from Craigmont have not yet been studied in detail.

HASTINGS AND RENFREW COUNTIES: VARIOUS OCCURRENCES

Reference: Adams, F.P. and Barlow,A.E.: Mem. No. 6, Geol.Surv.,Canada; No. 108.

Adams and Barlow (loc.cit.,page 252) in regard to zircon say: In some of the coarser phases of the rock, noticeably at York river in Dungannon and at Craigmont in Raglan, crystals are not uncommon which would measure from a quarter to half an inch in length. The same authors (page 253) believed they had identified eucolite. A mineral with the characters of eucolite occurs rather abundantly in the hornblendic variety of nepheline syenite at Egan chute, on York river, as well as at another locality a little lower down the same stream. It occurs with a yellow colour, usually with incomplete crystallographic boundaries. It is intimately associated with hornblende and garnet, frequently enclosed in the former, and with an appearance altogether suggesting the latter mineral.

LOUGHBOROUGH TOWNSHIP,FRONTENAC COUNTY:GADOLINITE-EUXENITE

Reference: Ellsworth, H.V.: Am. Min., March 1932.

Several years ago a dyke on lot 11, con. IX, Loughborough tp., Frontenac co., was worked a short time for feldspar by the M.J.O'Brien interests, the feldspar being shipped from Perth Road station on the Canadian National railway. Mr. N.B.Davis, who was in charge of the operations, collected from this dyke a few small specimens of euxenite and part of a crystal which subsequently proved to be gadolinite. No more of this material was found and operations ceased soon afterwards. Mr. Davis states that the dyke was of the ordinary type mined for felspar in this region, with no especially noteworthy features.

The gadolinite specimen weighs about a quarter of a pound. It appears to be a part of the end of a good-sized crystal with rough but distinct faces deformed by contact with the matrix minerals, and it is well preserved, being hard and in part very fresh and vitreous. Along some small fractures the mineral is dull and greyish and this grey substance was at first taken to be some othermineral, but on optical examination of a thin section it appears to be possibly an alteration of the vitreous material. Both parts appear to have an almost equal hardness of 6.5 or more, though the vitreous material may be slightly harder than the other. The vitreous material in small grains is clear and transparent like glass under the microscope, with very perfect conchoidal fracture, anisotropic character, and index greater than 1.75. There is no sign of cleavage. In the hand specimen this material is black and vitreous. The greyish material under the microscope is somewhat cloudy but largely anistropic also. It appears to be merely a less pure and perfectly crystallized form of the other or perhaps is the same material somewhat altered. The specific gravity of the selected material used for analysis was 4.101 at 13.80 degrees C

This gadolinite seems to differ somewhat in some of its reaction from the typical gadolinites of mineralogical literature. Nevertheless the chemical analysis indicates nothing unusual in its composition, which agrees with that of many previously described occurrences. The results of an analysis of selected material are given on page....

SHERBROOK SOUTH TOWNSHIP, LANARK COUNTY: EUXENITE

References: Miller, Willet, G. and Knight Cyril, W: 26th Rept. Ont. Bur. of Mines, 1917, pp. 314-317.
Carnochan, R.K.: Sum. Rept., Mines Branch, Dept. of Mines, 1921, p.195
Ellsworth, H.V.: Am. Min. Oct., 1927.

The occurrence of euxenite in the Orser-Kraft feldspar mine, lot 13, con.V, South Sherbrooke tp., Lanark co., about 3 miles south of Maberly, was first described by Willet G. Miller and Cyril W.Knight[1], with an analysis of the euxenite by the Imperial Institute, London. Mining continued more or less intermittently for quite a number of years after this first description was written and a large quantity of feldspar was shipped, mainly for the manufacture of household scrubbing powder.

The dyke was in places as much as 75 feet wide with strike north 75 degrees east magnetic and dip slightly to the north. The opening when last seen by the writer was over 200 feet long, 56 feet wide at the top, and 30 to 40 feet deep. A large portion of the dyke was composed of graphic intergrowth of feldspar and quartz but more segregated areas of large crystals of feldspar and massive quartz occurred at the eastern end and at depth, and some high-grade crystal feldspar was produced. The feldspar on the whole was fairly light coloured, and was said to grind to a good white powder. Black tourmaline

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[1] 26th Rept. Ont., Bur. of Mines, 1917, pp. 314-317.

crystals were abundant in some parts of the dyke, particularly at the west end and in some areas quite a little black mica occurred. Scaly wide and yellowish mica was also not uncommon. Euxenite was in evidence, according to the operators, during the whole period of mining, occurring in the feldspar and particularly along with black mica. It was quite common also to see tourmaline crystals with a central core of euxenite. The feldspar around euxenite was always c coloured a deep red in contrast with the lighter tints where euxenite was absent. The euxenite varied somewhat in depth of colour and individial crystals might be found to differ in composition. Other rare minerals such as xenotime were present in very small amounts. The euxenite analysed by the Imperial Institute, London, was obtained from the first shallow workings and probably was more altered than that subsequently analysed by the writer. The analysis as quoted by Miller and Knight (loc.cit.) is given on page .....

At various times the euxenite appeared to be almost abundant enough to be worth recovering and during the winter of 1921 Mr. Orser, at the writer's suggestion, sorted out a quantity of the red feldspar containing euxenite and submitted it to the Ore Testing Division, Mines Branch, Department of Mines, Ottawa, tests for concentration the results of which made under direction of R.K.Carnochan (loc.cit.) are reproduced below.

TEST NO 159

A shipment of euxenite ore weighing 1,593 pounds net was received on November 29, 1921, from the Orser-Kraft Feldspar, Limited, Box. 266, Perth, Ont. The ore came from the company's property at Maberly, Ont., and consisted of fair-sized crystals of black euxenite in red orthoclase feldspar.

It was desired that the euxenite be separated from the feldspar and that both be recovered in the form of clean products.

A number of specimens were picked out of the ore and the remainder was reduced in a jaw crusher to ¾ inch.

Product	Weight, pounds	Per cent of pounds
¾ inch	1,582.00	99.80
Loss	3.25	0.20
Heads	1,585.25	100.00

The ¾-inch material was crushed in rolls and then screened on 12-inch shaking Ferraris screen, the oversize from the screen being fed back to the rolls until it all passed through the screen.

Product	Weight, pounds	Per cent of pounds
12 INCH	1,472	92.86
Loss	110	6.94
¾ inch	1,582	99.80

The 12-mesh material was sized on a Keedy sizer into four sizes: - 8+20; -20+42; -42+86; and -86 .

Product	Weight, pounds	Per cent of heads
-8+20	394.0	24.86
-20+42	535.5	33.78
-42+86	260.5	16.43
-86	267.0	16.84
Loss	15.0	0.95
- 12 mesh	1,472.0	92.86

Each of the four sizes from the Keedy sizer was tabled separately on a large Wilfley table, so as to make a euxenite concentrate and a feldspar tailing of each size. These products were collected as they came from the tables in long settling boxes. The water from the tailing box was pumped to a callow cone during the tabling of all the different sizes, and by this means a certain amount of slime was removed. After tabling all products were dried and weighed. The four concentrates produced were very good, being nearly all euxenite with only a small percentage of feldspar. The tailings were composed of clean feldspar. The slime from the Callow tank was very fine, and drab in colour, and under the microscope was seen to be made up mostly of feldspar with a little euxenite.

Product		Weight, pounds	Per cent of heads	
Concentrate	- 8 20	14.00	0.89)	
"	-20 40	23.50	1.48)	3.67
"	-42 86	10.50	0.66)	
"	-86	10.12	0.64)	
Tailing	-8 20	370.00	23.34)	
"	-20 42	504.00	31.79)	83.45
"	-42 86	244.00	15.39)	
"	- -86	205.00	12.93)	
Slimes		42.00	2.65	
Loss		33.83	2.14	
Feed to table		1,457.00	91.91	

The concentrate, after sampling, and a sample representing in proper proportions the combined four sizes of tailings, were shipped to the Orser-Kraft Feldspar, Limited, Perth, Ont.

Summary and Conclusions: The euxenite concentrate produced equals 3.67 per cent of the ore treated.

The feldspar tailing product equals 83.45 per cent of the ore treated.

The slimes produced equal 2.65 per cent of the ore treated.

The loss in treatment equals 10.23 per cent of the ore treate

A good separation of the euxenite from the feldspar can be made. Good clean products can be produced.

Dry crushing and tabling is a very suitable method of treating the ore as submitted.

Samples of the various concentrates were mixed in the proper proportions to represent the whole, and on analysis yielded the following results (Analyst, H.V.Ellsworth).

	Per Cent
U_3O_8	5.7
ThO_2	2.30
Cerium group earths	0.48
Yttrium group earths	16.31

Ground samples of tailings and slimes were tested in the alpha-ray electroscope against the analysed concentrate with the following results:

Tailings ... alpha-ray activity practically nil
Slimes ... alpha-ray activity 1/ 178 that of concentrate

The slimes, therefore, carry about 0.04 per cent $U_3O_8 + ThO_2$ or about 0.03 U_3O_8 and 0.01 per cent ThO_2 , and the separation from the tailings is practically 100 per cent complete. Thus on a ton of 2,000 pounds, the recovery was 73.4 pounds of concentrates containing 4.18 pounds U_3O_8 and 1.68 pounds ThO_2, and 53 pounds of slimes containing 0.02 pounds U_3O_8 and ThO_2. The ore, therefore, carried about 0.2 per cent U_3O_8 and 0.08 per cent ThO_2. It is evident that the concentration treatment was highly successful, but prices offered by European radium refiners for the concentrate were too low to stimulate further interest in the recovery of the euxenite.

The original analyses of the euxenite made on material from the superficial workings yielded a verylow lead ratio and as the writer subsequently obtained large quantities of very fine, apparently fresh material from a depth of 30 to 40 feet it was thought to be worth while to analyse a large average sample with a view to checking the age of the pegmatite.

The sample for the writer's[1] analysis consisted of 200 grams of the finest, pure, brilliant fragments picked at random from an average sample of the coarse concentrate -- in all 14 pounds -- derived from 1593 pounds of euxenite-bearing feldspar which was tabled by the Ore Testing Division. The 200 grams selected represented an average sample of the total euxenite concentrate of 58.12 pounds obtained from 1593 pounds of ore. It appeared that there might be some variation in different euxenite individuals, as some grains were darker in colour than others and possibly would be found to carry more iron or uranium, or both, if they were to be analysed separately, but no detailed study was made of the differently coloured specimens, the intention being simply to secure an average sample of the whole concentrate. The 200-gram lot was reduced to 100 mesh, mixed and resampled, a smaller lot being finally ground fine for analysis. Several determinations of Pb, U, and Th were made in the course of investigations on analytical methods, in some instances, quantities of 5,10, and even 20 grams

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[1] Ellsworth, H.V.: Am.Min.,October, 1927.

being used, so that the results for these elements are believed to be accurate to two or three hundredths of one per cent. The analysis gave the results printed on page....

Although this analysis indicates a much greater age than the earlier one, it is still less than the general average (1,100 to 1,200 million years) for the Ontario Precambrian. The writer at one time considered this result as evidence for the later age of some of the Ontario Precambrian but now after more experience with these complex minerals is inclined to believe that the low age result in simply an indication of a certain amount of leaching or replacement of the lead, possibly by silica.

Neighbouring Occurrences. Nuggets of euxenite an inch or more in diameter were seen in a large detached block of a dyke south of the Orser mine and on the same lot. This dyke has never been opened.

About 1923 Mr. Orser opened another dyke on the west side of the road south of the Orser-Kraft mine and on the same lot. This dyke where opened was highly segregated showing large masses of pure white quartz measureable in cubic yards and areas of greyish crystal microcline up to 4 by 6 feet. Both quartz and feldspar were sold. In some of the fragments on the dump a half dozen or more nodules of euxenite up to one-quarter inch diameter could be seen. Other minerals present were a little black tourmaline; very little mica; thin iron pyrites in fissures; and a little green apatite in small crystals ½ inch by 1 inch

Dykes are numerous in Maberley area and probably euxenite, etc. would be found in many of them if they were opened.

NORTH BURGESS TOWNSHIP, LANARK COUNTY: CENOSITE

Reference: Graham, R.P.D. and Ellsworth, H.V.: Am. Min., June, 1930.

The rarity of cenosite and the fact that the Canadian variety differs in some of its character from the older ones makes this occurrence of considerable scientific interest. Specimens of rare minerals such as this often can be sold at high prices to mineral dealers and collectors, so that prospectors and miners should be on the lookout for such occurrences. The Canadian cenosite material, for example, was sold at high prices to mineral dealers, museums, and collectors, and must have realized a considerable sum in this way, for the fortunate discoverers.

The mineral was first noted by W.F.Ferrier and W.M.McLaren on some specimens of calcite and quartz collected on lot 8, con.V, North Burgess township. The following particulars regarding the occurrence were furnished by Messrs Ferrier and McLaren and C. Palache.

The specimens came from an old put about 50 feet deep, now filled with water, which was originally opened for apatite on a vein running north. It was also worked for mica some years prior to 1907 and again in that year.

The indications are that the material in which the cenosite occurs was taken out during the last days of the work done in 1907, which consisted of drifting along the vein at a depth of 25 feet from the surface.

In the dump there are large masses of brecciated material made up of phlogopite,apatite, and calcite which are often coated with a later layer of calcite, and it appears as if the cenosite and its closely associated minerals have been formed in solution cavities in this calcite.

The specimens showing cenosite have a matrix of coarsely granular limestone containing apatite grains, plates of phlogopite,and a few grains of sphalerite. Solution cavities in the limestone are lined with crystals of quartz or of calcite. In some cavities, planted on both these minerals, are crystals of cenosite. Chalcopyrite, in well-formed but deeply striated crystals, is sparsely present. The latest mineral to form is celestite, in platy aggregates which sometimes cover all the other minerals on the cavity walls.

On one specimen, tiny rosettes of silvery needles are implanted on quartz and calcite. Optical tests indicated that these are a soda pyroxene near aegirite. The needles are thin blades.

An analysis of the mineral is given on page....

NORTH BURGESS TOWNSHIP,LANARK COUNTY: ZIRCON

Reference: Palache,Charles, and Ellsworth, H.V.: Am.Min.,July, 1928.

Zircons of scientific interest only, from this old occurrence have been studied. The zircons do not occur in sufficient quantity to be of commercial interest as ore but as is usual in the case of well-crystallized rare minerals, they have some value as museum specimens.

The locality is near Otty lake, North Burgess township, about 4 miles directly south of Perth. The two pits from which the zircons came, lie among scores of similar openings, originally developed about 1870 as apatite mines, later reworked in part as mica mines, and now all abandoned. Most of the crystals were taken from a pit located in concession VIII, lot 4, known as the Sand Pit. The one matrix specimen from here consists largely of serpentinized pyroxene with some granular calcite and fragmentary crystals of apatite. Several matrix specimens from the Megantic Pit show fresher rock with coarse cleavages of calcite, crystals of pyrite and phlogopite, and areas of much fractured green apatite. The zircon in both groups of specimens is identical in colour and properties. In the collections are a few matrix specimens of zircon from South Burgess which look much like these, but the zircon proved not to have the abnormality of angles which is peculiar to the North Burgess crystals. An analysis of carefully prepared material is given on page ....

MARCH TOWNSHIP, CARLETON COUNTY: URANINITE

Some four years ago a dyke on lot 6, con.2, March tp., Carleton co., about 14 miles southwest of Ottawa, was worked for feldspar by O'Brien and Fowler. Thanks to the interest of Mr. N.B.Davis, who was in charge of operations, a few specimens of uraninite which otherwise would not have been noticed, were saved and presented to the writer. The dyke is close to the north side of the road, strikes about north and cuts highly deformed pyroxenic gneiss. It is about 30 feet wide and has been opened up for a length of 120 feet. It consists of coarsely crystallized deep pink microcline and quartz with considerable black mica, black tourmaline, and magnetite in places, and small amounts of calcite and fluorite. The uraninite occurred very sparingly as nodules not exceeding one-half inch in diameter in the crystal microcline which was mined for spar. It was not sharply crystallized. The colour waspitch black the fracture conchoidal showing that it had undergone the initial stage of alteration. The results of an analysis of the best material are given on page....

The analytical results for water and silica and the low specific gravity support the impression derived from the colour and fracture that the mineral is in the black stage of alteration, though the UO_2 content is higher than would be expected. However, traces of carbon, hydrocarbon, or pyrite if present would increase the apparent UO_2 content. The somewhat higher lead ratio (0.164) as compared with other less altered Ontario uraninites (Parry Sound = 0.155) is probably due in part at least to alteration.

About 100 feet or so south of the main opening just described there is a smaller pit where a complex radioactive mineral occurs. Black tourmaline is abundant here and the radioactive mineral is sometimes found in the very middle of the tourmaline.

QUEBEC

The rocks at Quebec north of St. Lawrence river are of Precambri age with the exception of some comparatively small areas of Palaeozoic sediments on James bay and along the north shore of the St.Lawrence between Quebec city and Ottawa. In the better-known, southern parts of this area the rocks consist of the usual granite-gneisses and other irruptives characteristic of the Canadian Shield with in places a considerable amount of the ancient crystalline limestone, quartzite, and paragneiss of the Grenville series. In this area pegmatites are abundant and many have been worked for feldspar or mica. The district tributary to the Lievre and Gatineau rivers is particularly well known and has been more carefully prospected and studied than other parts, because of the early discovery of extensive apatite-phlogopite deposits which were worked long ago for phosphate and more recently for mica. Pegmatites also seem to be particularly abundant in this region and many have been opened for feldspar or muscovite, the Buckingham district being well known for its high-grade feldspar production. Passing eastward fromthe Lievre area little is known of the pegmatites until the Saguenay River-Lake StJohn district is reached, where a number of dykes have been worked at various times for muscovite. Little or nothing is known as to the occurrence of pegmatites in the northern parts of Quebec, but the same Precambrian complex of igneous rocks and Grenville sediments is known to extend to Labrador. Large sheets of muscovite have been brought down Peribonka river from about 250 miles north of lake St.John, from which it may be inferred that good-sized pegmatites occur in that locality.

South of the St.Lawrence and around Montreal igneous rocks of Palaeozoic age occur. Examples of these are the basic rocks of the serpentine asbestos belt, and the rocks of mount Royal and other nearby extinct volcanic plugs. Granites of this age also occur and small pegmatites associated with granites of this period are known. E. Poitevin[1] has examined such small pegmatite dykes in the vicinity of Black lake and has collected specimens of scaly lepidolite and pink lithia tourmalines which sometimes occur in them. These dykes resemble in a small way and are probably related in age to the lithium-bearing pegmatites of the New England states. Professor Mailhiot of the Ecole Polytechnique, Montreal, states that small pegmatites are abundant in connexion with the Stanstead granite areas of the southeastern part of Quebec, and that in some cases these pegmatites carry small amounts of beryl.[1]

LEDUC MINE, WAKEFIELD TOWNSHIP, OTTAWA COUNTY: LEPIDOLITE

References: Geol. Surv., Canada Ann. Rept., vol.X, 1897, pt.S, p.220;
vol. XII, Ann. Rept., 1899, pt.R, p.11; vol.XVI, Ann. Rept., 1904, pt.A, p.229.
Mines and Minerals of the province of Quebec, 1889-1890, p.135.
Quebec Bur. Mines., 1892, p.86.
Mines Branch, Dept. of Mines, Canada, Mon. Mica, 1912, p.193

The Leduc mine, on the east half of lot 25, range VII, Wakefield township, is interesting as the only mine everworked in Canada with the idea of producing gemstones, transparent green, bluish

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[1] Private communication.

[1] Mailhiot, A.: Geol. Surv., Canada, Sum. Rept., 1913, pp. 217,218.

and pink tourmaline being the mineral sought.

The deposit is said to have been first opened in 1885 for the mica, which was mistaken for muscovite, about a tone of which was obtained from one small surface pit.[1] In 1908 the property was acquired by M.J.O'Brien, Limited, and worked with the possibility in mind of producing gem tourmaline.

The dyke is 40 feet wide with strike about northeast. It has been open-cut from the southwest face, outcropping on a hillside, for a length of 75 feet, the opening being about 12 feet wide and 20 feet deep. It consists chiefly of light-coloured microcline with white and smoky quartz, occasional large crystals of green amazon-stone, and a little albite. The mica occurs rather abundantly in platy masses, rarely if ever having definite crystal outlines. Large masses as much as 14 by 28 inches across and several inches thick were obtained, and masses from 6 inches to 1 foot across were common. The mineral is fairly cleavable, but there are often plates of feldspar or quartz included between the basal cleavages and in the middle of masses. The colour is greyish to brownish, usually more or less cloudy. Some pieces show a perfect basal cleavage and could not be distinguished by appearance from brownish muscovites. Others show wrinkling and twinning somewhat suggestive of zinnwaldite. An analysis of the lepidolite, by R.A.A.Johnston, is given on page....

The tourmalines occurred abundantly as large crystals up to 2 inches in diameter and also in aggregates, commonly showing different

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[1] Spence(DeSchmid), H.S.: "Feldspar in Canada"; Mines Branch, Dept. of Mines, Canada, Rept. No. 401.

colours in different parts of the crystals, for instance light green passing to darker green to greenish blue to almost black. Various shades of pink also occurred. The crystals though frequently transparent in small fragments and beautifully coloured, were too much fractured to yield profitable gem material. A few red garnets occur and Spence states that "small quantities of uraninite, gummite, fluorite, and spodumene are also recorded from this mine". The writer saw none of these latter minerals, but R.A.A.Johnston (loc.cit.) states that "some aggregations of light purplish crystals of fluorite" were present.

The mica has been generally called lepidolite though, as shown by the analysis of R.A.A.Johnston (loc.cit.), it contains more iron and manganese than is usual for lepidolite, and in fact about half the combined amounts of these elements commonly found in zinnwaldite. It may, therefore, be regarded as a mica about midway between lepidolite and zinnwaldite.

VILLENEUVE MINE, VILLENEUVE TOWNSHIP, OTTAWA COUNTY: URANINITE AND MONAZITE

References: Geol. Surv., Canada, vol.II, Ann. Rept., 1886, pt.T, p.11; vol.III, Ann. Rept., 1887, pt.T, p.58; vol.IV, Ann. Rept., 1888-89, pt.K, p. 158; vol.X, Ann. Rept., 1897, pt.S, p.220; vol. XII, Ann. Rept., 1899, pt.J, p. 112, and pt.R, p.24

Mines and Minerals of the Province of Quebec, 1889-90, p.134.

Quebec Bur. Mines, 1888, p.90; 1889, p.96; 1892, p.87, 1893, p. 105; 1894, p.94; 1905, p.40.

The Villeneuve mine, lot 31, range I, Villeneuve township, was first opened in 1884 for muscovite, and was worked intermittently until 1909. It probably produced the largest quantity of muscovite of any single mine in Canada. Eventually the rock dump was reworked for feldspar and even the old waste mica dump was disposed of. An excellent detailed description of the mine is given by H.S.Spence(de Schmid) in "Feldspar in Canada".[1]

[1] Mines Branch, Dept. of Mines, Canada, Rept. No. 40 (1916)

The mine is on the east end of a low hill a short distance north of the main road from Notre Dame de la Salette, and is about 20 miles north of Buckingham and 3 miles east of Lievre river. The dyke is about 150 feet wide and strikes northeast, parallel to the bedding of the garnet gneiss country rock. The dyke was worked from the face on the southwest side by an open-cut which reached a length of 100 feet or more along the dyke and a vertical depth of 60 or 70 feet below the top. A shaft and drifts were also opened from the open-cut.

The dyke is composed of light-coloured to white microcline, verg white, massive albite, and quartz. Some amazon-stone was found. Muscovit was abundant and often came in very large crystals. Spence mentions one which weighed 281 pounds and measured 30 inches by 22 inches yielding $500 worth of mica. The mica is greenish, readily cleavable but often marred by dendritic stains of iron or manganese or by the presence of thin flattened garnets. Black tourmaline crystals were very abundant and commonly occurred inradiating aggregates. They were mostly one-half inch to an inch in diameter, but reached 2 inches and a length of perhaps 2 or 3 feet. They are nearly all more or less altered externally to a small, scaly variety of mica, probably damourit and in many cases nearly the whole crystal has been altered inthis way, the original form of the tourmaline being retained but only a core of it remaining in the middle. Some smaller crystals are completely changed to mica. The tourmalines commonly carry nodules of yellow, orange, or red gummite, so-called, in pits on their outer surfaces. These are rarely more than 1/8 inch in diameter, but sometimes as much as ¼ inch or more. Red garnets, variety spessartite, occur rather freely. Other minerals that are listed as occurring here, are: massive grey-green apatite; zircon; purple fluorite; beryl; monazite; uraninite; and cerite.

The feldspars, both microcline and albite, were of exceptionally high quality, and both were shipped, the pure white microcline bringing $20 per ton for use in making artificial teeth. Very beautiful examples of peristerite, the iridescent variety of albite, were common.

Uraninite and Alteration Products. In December, 1886, G.Christian Hoffmann,[1] then chemist and mineralogist to the Geological Survey, reported the receipt of a specimen of uraninite weighing nearly a pound from this mine, with the remark that it was the first pitchblende found in Canada. This statement, however, was not strictly correct, as the so-called coracite from Mamainse, really an altered uraninite or pitchblende, had been found long before. A part of this specimen was sent by Hoffmann to Dr. W.F.Hillebrand at the United States Geological Survey Laboratory in Washington and analysed by him and reported in

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[1] Geol.Surv.,Canada, Ann. Rept., 1886, pt.T, p. 10

American Journal of Science, 42, 390, 1891.

During the winter of 1927, Dr. W.F.Ferrier in the course of rearranging the old mineral collection of the Geological Survey which had been packed away in boxes for many years, came across a fine specimen labelled "Uraninite with Gummite, lot 31, Range I, of Villeneuve, Ottawa county, Que." This unquestionably is the original specimen of uraninite referred to by Hoffmann and analysed by Hillebrand. The specimen still weighs over 370 grams after removing some material for analysis and it evidently is only a comparatively small part of an originally much larger mass, thus substantiating a tradition which has been handed down that during the time of Hoffmann a mass of uraninite the size of a cannon ball and weighing about 50 pounds was found in the Villeneuve mine. From the form of the specimen and the arrangement of the altered material one can readily believe that the original mass was roughly spherical and quite possibly 5 or 6 inches in diameter.

The uraninite is particularly interesting because it shows four well-marked zones of differing materials, due to progressive alteration. ZoneA, the part that evidently was nearest the centre of the original mass, naturally is the least altered and has Sp.G.=9.144; H =6; colour steely black; lustre more or less metallic; fracture, uneven. Zone B, representing the next stage of alteration has Sp.G.= 7.779; H =4.5; colour pitch black; lustre non-metallic; fracture conchoidal. Zone C is composed of a beautiful, bright "flame-scarlet"

(Ridgway)[1] coloured substance, Sp.G. =5.273; H=3.5; waxy lustre; brittle; conchoidal fracture. It has n greater than 1.75 and is mostly anisotropic, but does not appear to be entirely homogeneous. Zone D, representing the extreme stage of alteration, comprises an irregular layer seldom more than 1 mm. thick which evidently was the outside of the original uraninite mass in contact with the rocky matrix. On its outer surface it bears partly embedded scales of altered muscovite. A certain amount of D penetrates into C along fractures, etc., but D is plainly a more advanced alteration than C. The material of D is physically much like C, but slightly softer. H = 3+. Sp.G. not determined; colour buff-yellow to apricot-yellow (Ridgway: loc.cit.); lustre waxy; brittle; fracture conchoidal. It is anisotropic with index less than 1.75.

Although the Villeneuve uraninite, probably a part of this very mass, was analysed by Hillebrand, it appeared to the writer that this specimen offered an unique opportunity to obtain valuable data as to the effect of alteration on the lead ratio of uraninite. Here we have a single mass showing the whole sequence of alteration products all in place in their relative order and conveniently arrange in zonal fashion in sufficient quantity to permit obtaining samples for examination. Quantities of A, B, and C sufficient for chemical analysis were readily obtainable without injuring the appearance of the specimen, but to secure enough of D it would have been necessary to sacrifice the whole outer layer, so no analysis of this substance

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[1] Ridgway, Robert: "Colour Standards and Nomenclature".

was made. The analyses yielded the results presented on page.....

The analyses throw considerable light on the changes that may take place accompanying alteration. It is evident that in the case of the Villeneuve uraninite the percentages of Pb, UO_3, Th, Ca, SiO_2, and H_2O increase with increasing alteration, whereas total U, UO_2 and rare earths decrease. It also appears that the ratio of cerium group earths to yttrium and erbium earths decreases as alteration progresses. The lead ratio fortunately increases only slightly so long as the mineral remains black, due to an appreciable UO_2 content, but once the UO_2 is entirely oxidized uranium is lost much faster than lead and the lead ratio rises to a large and entirely misleading value This observation appears to supply the answer to the question whether to include the decomposition products, which arises when analysing altered uraninites for age determinations. It is evident that all red and yellow decomposition products should be excluded and probably results nearer the truth would be obtained if the material were given a preliminary digestion with hydrochloric acid to remove the more soluble alteration products. Much the same results as these were obtained by the writer some years ago in connexion with the Cardiff township uraninite. In fact it is now apparent that the analyses of this mineral from Cardiff township by Todd and the writer, (See pages ....) show more or less similar effects, amongst which the augmentation of the lead ratio with increasing alteration is notable. The percentage of UO_2 relative to UO_3 in any uraninite gives an accurate index of the degree to which the mineral has altered, so that it may be seen that Todd's specimen was the least altered, followed in order by the "Ellsworth hard XI and the Ellsworth massive, much altered". The results are not strictly comparable because these were three entirely different specimens and the writer has found that single crystals from the same occurrence may vary slightly in composition. However, even so, it is clear enough that alteration of the Cardiff uraninite is accompanied by an increase in the Pb and Th and a decrease in the total U content, with also a decrease in the total rare earths. The effect on the CaO content is not certain. Further evidence of the effect of alteration in causing a higher lead ratio is to be seen in the case of Hillebrand's[1] two analyses of the Arendal, Norway, uraninite. One sample as indicated by the greater UO_3 content was evidently much more altered than the other and yields a considerably higher lead ratio.

From the evidence of the examples cited it is seen that the lead ratios of greatly altered uraninites containing 10 to 15 per cent UO_2 may need scaling down to the extent of 0.01 or more. The question then arises whether all uraninites which have a UO_2 content greater than would be produced by autoxidation[2] alone do not yield lead ratios that are slightly too high. The amount of UO_3 due to autoxidation alone would not exceed 15 or 20 per cent for the uraninites considered here, so that

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[1] U.S.Geol. Surv., Bull. 78, 1891, p.67

[2] Ellsworth, H.V.: "Radioactive Minerals as Geological Age Indicators"; Am. Min., Feb. 1925, pp. 137-144.

UO_3 in excess of this must be the result of normal external alteration. The amount of the normal external alteration thus calculated may afford a rough index of the reduction in the lead ratio necessary to give exact results. It may well be that uraninites containing 10 to 20 per cent UO_3 in excess of that due to oxidation should have their lead ratios scaled down by 0.002 to 0.005 to represent more correctly the true values. Evidently only a very small, practically negligible correction of this sort is necessary for well-preserved specimens, but when dealing with considerably altered uraninites it might well be taken into account.

It is interesting to note that the effect of alteration on uraninite as just cited is exactly the opposite of the effect on complex titano-tantalo-columbates, which appear to lose lead to a greater degree than uranium.

Monazite. Hoffmann also obtained specimens of monazite from the Villeneuve mine, some of which he sent F.A.Genth[1] who analysed them with results given on page.....

Genth states that "it has a reddish brown colour, indistinct cleavage, and little or slightly waxy lustre. The specific gravity of the purest cleavage pieces was found to be = 5.233".

Specimens of the Villeneuve monazite in the Geological Survey, Canada, collection appear to be considerably altered, and probably would yield low values for the lead ratio.

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[1] Am. Jour. Sci., 3rd ser., vol. 38, 1889, p. 203.

PORTLAND EAST TOWNSHIP, LABELLE COUNTY; ALLANITE

Reference: Walker, T.L. and Parsons, A.L.: University of Toronto Studies No.16, 1923, pp. 30-31.

Walker and Parsons[1](Loc.Cit.) have described this occurrence.

Allanite occurs on lot 13, range III, in the township of Portland East, in Labelle county in the province of Quebec. It is found in a dyke of coarse grey pegmatite in the form of large, ill-defined crystals sometimes several inches in diameter. The mineral is jet black in colour with a pitchy lustre. The powdered mineral, when examined under the microscope, is seen to be olive-green in colour, isotropic with n = 1.650. It is unusually free from foreign grains. It shows no brownish alteration on the surface and is apparently unusually fresh.

The results of an analyses are given on page....

In chemical composition, optical properties, and specific gravity these two types (This and the Seguin Falls allanite,)of allanite vary considerably. They both appear to be perfectly fresh. If one of them represents an original type and the other an alteration product, the process would appear to have been a very thorough one, as in neither sample does one observe grains of the other type. The puzzle as to the alteration of allanite has recently been carefully studied by Watson,[1] Larsen,[2] and others. No attempt was made to separate the rare earths except as indicated in the analyses. The spectroscope showed that in both samples the cerium group contains considerable

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[1] Watson, E.L.: Bull. Geol. Soc. Am., vol. 28, p. 463

[2] Larsen, E.S.: Bull. U.S.Geol. Surv., 679, p.36

didymium.

WALLINGFORD MINE, DERRY TOWNSHIP, OTTAWA COUNTY, QUEBEC:

THUCHOLITE AND URANINITE

REFERENCE: Ellsworth, H.V., Am. Min., Aug. 1928.

Thanks to the interest of Mr. N.B.Davis, who has been in charge of development at the Wallingford feldspar mine, both thucholite and uraninite have been found in small quantity in this mine. The finding of these minerals gives point to a statement once made by the writer in which the belief was expressed that if competent observers were available to watch the workings it would probably be found that radioactive minerals occur much more frequently in pegmatites than is generally supposed. The casual visitor to the Wallingford would be very fortunate indeed if he found a single specimen of either mineral, even though he knew they occurred there and looked particularly for them.

The wallingford mine is on lot 14, range II, Derry township, Ottawa county. It is reached by a mine road from the Derry feldspar mine which itself is connected to the main Lievre River highway by a road over which automobiles can be driven. This is an old mining region noted long ago for its production of apatite and mica, and more recently for its high-grade feldspar.

The pegmatite of the Wallingford is a large dyke of varying width which it is said can be traced for a mile or more in a northwest-southeast direction. Mr. Davis states that the narrower parts consist

Largely of the usual graphic intergrowth of quartz and microcline with occasional patches of coarse crystal microcline and massive quartz in some of the wider swellings, and further that at the south-east end it becomes narrow and joins or appears to be an offshoot from a large dyke of graphic granite perhaps 150 or more feet wide which strikes in a general northeast direction. At the Wallingford mine the dyke outcrops for 100 feet or more over the face of a hill, dipping southwest, the actual width being possibly 75 feet. It consists of great masses of white quartz comprising, so far as at present explored, perhaps two-thirds of the whole, the remainder being chiefly a very light-coloured, in places pure white, microcline containing a small amount of plagioclase as a fine perthitic intergrowth.The mine is worked from a tunnel and also by open cutting at the top of the hill. Both quartz and feldspar are mined and sold, the proportion of quartz being so great that probably the feldspar by itself could not be profitably won. Besides the microcline and the huge masses of white quartz there are patches, as much as several feet in diameter, of greenish grey plagioclase feldspar, in which small masses or veins of pyrite and pyrrhotite an inch or so wide sometimes occur. Masses of granular, dark, smoky quartz several feet in diameter are also present. Thin dentritic crystal growths of black tourmaline are quite often seen and more rarely crystals up to an inch diameter may be found. At one place in the open-cut on top there were bodies several feet long of a streaky looking dull greyish black material which qualitative tests indicate to be allanite.

This allanite has a peculiar appearance which the writer has never previously seen in connexion with this mineral. It shows nowhere the slightest indication of crystal outlines, contains long, narrow streaks of plagioclase feldspar, and in general has a coarse fibrous structure parallel to the long direction of the bodies, giving the impression that the structure may have been produced by shearing, or rather by plastic deformation during the crystallization of the mineral. Some of these streaks of allanite have superficially the appearance of veins an inch or more wide and several feet long cutting the feldspar; but on closer examination it is seen that these "veins" have a fibrous structure parallel to the long direction, with included long, narrow streaks of plagioclase, and in short, every appearance of having been produced mechanically. The allanite is quite radioactive and contains an unusually high percentage of thorium, so that it will be possible to make an interesting comparison of the lead ratios of the two minerals. Nodules of both uraninite and thucholite, up to one-quarter inch diameter have been found but unfortunately both are usually much altered, the uraninite to yellow gummite so-called, the thucholite to a powdery black substance. Even the best specimens of uraninite so far obtained are more or less altered and only small amounts have been secured, so that it has not yet been possible to make an analysis of the highest accuracy using 2-gram portions, as have been done in the case of other Canadian uraninites. At one time a patch 3 by 6 feet in area, chiefly microcline, was exposed, which was quite abundantly encrusted with a thin coating of yellowing green uranium (and vanadium?) decomposition products. Within this area were quite a number of nodules of gummite from a millimeter to a quarter inch in diameter and some blackish specks probably representing decomposed uraninite-thucholite intergrowth. Thucolite occurs in various forms in microcline, quartz, or plagioclase. Much of it is powdery and dead looking, but some retains its original brilliant black lustre exactly resembling the Parry Sound mineral, the description of which applies to this also. Most often it is in rounded grains, but it also occurs intergrown with altered uraninite or possibly partly replacing the latter as cubes and octahedrons about 5 mm. in diameter. These crystals have a coating of more or less lustrous thucholite next the matrix with altered uraninite inside. A typical example of the cubic form was extracted from the rock and analysed with results as on page... One specimen, the largest and more interesting of all is a pseudomorph after tourmaline. So perfectly are some of the faces (a and m) of the original tourmaline preserved that they could be accurately measured and identified by means of a contact goniometer. The thucholite of this unique tourmaline pseudomorph fortunately is fairly well preserved, solid and brilliant in lustre. Associated with the thucholite in the pseudomorph is quite a little pyrite and some soft whitish substances not yet exactly identified, but evidently sulphate decomposition products, which are probably new minerals.

A small crystal of zircon or more probably cyrtolite can be seen embedded inthe pseudomorph, and similar small crystals or crystal aggregates of this mineral can usually be found in the rock close to or touching thucholite nodules.

The similarity of the Parry Sound and Wallingford thucholite o occurrences is evident. At both places thucholite, uraninite, and cyrtolite occur in close association. At the Wallingford, however, though some of the thucholite apparently was formed at the same time as uraninite, there is evidence of considerable late pneumatolytic activity in the replacement of tourmaline and possibly uraninite by thucholite, whereas at Parry Sound thucholite seems to be entirely contemporaneous with uraninite.

The thucholite for analysis was from nodules of the best preserved materials carefully examined under the bincular microscope. The small amount of good material obtained did not yield sufficient ash to permit making a complete analysis.

The analytical examination suffices to show the resemblance of this mineral to the Parry Sound thucholite. The variations in composition of the mineral from the two localities are probably no greater than the differences between individual nodules from either locality.

The Wallingford thucholite is particularly interesting because it not only is intimately associated with uraninite, but it actually replaces tourmaline, showing that it is not confined to relatively high temperature conditions but can also be produced by late pneumatolytic action. Thus it appears that carbon must be included with boron, fluorine, sulphur, water, etc., as one of the constituents of the residual solutions of granite magmas.

ANALYSIS OF URANINITE-THUCHOLITE CRYSTAL FROM THE WALLINGFORD MINE

A typical crystal was extracted and analysed, with results as follows:

Wt. of substance .... 0.1328 g.
Loss on ignition 0.0115 g.
Thucholite+H_2O,He,etc.=8.66 per cent approx.

Allowing for water present there probably is not more than 6 or 7 per cent thucholite by weight in this specimen, though others might have been selected which would show considerably more.

On heating the black ignited material with HNO_3 it behaved exactly like uraninite, dissolving with effervescence accompanied by evolution of red nitrous fumes and the production of a strongly yellow coloured solution. A certain amount of reddish coloured material, probably thorium and cerium oxides, remained undissolved however, so the whole was heated for several hours with H_2SO_4 , after which treatment everything appeared to dissolve except silica, etc., and lead sulphate. A careful analysis was then carried out with the results given on page.

A certain amount of decomposed feldspathic and micaceous material from the matrix adhering to the uraninite-thucholite crystal doubtless accounts for the high alumina, iron, and silica.

Though the amount of substance taken was small the percentages of Pb, U, and Th are such that the results may be considered sufficiently accurate to demonstrate that this uraninite agrees perfectly in its age indications with those of other Canadian uraninites examined by the writer.

HEIGHT-OF-LAND MINE, PREISSAC TOWNSHIP, TIMISKAMING DISTRICT, QUEBEC:

BERYL AND PHENACITE

References: Walker, T.L.: Mines Branch, Dept. of Mines, Canada, Rept. No. 93, (1911).
Wilson, M.E.: Geol. Surv., Canada, Sum. Rept., 1910, p.207.
Bancroft, J.A.: Rept. Mining Operations, Prov. of Quebec, 1911, pp. 192-195.
Graham, R.P.D.: Trans. Roy. Soc., Canada, Ser.III, vol. XII, 1918.

On the west bank of Kewagama river, about 3 miles north of Kewagama lake, dykes of granite and pegmatite occur in a zone which varies up to about 90 feet in width along the margin of the river. The individual dykes are very irregular in width and in length. Toward the northern end of the property of the Height of Land Development Company, at least three dykes, with variable widths up to 15 feet, are distinguishable. The dykes of granite are intersected by dykes of pegmatite rich in feldspar, and both types are traversed by dykes or veins of quartz containing some muscovite. In certain places the granite passes into pegmatitic and aplitic phases. Especially at the southern end of the exposures granite and pegmatite so predominate over schist that the schist has the appearance of forming inclusions in granite. Towards the south a quartz vein, 15 feet wide, intersects the granitic rocks; the quartz carries both bismuthinite and molybdenite.

Near the large quartz vein, a shaft was sunk 74 feet in the granite-pegmatite zone, and from the bottom drifts were run in opposite directions for lengths of, respectively, 27 feet and 60 feet. In the easterly drift, one dyke of pegmatite, 3 feet wide was noted to carry a little bismuthinite, occasional crystals of molybdenite, and a few crystals of beryl. The eastern drift also crossed a quartz vein 17 feet wide and containing muscovite, a little bismuthinite, a few flakes of molybdenite, and some crystals of beryl.

Towards the northern end of the property, at a point where the micaceous selvage on the side of a quartzose pegmatite dyke was exceptionally thick, a pocket rich in molybdenite was found; some of the molybdenite crystals measured 2 inches in width. In this pocket large crystals of beryl were abundant. Small segregations of chlorite were present here and there in the quartz within some of which minute transparent, colourless crystals of phenacite were found. These have been described by R.P.D.Graham (loc.cit.)

TIMISKAMING DISTRICT: OTHER BERYL OCCURRENCES

R.A.A.Johnston[1] lists beryl as occurring also at the following additional localities in Timiskaming district: St. Maurice Syndicate mine, and at the southern end of Long lake, south of lake Kienawisik.

MAISONNEUVE MINE,[2] DE MAISONNEUVE TOWNSHIP, BERTHIER COUNTY: BERYL - SAMARSKITE OCCURRENCE

Samarskite from this occurrence was described and analysed by G. Christian Hoffmann, then chemist to the Geological Survey, in 1882 (Chemical Contributions to the Geology of Canada, Geol. Surv., Canada, Repts for 1880-81-82.) His analysis is given on page....

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[1] A List of Canadian Mineral Occurrences: Geol.Surv., Canada, Mem.74.

[2] In the List of Canadian Mineral Occurrences (Mem.74, Geol. Surv., Canada) beryl is stated to occur in both Brassard and De Maisonneuve townships. By reference to original records it has been found that both these references really apply to the Maisonneuve mine, the location of which was not definitely known at the time of the earlier records.

The Maisonneuve mine, on lots 1 and 2, range II, De Maisonneuve township, is reached from Joliette by Canadian Pacific Railway, to St. Félix-de-valois, then by road 20 miles to St. Emelie-de-l'Energie, and 33 miles to St. Michel-des-Saints. The mine is on the roadside about 100 feet south of the outlet of a small lake called Mica lake, 10 miles north of St Michel. It is in a large pegmatite dyke about 100 feet wide which strikes east magnetic across the road. The country rocks are mostly quartzite and garnet paragneiss with injections of aplite and pegmatite. A shaft was sunk on the dyke about 100 feet west of the road and a man who had worked there said it was 35 feet deep with drifts extending 200 feet to the west and 100 feet to the east, but the dump does not appear large enough to correspond to such extensive workings, though evidently a considerable amount of work was done. The shaft at the water level, 6 feet below the surface, is round and 12 or 15 feet in diameter. The pegmatite consists chiefly of pink microcline and white quartz, with a minor quantity, perhaps 5 per cent, of white to grey iridescent plagioclase. Books of white mica up to 1-1½ inches in diameter are abundant and some reach dimensions of 3 or 4 inches. Black mica also occurs. Black tourmaline and garnets are common. Some slightly smoky quartz occurs. One good-sized crystal of beryl was seen in place on the surface and quite numerous nodules of samarskite or fergusonite, mostly less than

1/8 inch but up to ¼ inch diameter, were noted in the old workings.

The shaft evidently was put down on the most segregated portion as a mass of white quartz 10 feet wide occurs just northwest of the opening with 4 to 8 feet of pink crystal microcline on each side of it. To the west of the shaft there is an open-cut 10 to 20 feet wide, 50 feet long, and 10 feet deep. On the south wall of this opening, small samarskites up to 1/8 inch in diameter were fairly abundant over an area 10 by 30 feet, but probably mainly confined to a zone only a few inches thick.

A few shots had been put in on the outcrop of the dyke at the east side of the road, showing chiefly red microcline and black mica up to 6 inches in diameter.

Eight or nine hundred feet west of the shaft on top of the hill there is an open-cut 12 to 20 feet wide, 120 feet long, and 6 to 15 feet deep. Patches of the side walls of this cut show mica up to 3 inches in diameter. There is a good deal of white quartz and fine-grained white feldspar aplite carrying red garnets and small white mica one-quarter inch in diameter on the dump, and the latter is also prominent on the walls of the cut. A few small samarskites were also seen here.

A local informant stated that the mine had never sold a pound of mica. Obalski[1] mentions that the Maisonneuve mine and the Pied des Monts mine were taken over in 1904 by a company "The Canadian General

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[1] Obalski, J.: "Mining Operations in the Province of Quebec for the year 1905".

Mining Company Limited" with head office in Paris, for the purpose of obtaining the rare-element minerals, and that several tons of material from the Maisonneuve mine were sent to Paris for tests. In the Report of Mining Operations in the Province of Quebec for 1906, Obalski states that samarskite and fergusonite were found in fairly important quantities in the rock in small masses varying from a few grains to one pound or even more. A sample of the samarskite submitted to Prof. H.E.Barnes of MCGill University was found by him to contain 0.04 to 0.05 grammes radium per ton. A sample of the samarskite analysed by Milton Hersey yielded 5.60 per cent tantalum oxide and 3.24 per cent thorium oxide. This is apparently the first instance in Canada of a mine being worked exclusively for a rare-element mineral content.

LAC PIED DES MONTS[1],CHARLEVOIX COUNTY:URANINITE AND THUCHOLITE

About 1894 J. Obalski, then Inspector of Mines for the Province of Quebec, discovered and identified a large crystal of uraninite in a mine worked for muscovite on the north side of lake Pied des Monts, 18 miles north of Murray Bay. Ten years later he described[2] the occurrence in part as follows:

"About ten years ago I found in a mine of Saguenay district, then operated by the Canadian Mica Company, a remarkable specimen

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[1] In " AList of Canadian Mineral Occurrences (Mem.74,Geol.Surv.,Canada) it is wrongly stated that fergusonite occurred at the Pied des Monts mine. The original reference (Obalski,J.: Mining Operations in the Province of Quebec, 1906, p.42) was to the occurrence of fergusonite at the Maisonneuve mine in Berthier county.

[2] Obalski, J.: "On a Mineral Containing Radium in the Province of Quebec"; Jour. Can. Min. Inst.,vol.VII,1904.

which I identified as cleveite...... This specimen has a specific gravity of 8.43 and weighs 375 grammes, or about 13 ounces. It is well crystallized in a dodecahedron form......... A complete analysis has not yet been made, but it contains 70.71 per cent of uranium oxide. The white mica vein where these specimens come from is situated near the lake "Pied des Monts" about 18 miles back of Murray Bay, in the county of Charlevoix, on the north shore of the St.Lawrence."

The mine is about half-way up a high hill[1] on the north side of the lake, and is best reached by boat from a farm at the end of the road from Pointe au Pic on the south side of the lake. The dyke is perhaps 15 to 20 feet thick and can be traced for 200 feet along the hill with strike apparently about east. It appears to lie horizontal and mining has been onthe face only. The country rock is hornblende gneiss, which at the west end of the dyke strikes 30 to 40 degrees west of north magnetic and dips 75 degrees to the northeast.

The dyke is composed of pink microcline, white albite, and white quartz with much black mica and somewhat less white mica, all more or less mixed together, and with no large segregations of either quartz or feldspar. The structure is coarse granitoid to graphic. Mica books range up to a foot in diameter and the black and white micas are sometimes intergrown, in some cases parallel to the base, in others normal to it. Red garnets are plentiful and occasional fragments

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[1] Spence (DeSchmid) says the workings are 600 feet above the lake and 1,460 feet above the St.Lawrence (Feldspar in Canada).

may be of almost gem quality. A few little dark zircon crystals, one-quarter inch long, very fresh and bright, were seen. One or two small crystals, apparently monazite, were seen. No traces of uraninite or thucholite could be found, but this is not surprising, considering the age of the workings.

About half a mile down the creek running out of the east end of the lake, there are some workings on the north bank, in a dyke containing black and white mica and much red garnet. Nothing of interest was seen here. There is an old camp with much mica at the east end of the lake at the mouth of this creek.

Nothing appears to be known definitely as to what became of the specimens collected by Obalski, but it is supposed by some that he sent his rare mineral finds to the Curies.

Obalski also found "a carbonaceous material burning quite easily, and leaving ashes containing oxide of uranium". Obalski states he sent specimens of the "coal" for analyses and that the ash held 35.4 per cent of uranium. The various descriptions by Obalski make it quite evident that the "coal" was thucholite.

It is regrettable that specimens of the uraninite and thucholite from the Pied des Monts mine could not be obtained for detailed examination, in view of their great scientific interest.

LAC A BAUDE, NORMAN TOWNSHIP, CHAMPLAIN COUNTY; ALLANITE

References: Geol. Surv., Canada, vol. XI, pt. J, p. 36, also vol. VII, pt. R, pp. 12-13.
Harvie, Robert; Can. Min. Jour., July 22, 1921, p. 575.

This occurrence attracted attention at an early date because of the apparent abundance of the mineral. The description of the deposit is based on an account by R. Harvie.

Lac a Baude is in Normand township, in the northwest part of Champlain county. The mineral locality lies 44 miles due northwest of Grand Mere. The locality is best reached by way of Grand Piles, the terminus on St Maurice river of a branch line of the Canadian Pacific railway. From Grand Piles the trip of 32 miles upstream to Grand Anse may be made by steamboat during the summer season. At Grand Anse wagons are available to cross the 9-mile portage to lake Wessonneau. From this point the remainder of the journey at the present time must be made by canoe, the steps being as follows: lake Wessonneau 5 miles; seven portages in 1¾ miles to Steamboat Rock lake; lake 1½ miles; 9 portages in 2 miles to lake Wakaumekonke; lake 3 miles, portage to occurrence about 2 miles. In view, however, of the number of lumber roads that have been built under similar conditions in nearby districts it seems probable that a wagon road of about 12 miles could be readily built from the clubhouse on lake Wessonneau direct to the deposit, thereby completing connexion with the steamer service above mentioned.

Abundant allanite was found ina small cliff 200 yards east of the end of the portage leading to lake Wakaumekonke and about 50 yards south of the trail. Other exposures were not examined. This cliff is about 70 feet long and 20 feet high at one end. Below the cliff huge blocks derived therefrom form a talus about 50 feet high. The cliff face is of a coarse, reddish granite but at one end it may be seen that the granite runs back into the cliff for only about 20 feet, and at the other it is limited top and bottom by a brownish black hornblende gneiss. The granite has intrusive relations to the adjoining hornblende gneiss and the cliff face is close to the irregular contact.

Scattered through the granite of the cliff face are tabular crystals of allanite which attain a maximum size of about 6 inches by 4 by 1½ thick, individuals 3 inches long being quite common. The larger crystals are the centres of very prominent radiating fractures. This feature both assists in identifying the allanite and in separating the crystals from the rock. Although most of the larger crystals occur singly, there is a tendency for the smaller to occur in clusters of bunches, thus giving rise to very rich material.

The actual proportion of allanite in the granite was not calculated, but is probably not more than 1 per cent and as a mining proposition this proportion might be considered rather small. However, in the space of four hours with the geological hammer it was possible to obtain from the more easily reached portions of the cliff over 90 pounds of nearly pure allanite. In addition to the allanite there are occasional large crystals of hornblende which on account of their general resemblance in size and colour might prove confusing. However, when bruised with a hammer the hornblende has a greenish colour in distinction from the dead black or grey of allanite. An analysis of the allanite is given on page......

TACHE TOWNSHIP, CHICOUTIMI COUNTY: TOPAZ, BERYL AND SOLID HYDROCARBON

In Chicoutimi county several small pegmatites have been worked since 1913 for muscovite but so far as observed in 1923, only one contained rare minerals of particular interest. This is located in Tache township on lot 13, range V as nearly as could be ascertained, and on the shore of a lake which is perhaps a mile long with greatest extension about north and south. There is a small island in the lake about a quarter of a mile to the south of the mine. The location is reached by a path which connects with the main road running eastward from St. Nazare at a point about 2 miles east of the village church. The working is at the water's edge on the west shore of the lake and consists of a roughly circular opening 20 to 30 feet in diameter and 15 feet from the highest point down to water. The workings extended below lake level and the lower parts are flooded. No coarse pegmatite showed on the walls of the pit, so that the body must have been pipe-shaped. There was only perhaps 2 or 3 cubic yards of material from the mine on land, most of the rock apparently having been dumped into the lake, which appears to be quite deep here. The greater part of the dump material consisted of white mica, apparently discarded because of small size, crumpling, or other defects. No black mica was seen. A small quantity of the mica-bearing material from the mine was also scattered around. This consisted of books of greenish mica up to 6 inches in diameter associated with quartz and the cleavelandite variety of albite, beryl, and topaz. Both beryl and topaz are greenish and sometimes scarcely distinguishable by inspection; the topaz, however, is usually a deeper green than the beryl and sometimes shows the perfect basal cleavage. The beryl may show a rather perfect prismatic parting Rough crystals of both were obtained but most of the topaz is massive, intergrown with muscovite and albite, and apparently quite abundant; more so than the beryl in the specimens collected, which show masses of both 2 to 3 inches in diameter. The albite is frequently cavernous, the cavities resulting from the intersection of cleavelandite plates and, in many cases, these cavities are partly or wholly filled by a black hydrocarbon. In some cases the hydrocarbon is moulded to the shape of the cavity, but is nevertheless free from the walls and just loose enough to be easily detached or even to drop out if jarred. In other cavities the hydrocarbon takes the form of globular or tear-shaped masses which do not conform to the shape of the cavity and may be considerably smaller than the cavity. Again a few instances were noticed in which the hydrocarbon practically forms a graphic intergrowth with albite and quartz. Different specimens of the hydrocarbon varied in hardness when collected; some were sufficiently soft to be dented by the fingernail, the day being a rather warm one for that latitude. Specimens could be readily ignited with a match. In the laboratory the hydrocarbon was found to be only very slightly radioactive. It burns with a sooty flame and leaves a small amount of residue, which is chiefly iron. Besides the minerals mentioned, some very green amazon-stone was seen and a few small nodules and crystals up to ½ inch in diameter of brownish radioactive mineral, probably complex tantalo-columbates. Several of the brownish specimens were tested for cassiterite, but none proved to be this mineral. Some of the larger pieces from the pit showed the coarse, cavernous, albite-mica-topaz-beryl association grading into a fine-grained, granular, albite rock of about 1 millimetre grain size. Specimens of coarse, compact cleavelandite were also seen.

The country rock in the vicinity of the pit is composed chiefly of plagioclase with a little quartz and abundant streaks of mixed green hornblende and chlorite. The streaks are oriented about east and west following the general trend of the rock. There are also inclusions of pyroxene with reaction rims of brown hypersthene. A dyke of fine-grained aplite or feldspar rock strikes about south into the opening and two parallel pegmatite dykes about 100 feet apart, 2 to 3 feet wide, and 4 to 5 feet wide, respectively, strike about east near the opening.

The writer was unable to find anyone who could give reliable information regarding the history of the deposit. It was stated that the deposit had been known locally for ten years and had been worked for two years previously to 1923.

GADOLINITE AND ORTHITE OCCURRENCE

Obalski[1] mentions that "In the environs of lake StJohn also, a mine of white mica has been opened in which are ores of cerium".

No further details of th

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[1] Mining Operations in the Province of Quebec, for the year 1905

No further details of the location are given but in the same report is an article on "Rare Earths in the Province of Quebec" by H.Nagant, which refers to the same occurrence and is in part as follows:

"I have carefully examined some specimens of greenish or brownis black ore of vitreous aspect, from this new deposit which will be worked this year. The two varieties they contain are silicates of rare earths not yet mentioned in the province; gadolinite and orthite (allanite). I noticed the presence of a small quantity of tin (about 2 per cent) as well as scales of native bismuth."

The writer (Ellsworth] has been unable to find any further reference to this mine. Many inquiries were made in Tache township but nothing could be learned of it and nothing further was known of it by the Quebec Mines Department.

JONQUIERE TOWNSHIP, CHICOUTIMI COUNTY: BERYL

Reference: Laflamme, J.C.K.: Geol.Surv.,Canada, Ann. Rept. 1883, pt.D, pp. 9-10

Many years ago Abbe J.C.K.LaFlamme recorded finding beryl and garnet "in the township of Jonquiere, on the north range of the road leading to Kaskonia". The larger crystals were said to be 3 inches or more in diameter and 12 to 15 inches long.

Two or three persons were found who remembered the Abbe and who agreed that he obtained his"emeralds" on lot 21, North range, Jonquiere township. At this locality a dyke outcrops about 100 feet north of the road and near the back of a house. It is about 5 feet wide as exposed on the south end of a low rise. A few shots had been put in long ago and the dyke thereby exposed for a vertical height of 6 feet. It consists of pink feldspar and white quartz with a little small white and black mica in books up to 2 inches in diameter, a little magnetite or ilmenite, a few red garnets up to 1 inch in diameter and a little black tourmaline. No beryl nor cleavelandite was seen. The dyke cuts the porphyritic anorthosite characteristic of the area. The beryl crystals doubtless occurred only in a small pocket, as often happens with this mineral, and evidently all were removed.

KENOGAMI TOWNSHIP, CHICOUTIMI COUNTY: BERYL

Two small greenish beryl crystals ¼ inch in diameter and between 1 and 2 inches long were found by the writer in place in a small pegmatite on lot 1, range II about a quarter mile north of the line between ranges 1 and 2. The dyke occurs in a rock exposure 20 by 100 feet on a gentle rise covered with second growth, north of a field with two old buildings. The rock is a mixture of porphyritic anorthosite and fine-grained granite or aplite. One or two shots had been put in the dyke on the slope of a small rise, showing it to be 4 to 6 inches wide at the top and 1 foot wide at the bottom of the exposure. The dyke consisted chiefly of pink feldspar with a little black mica, a little pyrite, and about half a dozen minute specks that had the appearance of a radioactive mineral. No white mica was noticed.

SAGUENAY DISTRICT: BERYL

Along the north shore of the St. Lawrence east of the Saguenay there are a number of old mica or feldspar openings in which a few, small scattered crystals of beryl have been found. Of these the McGie mica mine in Block G, Gergeronnes, north of Pointe au Sauvage was much the largest and most important working and here it is stated[1] that beryl crystals up to 3 inches in diameter were found. A few scattered crystals smaller than this were found by the writer when visiting this long-abandoned mine several years ago.

Small crystals of beryl also occur sparingly in some old mica workings north of Tadoussac.

None of these occurrences appears to be of particular interest. There is nothing noteworthy about the dykes themselves nor were other rare-element minerals observed to be present.

NEW BRUNSWICK AND NOVA SCOTIA

INTRODUCTION

Over the greater part of these provinces the rocks are Palaeozoic sediments, but extensive areas of granite are present. These granites are believed to be of late Palaeozoic age. The pegmatites associated with the granite are neither so abundant nor do they attain as great size as they do in the Canadian Shield. Those that do occur are likely to contain lithium minerals and are apparently related in composition, age, and origin, to those of the New England states. A heavy coating of drift covers much of the granite areas in these provinces and but few pegmatites are known. No rare-element mineral occurrences are

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[1] Obalski, cited by Spence, H.S.: "Mica, Its Occurrence, Exploitation, and Uses": 1912.

known in New Brunswick, though the writer once identified grains of yellow monazite in a specimen of granite sent in for examination from near Sussex. The specimen, however, proved to be a boulder but which possibly had not travelled far, as there were granite a few mile distant.

In Nova Scotia the few small pegmatites which are known are distinctly of the lithium-tin type, being likely to carry lithium minerals and small quantities of cassiterite. This is the type of pegmatite which in the New England states produces gem minerals such as transparent, beautifully coloured beryls (aquamarine, emerald, etc.) and tourmaline. In both provinces quartz veins have been found representing the later phases of pegmatitic activity, which carry such minerals as scheelite, wolframite, and topaz. Uranium and thorium minerals have not yet been found in either of these provinces.

REEVES FARM, NEW ROSS, LUNENBURG COUNTY, NOVA SCOTIA: AMBLYGONITE

References: Faribault, E.R.: Geol.Surv., Canada, Sum. Rept., 1907, pp. 81-82.
Walker, R.L. and Parsons, A.L.: University of Toronto Studies, No. 17, 1924.

Interest in this occurrence, according to Faribault[1], was first aroused in 1903 by the finding of large pieces of quartz crystals on the surface. Later Mr. Chas. Keddy found cassiterite in the digging, and in 1906 and 1907 a pit was sunk and the various minerals mentioned in the reports of that time were brought to light. The locality was examined by Harry Piers, E.R.Faribault, G.A.Young, and

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[1] Faribault, E.R.: Geol. Surv., Canada, Sum. Rept. 1907, pp. 81-82.

R.A.A.Johnstin at the time and in 1922 by T.L.Walker and A.L.Parsons[1] who have described several of the minerals in detail. The location of the deposit is given by Faribault as about 3/8 of a mile south of the Dalhousie road and 3 miles west of New Ross, Lunenburg county. Faribault reports that on 1907 the King pit on Reeve's tin deposit was 18 feet deep, 12 feet long and 10 feet wide and was in a pegmatitic "segregation" in light grey granite. The pegmatite is described as being composed of "crystalline masses of feldspar enclosing very large crystals of smoky quartz with a little mica and other associated minerals .... The larger quartz crystals, the fluorite, the tin ore and other associated minerals occur chiefly in zones about the middle of the dyke, in feldspar generally much decomposed. There is no well-defined foot- or hanging-wall...At the outcrop the dyke was about 8 feet in width and 12 feet in length, but the development shows that at one end at least it extends farther to the northeast under a cap of granite."

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[1] University of Toronto Studies, No. 17, 1924.

The minerals obtained from the dyke were examined by R.A.A. Johnston, who identified amblygonite, durangite, cassiterite, scheelite, wolframite. A considerable number of more common minerals are stated by Faribault to have been identified by Johnston as occurring in the granites of New Ross, but it is not clear from the records how many of these were obtained from the Reeve dyke. They are "lepidolite, monazite, one of the columbite minerals, hubnerite, molybdenite, zinc blende, beryl, apatite, tourmaline, fluorite, pyrolusite, manganite, limonite, hematite, magnetite, siderite, bismuthinite, argentiferous galena, copper, iron and arsenical pyrites, kaolin and fire-clay, crystals of black smoky quartz." Of these, probably lepidolite, monazite, and beryl at least, were obtained from the Reeve deposit, in addition to those mentioned, and Walker and Parsons (loc.cit.) identified and described topaz, zinnwaldite and manganapatite, while they collected from the Reeve dyke.

A few minute crystals of the rare fluo-arsenate of sodium and aluminium, durangite, were identified by R.A.A.Johnston[1], but so far as known no detailed description was published.

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[1] Geol. Surv., Canada, Sum. Rept. 1907, p.96

Amblygonite was apparently much the most abundant of the unusual minerals found at this mine. At the time of the present writer's visit the dump was old, weathered, and more or less overgrown with moss, but good-sized masses of the bluish amblygonite could still be found. It has been described by Walker and

Parsons[1] as follows: "This mineral occurs in the pegmatite in masses several inches in diameter. It is devoid of crystal form, white or pale bluish in colour, and quite free from other minerals. The analysis by E.W.Todd shows that the mineral is unusually low in fluorine and very high in water. It is very similar in composition to some amblygonite from Montebras, France." The results of the analysis by Todd are given on page....

Walker and Parsons (loc.cit.) have also described lepidolite and zinnwaldite as follows: "These micas occur in the solid albite in the form of irregular masses devoid of crystal outline .... the lepidolite is violet, and the zinnwaldite amber-brown when of considerable thickness. In thin places they are both colourless.... Sometimes the two minerals are seen to merge into one another and to form part of a single cleavage plate."

The present writer obtained a part of a crystal of green beryl 1 inch in diameter from the dump.Scales of pinkish lepidolite up to ½ inch in diameter and also apparently of muscovite about the same size were seen and some small dark purple fluorite. The feldspar was badly weathered. There was evidently a good deal of quartz, commonly forming large crystals. Walker and Parsons state that numerous, large, doubly terminated crystals were found, up to 27 inches in length by 10 inches in diameter.

No indications of the presence of uranium or thorium minera

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[1] Walker, T.L. and Parsons, A.L.: University of Toronto Studies, No. 17, 1924.

were noticed by the writer. The opening itself was full of water and only the old dump was available for study.

NEAR SEFFERNSVILLE, LUNENBURG COUNTY, NOVA SCOTIA: LEPIDOLITE

Lepidolite occurs insmall amount as feathery masses in quartz and feldspar in a dyke about 1½ or 2 miles west of Seffernsville, a settlement 8½ miles from Chester basin. The dyke is entirely in the coarse biotite granite which covers this area. It outcrops in two places on the north side of a rather high hill near the top. One exposure shows a mass of solid white quartz 6 to 8 feet by 30 feet. At one point in this a pit 5 feet square and 8 feet deep has been sunk. A foot or two of pinkish feldspar shows on one side of the pit. The dump shows nothing but white quartz carrying a little black tourmaline and some smoky quartz which occurs as well-formed crystals reaching a diameter of several inches. These are the finest examples of smoky quartz crystals so far found in Canada, both in regard to perfection of form and dept of coloration. They are in some cases almost black, free from flaws, and would probably make excellent cairngorm stones. The other pit 50 feet to the west of the one mentioned is 4 by 8 feet and 4 feet deep and the dump consists of mixed quartz, feldspar, and feathery lepidolite. The two exposures line up in a direction about east and west.

LAKE RAMSAY, NEW ROSS, NOVA SCOTIA: COLUMBITE(?)

Minute black crystals that were found to be slightly radioactive occur very sparingly in dykes discovered by Chas. Keddy, about 2 miles from lake Ramsay. The dyke is about 4 feet wide as exposed in a granite exposure 20 by 60 feet. A few specks of molybdenite and dark purple fluorite were also seen. The black crystals were not obtained in sufficient amount to permit identification, but are probably columbite or other columbate.

LAVERS MINE, NEW ROSS, NOVA SCOTIA: COLUMBITE

Reference: Geol.Surv., Canada, Sum. Rept. 1907, p.83.
University of Toronto Studies No. 16, 1923, pp.34,35.

Faribault states (loc.cit.) that "ores of tungsten and rare earths were discovered on Dr. Lavers" and Frank Boylen's claims in a dyke of pegmatite 20 feet wide situated one mile east of New Ross corner". Walker and Parsons (loc.cit.) have described columbite from this mine. "The mineral is found in the form of crystals often weighing several grammes, in a coarse pegmatite which cuts an even-grained granite. While the crystals are generally well formed, none was found sufficiently bright for crystallographic measurements. The results of an analyses are given on page .....

CHAPTER XIII

CHEMICAL ANALYSES

	I	II	III	IV	V	VI	VII	VIII	IX
SiO_2	31.88	29.90	31.94		1.08	65.85	64.40	1.92	2.39
TiO_2		1.91				0.00		1.43	2.50
Al_2O_3	16.66	13.68	18.18	33.14	32.92	19.01	18.08	0.65	0.16
Fe_2O_3	4.91	4.64	3.30		0.31	0.49	0.97		7.67
BeO						12.74	14.38	0.49	0.26
$FeO+Fe_2O_3$ as Fe_2O_3								3.01[1]	
FeO	9.56	12.45	12.13						0.21
CaO	12.94	9.46	14.76		2.22	0.84	0.18	4.76	7.56
MgO	1.03	1.20	0.32			0.08	0.33	0.14	0.02
MnO	0.74	1.18	1.10		0.06	0.00	0.04	0.23	0.04
K_2O		0.03		0.26	0.06	trace	0.18		
Li_2O				8.20	7.45		0.18		
Na_2O		0.07		2.96	2.53	0.43	0.35		
ZrO_2								0.24	0.02
SnO_2								0.48	1.49
Ta_2O_5								4.86	2.54
Cb_2O_5								43.50	43.32
PbO								0.38	0.44
UO_2								(10.00[2])	9.00
UO_3								(3.06[3])	1.67
U_3O_8								13.38	
ThO_2	0.44	0.41	0.52					2.16	3.34
$(Ce,La,Di)_2O_3$	19.58	21.15	13.44					4.04	1.68
$(Yt,Er)_2O_3$	1.64	1.58	0.76					10.71	11.38
P_2O_5		0.04		48.63	46.62				
H_2O	1.33		2.99	5.12	6.38	0.08	1.08		
$H_2O(-110^\circ)$		0.13						0.68	0.40
$H_2O(+110^\circ)$		0.59						5.76	3.24
CO_2		trace							
F_2				2.15	1.38				
Insol.		1.26[1]							
Less for F				0.91	0.58				
	100.71	99.68	99.94	99.55	100.45	99.50	100.17	98.82	99.33
Sp.G.	3.658		3.279		2.989		2.726	4.485	4.738

(To face preceding page with analyses I to IX)

I. Allanite, Fry lake, Monteith township, Parry Sound district, Ontario; analyst, E.W.Todd; for description of occurrence, see page...

II. Allanite, Lac A Baude, Norman township, Champlain county, Quebec; analyst, H.V.Ellsworth; for description of occurrence, see page....

<u>Note</u> (1) The insoluble material gave:

SiO_2	0.94
TiO_2	0.15
Undet.	0.17

III. Allanite, Portland East Township, Labelle county, Quebec; analyst, E.W.Todd; for description of occurrence, see page....

IV. Amblygonite (var., montebrasite), Bear mineral claim, Manitoba; analyst, R.J.C.Fabry; for description of occurrence, see page....

V. Amblygonite, Reeve's farm, New Ross, Nova Scotia; analyst, E.W.Todd; For description of occurrence, see page...

VI. Beryl, greenish, Bear Mineral claim, Manitoba; analyst, R.J.C.Fabry; for description of occurrence, see page....

VII. Beryl, Lyndoch township, Renfrew county, Ontario; analyst, H.C.Rickaby; for description of occurrence, see page....

VIII. Calciosamarskite, Conger township, Parry Sound district, Ontario; analyst, H.V.Ellsworth; for description of occurrence, see page....

Note (1) FeO not determinable because of the presence of carbon from thucholite.

(2) UO_2 and UO_3 not determinable because of carbon; the amounts stated are estimated. U was all weighed as U_3O_8.

IX. Calciosamarskite, Woodcox mine, Monteagle township, Hastings county, Ontario; analyst H.V.Ellsworth; for description of occurrence, see page ....

<u>Note</u> He, etc., and alkalis not determined.

	X	XI	XII	XIII	XIV	XV	XVI	XVII
SiO_2	34.66	0.64		1.28	0.34	2.54	2.68	2.49
TiO_2		5.22		5.19	1.47	10.47	9.79	15.06
Al_2O_3	0.22[3]					0.42		0.12
Fe_2O_3						4.10	3.80	2.74
BeO								0.02
FeO		8.61	11.14	10.90	10.46			0.22
CuO			0.03					
CaO	16.72			0.15		11.73	13.62	8.94
MgO	0.19							0.08
MnO	0.02	9.06	10.22	10.24	10.44	0.43	0.22	0.04
SrO	0.31[2]							
K_2O	trace							
Na_2O	0.27							
ZrO_2		1.25						
SnO_2		0.36	0.92	0.56	0.22	0.10	0.25	0.06
Ta_2O_5		1.74	75.75	15.21	14.48	4.32	4.27	9.97
Cb_2O_5		66.60		55.79	63.08	34.22	34.27	23.44
PbO						0.24	0.41	1.73
UO_2							8.42	1.56
UO_3						18.50	10.68	20.46
U_3O_8								
ThO_2		3.44						0.10
$(Ce,La,Di)_2O_3$	3.22[1]							1.49
$(Yr,Er)_2O_3$	35.46							0.12
Rare earths		1.68	2.00	0.82		0.21		
P_2O_5								trace
H_2O	2.54	1.41				12.22	11.42	
H_2O (-110°)								
H_2 (110-130°)	0.04							4.59
H_2O (+110°)								
H_2U (+130°)								6.61
CO_2	6.58							
SO_3	0.04							
F_2						0.22	0.49	trace
Insol.								0.21
Ignitionloss								11.54
	100.25	100.01	100.06	100.14	100.49	99.72	100.32	100.05
Sp.Gr.	3.612	5.147			5.613	3.608	3.758	3.705

(To face page with analyses X to XVII.)

X. Cenosite, North Burgess township, Lanark county, Ontario; analyst, H.C.Ellsworth; for description of occurrence see page....

Notes 1. The oxides after heating in air were a strong brown colour indicating the presence of considerable praseodymium. After heating in hydrogen they became white.

2. Barium not detected by flame test. The strontium was separated by repeated amylalcohol treatments and appeared perfectly pure.

3. Little iron, apparently mostly alumina. No test for beryllium.

XI. Columbite, Woodcox mine, Monteagle township, Hastings county, Ontario; analyst, E.W.Todd; for description of occurrence see page....

XII. Columbite, Lyndoch township, Renfrew county, Ontario; analyst, W.L. Goodwin; for description of occurrence see page...

XIII. Columbite, Lyndoch township, Renfrew county, Ontario; analyst, E.W. Todd; for description of occurrence see page....

XIV. Columbite, Dr. Laver's and F. Boylen's claim, 1 mile east of New Ross corner, Nova Scotia; analyst, E.W.Todd; for description of occurrence see page....

XV. Ellsworthite, light type, MacDonald mine, Monteagle township, Hastings county, Ontario; analyst, E.W.Todd; for description of occurrence, see page....

XVI. Ellsworthite, dark type, MacDonald mine, Monteagle township, Hastings county, Ontario; analyst, E.W.Todd; for description of occurrence, see page....

XVII. Ellsworthite, Cardiff township, Haliburton county, Ontario; analyst, H.V.Ellsworth; for description of occurrence see page...

	XVIII	XIX	XX	XXI	XXII	XXIII	XXIV	XXV
SiO_2	0.09	0.74	1.08	0.03	25.97	1.57	1.56	2.17
TiO_2	22.96	27.70	25.04	26.17		11.37	8.82	54.49
BeO	0.26		0.05	0.28	10.29			
Al_2O_3			0.45		0.32			0.68
Fe_2O_3	2.07	2.63	2.16	1.40	2.34	3.46	3.63	2.85 [1]
FeO	0.00	0.51	0.14	0.29	5.82			
CaO	1.92	0.09	2.03	1.08	2.36	13.25	13.62	35.10
MgO	0.03	0.12	0.07	0.05	0.55	0.36	0.20	0.21
MnO	0.28	trace	0.19	0.03	1.17	0.51	0.43	0.08
K_2O	0.04				0.09[1]			0.07
Na_2O	0.17							0.46
ZrO_2	0.05		0.00	0.03		4.12	5.90	
SnO_2	0.07		0.14	0.09		1.44	1.46	0.04 [2]
Cb_2O_5	28.62	12.73	22.28	18.49		31.33	31.70	
Ta_2O_5	2.65	13.89	5.32	12.12		10.29	15.28	
PbO	1.35	0.20	1.01	1.06		0.54	0.24	
UO_2	8.61		7.25	6.42		11.40	5.72	
UO_3	0.20		1.51	0.43		4.41	5.08	
U_3O_8		10.50						
ThO_2	3.94	1.34	2.64	0.97	0.14	0.52	0.42	0.06
$(Ce,La,Di)_2O_3$	0.44	0.62	0.37	0.20	2.35	0.12	0.50	2.33
$(Yt,Er)_2O_3$	24.31	25.64	24.95	28.07	46.47	0.62	0.62	0.05
P_2O_5					trace			
H_2O					1.23	4.29	5.05	0.68
$H_2O(-110^\circ)$	0.08		0.08	0.04				
$H_2O\ (+110^\circ)$	2.15		2.29	2.83				
He				present				
Ignition loss		3.00		(2.99)				
		99.71	99.55	100.08	99.60	99.60	100.25	99.27
Sp.G.	5.002	4.99	4.983	4.918	4.101	4.509	4.417	

(To face page with analyses XVIII to XXV)

XVIII. Euxenite, Sabine township, Nipissing district, Ontario; analyst, H.V.Ellsworth; for description of occurrence see page....

XIX. Euxenite, Sherbrooke South township, Lanark county, Ontario; analyst, Imperial Institute, London; for description of occurrence, see page ....

XX. Euxenite, Lot 13, Concession V, South Sherbrooke township, Lanark county, Ontario; analyst, H.V.Ellsworth; for description of occurrence, see page....

XXI. Euxenite-polycrase, Mattawan township, Nipissing district, Ontario; analyst, H.V.Ellsworth, for description of occurrence, see page...

XXII. Gadolinite, Loughborough township, Frontenac county, Ontario; analyst, H.V.Ellsworth; for description of occurrence, see page..

Note I Weight as chlorides.

XXIII. Hatchettolite, dark type, Woodcox mine, Monteagle township, Hastings county, Ontario; analyst, E.W.Todd; for description of occurrence, see page...

XXIV. Hatchettolite, light type, Woodcox mine, Monteagle township, Hastings county, Ontario; analyst, E.W.Todd; for description of occurrence.see page....

XXV. Knopite, Moose creek, B.C.; analyst. H.V.Ellsworth; for description of occurrence, see page.....

Notes (1) All iron as Fe_2O_3. It is probably present in the mineral chiefly in the ferrous condition.

(2) Amount too small for absolute confirmation.

	XXVI	XXVII	XXVIII	XXIX	XXX	XXXI	XXXII	XXXIII
SiO_2	0.91	1.54	0.07		49.28	47.18	47.89	49.06
TiO_2			16.39			0.00		0.00
BeO			0.13					
Al_2O_3		0.10			24.36	31.80	21.16	27.22
Fe_2O_3	1.07	0.08	1.32		0.63	0.07	2.52	0.24
FeO			0.77	0.24		0.16		trace
CaO	1.54	0.35	4.86	1.03	0.26	0.40		0.44
MgO	0.04	0.02	0.13	0.04	0.73	0.28	0.36	0.52
MnO			0.59	45.18	0.87	2.05	4.19	0.90
Rb_2O					0.32			
Cs_2O								0.21
ZrO_2			0.04					
SnO_2			0.12					
Cb_2O_5			41.43					
Ta_2O_5			3.84					
Li_2O				6.99	5.36	1.06	5.44	3.39
Na_2O				0.50	0.66	2.94	1.34	1.92
K_2O				trace	11.24	10.50	10.75	11.03
PbO_2		0.33	0.37					
UO_2			0.67					
UO_3			0.04					
U_3O_8		0.32						
ThO_2	12.60	7.32	4.95					
Ce_2O_3	24.80	22.63						
$(La,Di)_2O_3$	26.41	34.63						
$(Ce,La,Di)_2O_3$			4.34					
$(Yt,Er)_2O_3$	4.76	4.66	18.22					
P_2O_5	26.86	27.89		44.47				
H_2O	0.78			1.39	0.87	2.40	1.90	1.95
H_2O (-110°)		0.06	0.06					
H_2O (+110°)		0.34	1.90					
F					8.92	2.15	7.41	4.30
Ignition loss			(1.76)					
Less O for F					3.76	0.89	3.12	1.81
	99.77	100.27	100.24	99.84	99.74	100.10	99.82	99.37
Sp.G		5.270	4.909		2.869	2.87	2.86	

(To face page with analyses XXVI to XXXIII)

XXVI. Monazite, Villeneuve mine, Villeneuve township, Ottawa county, Quebec; analyst, F.A.Genth; for description of occurrence, see page....

XXVII. Monazite, Dickens township, Nipissing district, Ontario; analyst, H.V.Ellsworth; for description of occurrence, see page....

XXVIII. Lyndochite, Lyndoch township, Renfrew county, Ontario; analyst, H.V.Ellsworth; for description of occurrence, see page....

XXIX. Lithiophillite, Bear mineral claim, Manitoba; analyst, R.J.C.Fabry; for description of occurrence, see page....

XXX. Lepidolite, Reeve's farm, New Ross, Nova Scotia; analyst, E.W.Todd; for description of occurrence, see page.....

XXXI. Dark coloured, radiating mica (low lithium lepidolite?),Bear mineral claim, Manitoba; analyst, R.J.C.Fabry; for description of occurrence, see page.....

XXXII. Lepidolite, Leduc mine, Wakefield township, Ottawa, county, Quebec; analyst, R.A.A.Johnston; for description of occurrence, see page...

XXXIII. Lepidolite, Bear mineral claim, Manitoba ; analyst, R.J.C.Fabry; for description of occurrence, see page.....

	XXXIV	XXXV	XXXVI	XXXVII	XXXVIII	XXXIX	XL	XLI	XLII
SiO_2	45.58	46.56	45.36		66.50	14.70	6.40	1.77	32.13
TiO_2	0.00	0.00	0.00		0.00	trace[1]		0.35	
BeO								0.47	
Al_2O_3	37.45	29.53	33.21		26.04	1.45)	) 4.30	0.04	58.16
Fe_2O_3	0.16	0.12	2.20		trace	1.50		4.68	trace
FeO		0.10	2.57	4.83	0.11			4.38	
CaO	0.28	0.15	0.13	5.38	0.25	0.50[2]	15.70	2.02	0.00
MgO	0.13	0.29	0.13	0.11	0.07	trace		0.22	0.37
MnO	0.15	2.32	0.90	1.51	0.01	0.02		2.62	
Rb_2O		trace							
Cs_2O		0.33							
ZrO_2						0.80		0.06	
SnO_2				0.10				0.53	
Cb_2O_5				) 55.41[1]				53.73	
Ta_2O_5				)				8.97	
Li_2O	0.13	1.80	0.90		6.47				
Na_2O	0.93	2.65	1.14	0.25	0.92	0.22			0.24
K_2O	10.90	11.01	11.14	0.39	0.12	0.15			trace
PbO						0.20		0.44	
UO_2								8.71	
UO_3				10.75				2.37	
U_3O_8						5.80	18.20		
ThO_2						48.48	10.40	0.47	
$(Ce,La,Di)_2O_3$				4.78		5.45	22.80	0.76	
$(Yt,Er)_2O_3$				14.34		10.95	12.80	3.42	
V_2O_5						2.25			
P_2O_5						3.21	present[1]		
H_2O	3.16	3.12	1.41	2.21		1.60[3]			0.24
H_2O (-110°)								0.35	
H_2O (+110°)								3.59	
Hydrocarbons								trace	
F	0.97	3.45	1.84	trace					16.51
Water soluble						1.60			
Ignition loss								(3.42)	
LessO for F	0.41	1.45	0.77						6.95
	99.43	99.98	100.16	99.04	100.49	97.28	90.60	100.45	100.70
Sp.G.	2.85							5.041	

(To face page with analyses XXXIV to XLII)

XXXIV. Muscovite, light lilac, Bear mineral claim, Manitoba; analyst, R.J.C.Fabry, for description of occurrence, see page ....

XXXV. Curved muscovite, lilac variety, Annie mineral claim, Manitoba; analyst, R.J.C. Fabry; for description of occurrence, see page.

XXXVI. Curved muscovite, grey variety, Annie mineral claim, Manitoba; analyst, R.J.C.Fabry; for description of occurrence, see page.

XXXVII. Samarskite, Maisonneuve mine, de Maisonneuve township, Berthier county, Quebec; analyst, G.C.Hoffman; for description of occurrence see page...

Notes. (1) Apparently in great part, if not almost entirely, columbic acid.

XXXVIII. Spodumene, Bear mineral claim, Manitoba; analyst, R.J.C.Fabry; for description of occurrence, see page....

XXXIX. Freshly ignited ash of thucholite, Conger township, Parry Sound district, Ontario; analyst, H.V.Ellsworth; for description of occurrence, see page....

Notes (1) Doubtful trace.

(2) Probably should be about 3.00 per cent.

(3) not definitely identified

XL. Freshly ignited ash of thucholite, Wallingford, mine, Derry township, Ottawa count, Quebec; analyst, H.V.Ellsworth; for description of occurrence, see page...

Notes.

Loss in 3 days over conc H_2SO_4	8.64
Loss in 3 hrs at 110° ...	4.89
Loss in 1 minute at red heat in covered platinum crucible, CO_2 passing	28.70
Residue after combustion	19.84
	62.07

Hence, approximately:

H_2O	13.53
Gases	28.70
Ash	19.84
Fixed carbon	37.93
Heavy hydrocarbons	not detected
	100.00

(1) present, not detected.

XLI. Toddite, Dill township, Sudbury district, Ontario; analyst. H.V. Ellsworth; for description of occurrence, see page.....

XLII. Topaz, Bear mineral claim, Manitoba; analyst, R.J.C.Fabry ;

for description of occurrence, see page ....

	XLIII	XLIV	XLV	XLVI	XLVII	XLVIII	XLIX	L	LI
PbO	11.67	8.66	8.09	8.16	10.80	9.84	10.58	16.63	16.71
UO_2	53.63	49.85					43.33		
UO_3	26.32	29.76					33.42		
U_3O_8			79.30	79.35	79.48	76.87		63.08	64.86
ThO_2	3.22	1.78	1.73	2.11	1.56	1.83	1.23	14.18	13.94
$(Ce,La,Di)_2O_3$	0.92	1.47	2.87	3.48	5.02	2.71	0.96	0.57	0.28
$(Yt,Er)_2O_3$	2.19	1.48				2.77	4.02	1.02	1.19
Fe_2O_3	0.15	0.88			0.40	0.53	0.62	0.64	0.75
MnO	0.01	0.02		0.02	0.12	0.21	0.06	0.18	0.13
BeO	0.03	0.17			0.08	0.03	0.10	0.10	0.12
Al_2O_3									
CaO	0.41	2.69	2.82	1.97	1.18	1.50	0.98	1.45	1.72
MgO	0.02	0.03			0.07	0.03	0.04	0.07	0.06
CuO		0.03	0.03	0.02					
SiO_2	0.29	1.36	1.76	2.12	0.31	1.02	0.36	0.67	0.37
H_2O	0.72	1.44				1.33			
H_2O (-110°)					0.26		0.40		
H_2O(+110°)					0.35		0.34		
He	0.37						1	1	1
ZrO_2	1				1				
Bi,Tl									
$CO_2P_2O_5$	2						2		
K_2O,Na_2O									
Insol.	0.13				0.35	1.40	2.27	0.12	0.00
F					present		present		
	100.14	99.12			99.98	100.07	98.71		
Sp.Gr.	9.116	8.173	7.827	7.809	8.859		8.788	8.082	8.968

(To face page with analyses XLIII to LI.)

XLIII. Uraninite, Conger township, ParrySound district, Ontario; analyst, H.V.Ellsworth; for description of occurrence, see page .....

Notes (1) Not detected.

(2) Not determined

XLIV. Uraninite concentrate sp.g. 8.173, XLV concentrate, sp. g. 7.827, XLVI heavy fraction of single crystal sp.g. 7.809; Henvy township, Parry Sound district, Ontario; analyst, H.V.Ellsworth; for description of occurrence, see page .....

XLVII. Uraninite, good quality, single crystal, Butt township, Nipissing district, Ontario; analyst, H.V.Ellsworth; for description of occurrence, see page.....

Note (1) Not determined.

XLVIII. Uraninite, Butt township, Nipissing district, Ontario; analyst, H.V.Ellsworth; for description of occurrence, see page.....

XLIX. Uraninite, Butt township, Nipissing district, Ontario; analyst, H.V. Ellsworth; for description of occurrence, see page....

Note (1) Not determined.

(2) Not determined.

XL. Uraninite, heavy fraction of water concentrate, LI, and treated concentrate, Huron claim, Oiseau River area, Manitoba, Analyst H.V.Ellsworth; for description of occurrence, see page....

Note (1) Not determined.

	LII	LIII	LIV	LV	LVI	LVII	LVIII
PbO	11.60	10.52	10.36	11.05	10.95	10.40	11.61
UO_2	51.27	38.05		13.55	39.10	45.18	49.44
UO_3	28.37	39.13		52.04	32.40	24.90	24.28
U_3O_8			75.74				
ThO_2	3.55	3.35	1.13	13.56	10.60	11.40	4.92
$(Ce,La,Di)_2O_3$	0.44	0.78	5.58	1.26	1.88	1.82	2.10
$(Yt,Er)_2O_3$	2.31	1.90		1.87	2.14	2.74	2.30
Fe_2O_3	0.27	0.91	0.86	0.47	0.43	0.58	0.37
MnO	0.03	0.04	0.16	0.03	0.05	0.04	0.02
TiO_2				0.001			
BeO	0.02	0.11	0.07	0.11	0.09		0.05
Al_2O_3							
CaO	0.47	1.40	1.35	0.27	1.01	0.28	1.56
MgO	0.03	0.17	0.03	0.07	0.08	0.19	0.11
SiO_2	0.35	1.56	2.04	0.58	0.19	0.43	0.64
Na_2O	0.23						
K_2O	trace						
H_2O	0.74					0.61	
$H_2O(-110°)$		0.45	0.72	1.49	0.05		0.22
$H_2O(+110°)$		1.08	1.20	0.11	0.65		1.33
He					0.31	0.35	
Insol.	0.17	0.14	0.43	0.67	0.15		0.16
CO_2				0.67			
SO_3				0.58			
P_2O_5				0.04			
Ignition loss				(4.42)			
	99.85	99.39	99.67	98.42	100.06	98.92	99.11
Sp. G.	9.026			7.178	9.062	9.082	8.674

((face page with analyses LII to LVIII)

LII. Uraninite, Conger township, Parry Sound district, Ontario; analyst. H.V.Ellsworth; for description of occurrence, see page.....

LIII. Uraninite, single crystal considerably altered to black stage, Conger township, Parry Sound district, Ontario; analyst, H.V.Ellsworth; for description of occurrence, see page.....

LIV. Uraninite, single crystal, altered, Butt township, Nipissing district, Ontario; analyst, H.V.Ellsworth; for description of occurrence, see page....

LV. Uraninite, altered, associated with magnetite, Cardiff township, Halibutron county, Ontario; analyse. H.V.Ellsworth; for description, see page...

LVI. Uraninite, pure, hard crystal, Cardiff township, Haliburton county, Ontario; analyse. H.V.Ellsworth; for description of occurrence, see page....

LVII. Uraninite, Cardiff township, Haliburton county, Ontario; analyst. E. W. Todd; for description of occurrence, see page.....

LVIII. Uraninite, March township, Carleton county, Ontario; analyst. H.V. Ellsworth; for description of occurrence, see page.....

	LIX	LX	LXI	LXII	LXIII	LXIV	LXV	LXVI
SiO_2	3.46	19.56	46.58	32.51	26.14	22.86		0.13
TiO_2						0.06		0.49
BeO		0.13		0.21		3.12		
Al_2O_3	2.55		24.10					
Fe_2O_3		0.75	0.69	0.08	2.06	4.16		
MnO		0.07	1.34			0.02	21.13	2.17
FeO		0.43	4.28		1.72		21.70	14.77
CaO	0.93	4.38	0.69	0.22	1.16	1.58	0.65	2.66
MgO		0.01	0.49	0.01		0.18	0.23	0.45
Na_2O			0.84				0.12	
K_2O			10.81				0.44	
Li_2O			3.56				8.36	
Rb_2O								
ZrO_2				67.02	62.16	43.03[1]		0.63
V_2O_5						0.00		
Cb_2O_5					0.72			52.26
Ta_2O_5								26.41
FeS_2		trace						
PbO	9.38	1.32				present		
UO_2		7.67						
UO_3		9.46			1.26			
U_3O_8	68.92					1.46		
ThO_2	6.76	46.33				0.66		
$(Ce,La,Di)_2O_3$	0.66	0.08		0.04		0.34		
$(Yt,Er)_2O_3$	4.04	0.36				6.76		
P_2O_5						3.53	46.41	
H_2O			1.50		4.21		0.99	0.21
H_2O(-110°)		3.57				1.64		
H_2O(+110°)		5.67				10.90[2]		
F			7.90					
He								
Insol		0.15					0.20	
Ignition loss				0.03				
Less O for F			3.33					
	97.20	99.94	99.94	100.12	99.43	100.30	100.23	100.20
Sp. G.		4.414	2.916	4.659	4.102		3.482	5.87

(To face analyses LIX to LXIV)

LIX. Uraninite-thucholite, Wallingford mine, Derry township, Ottawa county, Quebec; analyst, H.C.Ellsworth; for description of occurrence, see page...

LX. Uranothorite, MacDonald mine, Monteagle township, Hastings county, Ontario; analyst, H.V.Ellsworth; for description of occurrence, see page ...

LXI. Zinnwaldite, Reeve's farm, New Ross, Nova Scotia; analyst, E.W.Todd; for description of occurrence, see page.....

LXII. Zircon, North Burgess township, Lanark county, Ontario; analyst, H.V. Ellsworth; for description of occurrence, see page....

LXIII. Zircon, variety cyrtolite, Woodcox mine, Monteagle township, Hastings county, Ontario; analyst, E.W.Todd; for description of occurrence, see page...

LXIV. Cyrtolite, Conger township, Parry Sound district, Ontario; analyst. H.V.Ellsworth; for description of occurrence, see page....

Notes (1) Probably includes an appreciable amount of hafnium.
(2) Includes traces of carbon from thucholite.

LXV. Triphyllite, pegmatite near Huron claim, S.E.Manitoba; analyst, V.J.Oswald; for description of occurrence, see page .....

LXVI. Columbite, Huron claim, S.E.Manitoba; analyst V.J.Oswald; for description of occurrence, see page .....

Analysis of a single specimen of uraninite, Villeneuve mine, Villeneuve township, Ottawa county, Quebec; analyst H.V.Ellsworth (A, B and C), and W.F.Hillebrand; for description of occurrence, see page....

	A	B	C
PbO	11.43	10.73	14.93
(Pb)	(10.61)	(9.96)	(13.85)
UO_2	41.08	9.49	none
UO_3	34.98	62.42	60.36
(Total U)	(65.34)	(60.33)	(50.24)
(As U_3O_2)	(77.05)	(71.13)	(59.24)
ThO_2	6.40	6.23	7.66
(Th)	(5.63)	(5.48)	(6.73)
(Th=U equiv.)	(2.14)	(2.08)	(2.56)
$(CeLaDi)_2O_3$	0.79	0.68	0.14
$(YtEr)_2O_3$	3.31	2.97	1.61
Fe_2O_3 Al_2O_3 etc.	0.18	0.13	0.14
CaO	0.36	0.42	1.37
MgO	0.03	0.02	0.12
SiO_2	0.21	0.34	3.81
H_2O	1.70	5.97	9.42
Bi_2O_3	2^1	?	?
CO_2			small amt. undet.
	99.47	99.40	99.56
Sp. Gr.	9.144	7.778	5.275