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Geological Comparison between East European and Canadian Uranium Deposits

V. Ruzicka

DEPARTMENT OF ENERGY, MINES AND RESOURCES

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GEOLOGICAL COMPARISON BETWEEN EAST EUROPEAN AND CANADIAN URANIUM DEPOSITS

V. Ruzicka

DEPARTMENT OF ENERGY, MINES AND RESOURCES

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ABSTRACT

The comparison of some geological features between the Canadian and East European (including the Asian part of U.S.S.R.) uranium deposits and types of deposits show many similarities, e.g. the deposits were formed during analogous mineragenetic processes, they were related to certain orogenies and to certain phases of the tectonic cycles in specific geological conditions.

The distribution of the endogenetic uranium deposits is structurally controlled by regional deep fault and fracture systems, along which the tectonic movements were repeated several times. The intersections and ramifications of such systems are the favourable loci for uranium deposits, if other favourable conditions are present.

Favourable lithological features of sedimentary rocks within the uranium-bearing areas and provinces influenced the localization of uranium mineralization in the sedimentary syngenetic deposits or in the epigenetic deposits in sediments.

The syngenetic differentiation and accumulation of uranium caused the primary enrichment of rocks with uranium.

Weathering processes, which affected the uranium enriched rocks, separated the uranium compounds and introduced them either as a part of weathered material into the detritus or into the hydrological cycle.

Metamorphic processes also participated in differentiation and accumulation of uranium.

Comparison of some geological features of uranium deposits from different geological environments as well as the hitherto published classifications of uranium deposits allowed a new classification of uranium deposits into several syngenetic, metamorphic and epigenetic groups and various types within them.

RÉSUMÉ

La comparaison de certaines caractéristiques géologiques des gisements d'uranium du Canada et de l'Europe de l'Est (y compris la partie asiatique de l'URSS) a permis de déceler plusieurs ressemblances; les gisements ont été formés au cours de phénomènes minérogénétiques analogues et ils étaient reliés à certaines orogenèses et à certaines phases de cycles tectoniques dans des conditions géologiques précises.

La répartition des gisements endogènes d'uranium est contrôlée structuralement par des réseaux régionaux de failles et de fractures profondes le long desquelles les mouvements tectoniques se sont répétés plusieurs fois. Les intersections et ramifications de tels réseaux sont les endroits favorables aux gisements d'uranium si d'autres conditions favorables s'y retrouvent également.

Les caractéristiques lithologiques favorables au sein des provinces et régions uranifères ont influencé l'emplacement de la minéralisation de l'uranium dans les gisements sédimentaires syngénétiques ou dans les gisements épigénétiques des sédiments.

La différenciation syngénétique et l'accumulation de l'uranium ont entraîné l'enrichissement primaire des roches renfermant de l'uranium.

Les intempéries, qui ont influé sur les roches enrichies d'uranium, ont séparé les mélanges d'uranium et les ont fait pénétrer soit dans le détritus en tant que matériaux soumis aux effets des agents atmosphériques ou dans le cycle hydrologique.

Les phénomènes de métamorphisme ont également participé à la différenciation et à l'accumulation de l'uranium.

La comparaison de certaines caractéristiques géologiques de gisements uranifères dans différents milieux géologiques ainsi que les classifications déjà publiées des gisements d'uranium ont permis d'établir une nouvelle classification des gisements en plusieurs groupes syngénétiques, métamorphiques et épigénétiques et en diverses catégories au sein de ces groupes.

GEOLOGICAL COMPARISON BETWEEN EAST EUROPEAN AND CANADIAN URANIUM DEPOSITS

INTRODUCTION

The geological comparisons between different and physically separate regions are useful tools in searching for solutions to specific geological problems.

The geological comparison between uranium deposits from certain regions from the Eurasian and North American continents helps to find some regularities in their distribution, in localization of uranium mineralization and to complete the genetic classification of uranium deposits.

For such purposes it is useful to summarize the selected geological features of such deposits, groups of deposits or metallogenetic areas, and to classify them.

The first three chapters of this report deal with the Czechoslovakian, other East European including the Soviet Asian, and Canadian uranium deposits or with typical groups of deposits. The geological comparison, the classification, and the regularities in distribution of uranium deposits and in localization of uranium mineralization are the topics of the fourth chapter.

The author had opportunity to visit and study many of the mentioned deposits during the last 20 years, but, unfortunately, various circumstances do not permit a more comprehensive publication at the present time.

The character of the present study demanded the use of many literature sources as shown in the list of the selected bibliography. The publications by J. Svoboda et al., F. Mrňa and D. Pavlů, A.H. Lang, L.P. Tremblay, S.C. Robinson and F.I. Vol'fson, editor, were the most comprehensive.

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The writer gratefully acknowledges the opportunity to prepare this report, to visit many Canadian and some United States uranium deposits and occurrences, to use the facilities of the Geological Survey of Canada, and to obtain scientific guidance there.

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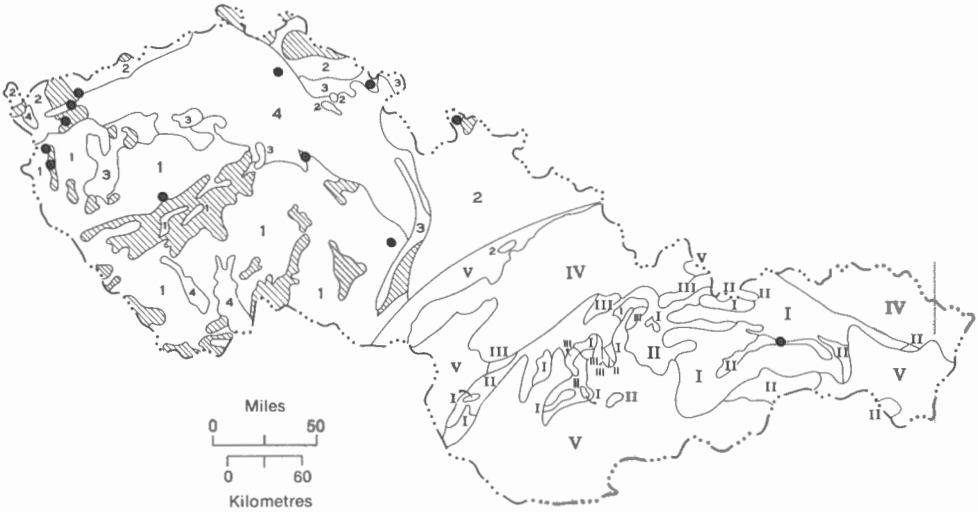
The time available to the author at the Geological Survey combined with other demands on the laboratory facilities of the Geological Survey did not permit more detailed analytical study. Because of that the analyses of ores from the Canadian uranium occurrences were done by the semiquantitative spectrographic method and therefore they can serve for orientation purposes only. The specimens collected by the author are stored mainly at the Geological Survey of Canada in Ottawa. The analyses of selected specimens were done by K.A. Church. Mineral identification, as quoted in the text, was done by H.R. Steacy.



METALLOGENETIC PROVINCES OF THE BOHEMIAN MASSIF

1 Moldanubian metallogenetic zone
2 Saxony-Thuringian and Sudetic-Moravian zone
3 Area of Permo-Carboniferous molasse sediments
4 Area of post-Variscan platform covers

METALLOGENETIC PROVINCE OF THE WEST CARPATHIANS

I Lower metallogenetic stage of the Inner West-Carpathians
II Middle metallogenetic stage of the Inner West-Carpathians
III Upper metallogenetic stage of the Inner West-Carpathians
IV Zones of the Outer Flysh and Inner Klippen Belts
V Neogene complexes

Granitoids of Variscan and pre-Variscan age . .

Uranium deposit . . . . . ●

GSC

Figure 2. Metallogenetic units in Czechoslovakia and distribution of characteristic uranium deposits (Metallogenetic map of Czechoslovakia; Ustredni ustav geol., Prague).

PART I

CZECHOSLOVAKIAN URANIUM DEPOSITS

INTRODUCTION

The writer welcomes this opportunity to prepare the first comprehensive report on Czechoslovakian uranium deposits, drawing together the concepts heretofore published in detail by many authors, in particular F. Mrňa and D. Pavlů (1958, 1961, 1963, 1967), Yu. M. Dymkov (1960), E. Drnzík (1963, 1965), F. I. Zhukov (1963), R. Nováček (1935, 1936), and I. Rojkovič (1968). Some facts about general problems of geology and mineralogy are contained in various publications, but the exact location of the deposits and necessary references are not given. Such information is given in the works of D.I. Shcherbakov and F. I. Vol'fson. During preparation for the 23rd International Geological Congress some important data were published, but the comprehensive and valuable studies are deposited in the archives of Czechoslovakian Uranium Industry in Příbram. The authors of these reports are P. Adámek, Yu.A. Arapov, V.E. Bojcov, E. G. Distanov, E. Drnzík, M. Fruehbauer, J. Habásko, J. Hřebec, V. S. Egorov, L. Kánský, V. S. Katarghin, J. Křesťan, F. Lepka, V. I. Malyshev, R. Petroš, O. Pluskal, S. Prokeš, V. Ruzicka, F. Šorf, A.V. Zavarzin, N. S. Zontov and others.

The territory of Czechoslovakia occupies a part of Middle Europe. As a land-locked country it is surrounded by other European countries, such as Poland, Soviet Russia, Hungary, Austria, and Germany. It belongs geologically to two different units. The western part of Czechoslovakia (i.e. Bohemia and the greater part of Moravia) belongs to the European continental block, the eastern part (i.e. Slovakia and a smaller part of Moravia) belongs to the Alpine-Carpathian system. Czechoslovakia produces several kinds of mineral raw material, among which the uranium ore production is of economic significance.

LOCALIZATION OF THE URANIUM MINERALIZATION WITHIN THE AREA OF BOHEMIAN MASSIF AND OF THE WEST CARPATHIANS WITHIN CZECHOSLOVAKIA

The subject of this section has a bearing on the questions of metallogenetic development in both these regions. The metallogenetic problems were studied by J. Kutina (1968), Z. Pouba (e.g. 1963), V. Sattran (1963, 1966), J. H. Bernard (1964, 1967), J. Chrt (1966, 1968), M. Máška (1956), J. Skácel (1962), M. Vaněček (1963), J. Ilavský (1968), J. Koutek (1964) and by others.

The region of Czechoslovakia is affected by two basic heterogenous polycyclic provinces (see Fig. 2):

(1) by the Bohemian Massif metallogenetic province, and

(2) by the West Carpathians metallogenetic province.

The metallogenetic province of Bohemian Massif is a part of the West European Variscan (perhaps Late Silurian to Permian) platform. Within this platform additional metallogenetic units can be distinguished:

(1)[1] Moldanubian[2] metallogenetic zone,

(2) Saxon-Thuringian and Sudetic-Moravian metallogenetic zone,

---

[1] The numbers in brackets correspond with numbers in Figure 2.

[2] Moldanubian is the southern part of the Bohemian Massif built up of katazonal metamorphosed rocks and large plutons.

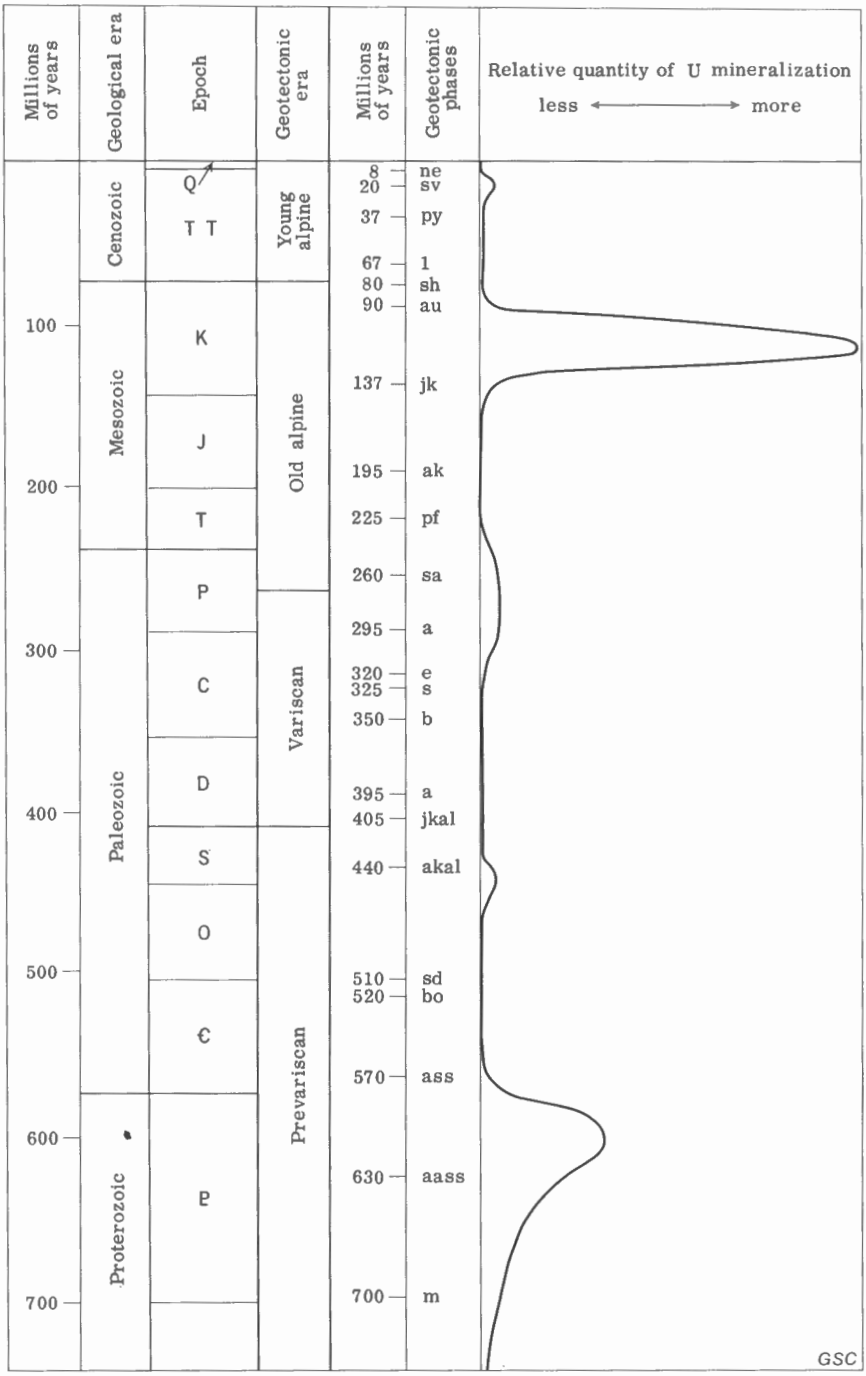


Figure 4. Relative quantity of uranium mineralization in relation to host rocks of different ages (Geotectonic phases according to Chrt et al., 1968).

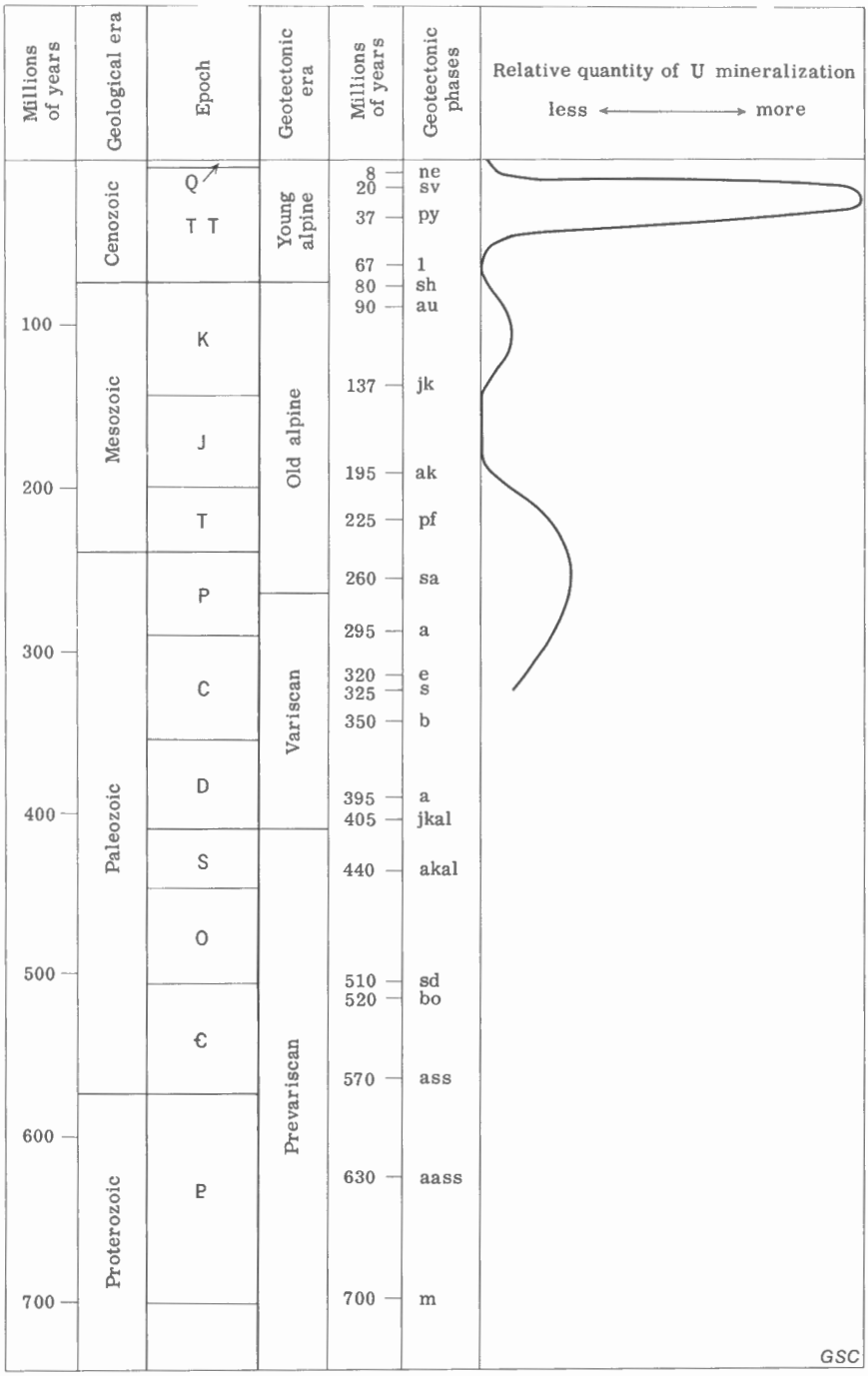


Figure 5. Relative quantity of uranium mineralization according to its absolute age (Geotectonic phases according to Chrt et al., 1968).

(3) area of Permo-Carboniferous molasse sediments,
(4) area of post-Variscan platform covers with alkaline volcanics.

Within these units further subprovinces can be distinguished, for example the subprovince of the Bohemian nucleus, the subprovince of the Krušné hory, the Sudetic subprovince and others. The Variscan granitoid intrusions are an important factor in the metallogenetic development of the Bohemian Massif.

Within the metallogenetic province of the West Carpathians the following units can be distinguished:

(I)[1] the lower metallogenetic stage of the Inner West Carpathians,
(II) the middle metallogenetic stage of the Inner West Carpathians,
(III) the upper metallogenetic stage of the Inner West Carpathians,
(IV) the zones of the Outer Flysh and of the Inner Klippen Belts, and
(V) the Neogene formations with neovolcanics.

Uranium mineralization is associated with the Variscan and Alpine metallogenetic epochs (see Fig. 5). Most of the uranium deposits are located within the metallogenetic province of the Bohemian Massif, but some belong to the West Carpathian metallogenetic province.

The schematic diagram (see Fig. 4) shows the relative quantity of uranium mineralization within the Bohemian Massif that lie within host rocks of different ages and the diagram (see Fig. 5) shows the relative quantity of uranium mineralization within the Bohemian Massif from the point of view of the absolute age of this mineralization. The difference between the diagrams indicates the epigenetic character of the most deposits. In Figure 5 the greatest peak of the curve represents a group of uranium deposits of the "roll type", which are suggested to be of Neoide epoch (young-Alpine). This suggestion is supported by the data of the absolute age of lead mineralization published by Chrt et al., (1968) obtained by means of the Pb-isotopes method (Pb^{206}/Pb^{207}).

Analogous curves for the uranium mineralization within the Bohemian Massif (for Proterozoic and Paleozoic ages) have been made by V.I. Kazanskij (in Shcherbakov and Vol'fson, editors, 1968).

All the West Carpathian uranium ore deposits found within Czechoslovakia belong to the Permo-Triassic period, however some are of epigenetic character and their mineralization might be younger.

From the metallogenetic point of view the uranium deposits within the metallogenetic province of the Bohemian Massif are located within the following units (see Figs. 1-3):

(1) within the Moldanubian metallogenetic zone: Příbram, Zadní Chodov, Rožná, and others,
(2) within the Saxon-Thuringian and Sudetic-Moravian metallogenetic zone: Jáchymov, H. Slavkov, Javorník, and others,
(3) within the Permo-Carboniferous molasse sediments: Žacléř-Svatoňovice Basin, Kladno-Slaný-Rakovník Basin, and others,
(4) within the areas of post-Variscan platform covers: Hamr and uranium deposits in Cretaceous sediments in northern and northwestern Bohemia, deposits in Tertiary basins within the Krušné hory graben, and others.

The uranium deposits within the metallogenetic province of West Carpathians are located in following units: within the Lower (I) and Middle (II) metallogenetic stage of the Inner West Carpathians: Novoveska Huta-Muran, Kravany and others.

Based upon metallogenetic relations there are certain rules that may be used as criteria for further investigations, prospecting and economic exploitation. There must be complex and complete analysis of all possible geological factors to obtain the most exact answer, because the distribution and the character of

[1] This number in brackets refers to location on Figure 2.

uranium deposits within the Bohemian Massif and the West Carpathians is the result of the magmatogenic, tectonic, sedimentological, lithological, metamorphogenical, geochemical, and other conditions. We will analyze some problems, which seem to be important for the geological investigation of uranium deposits within the area above mentioned.

THE LOCALIZATION OF URANIUM DEPOSITS IN RELATION TO MAGMATOGENIC PROCESSES

This question was intensively studied, especially by the geologists working in the Czechoslovakian uranium industry. Among the published studies the important ones were done by Yu. M. Dymkov (1960), I. Rojkovič (1968), Z. Pouba (1968), J. Hrubý and F. Šorf (1968) and F. Mrňa and D. Pavlů (1961).

Within the area of Karlovy Vary massif V. Zoubek (1958) ascertained that two independent differentiation products are within the late-orogenic Variscan magmatization: the first is without discernible autometamorphism, the "Normal granite", the second, comprising the younger intrusions, which have very strong autometamorphism and is the "Autometamorphic granite". The first group (Normal granite) may be further divided according to the sequence of intrusion:

(1) porphyritic biotite- or muscovite-biotite adamellite,
(2) medium-grained, indistinctly porphyritic biotite granite,
(3) marginal facies of porphyritic biotite adamellite,
(4) porphyritic biotite granite,
(5) porphyritic, lamporphyric and aplitic dykes.

The second group (Autometamorphic granite) has the following intrusion sequence:

(1) mostly autometamorphosed porphyritic tourmaline-biotite or biotite-muscovite granite,
(2) autometamorphosed aplitic granite and tourmaline granite dykes,
(3) the dyke-suite (porphyry, lamporphyre, and aplite) of the Autometamorphic granite.

After this later intrusion, the hydrothermal postmagmatic phase followed during which the Jáchymov uranium deposit was formed.

The Autometamorphic granites, which are altered by albitization and muscovitization, are rich in lithium and fluorine. Greisenization is another characteristic feature of the autometamorphic processes. Within the greisenized zones in the granites is an extensive cassiterite metallization.

The most important phases of the magmatic development of the Karlovy Vary massif are the younger phase of granitic intrusions and the postmagmatic hydrothermal phase. The latest is characterized by polymetallic mineralization, whereby F. Mrňa and D. Pavlů (1967) distinguished seven stages:

(1) older sulphidic,
(2) quartz,
(3) pitchblende-bearing,
(4) arsenidic with native silver,
(5) arsenidic with native bismuth,
(6) sulphoarsenidic,
(7) young sulphidic.

These hydrothermal postmagmatic mineral deposits are extensive over a large region of regionally and pyrometamorphosed mantle of the Karlovy Vary massif.

In the area of the Central Bohemian Pluton several zones of metallization accompanying some intrusions can be distinguished within this massif.

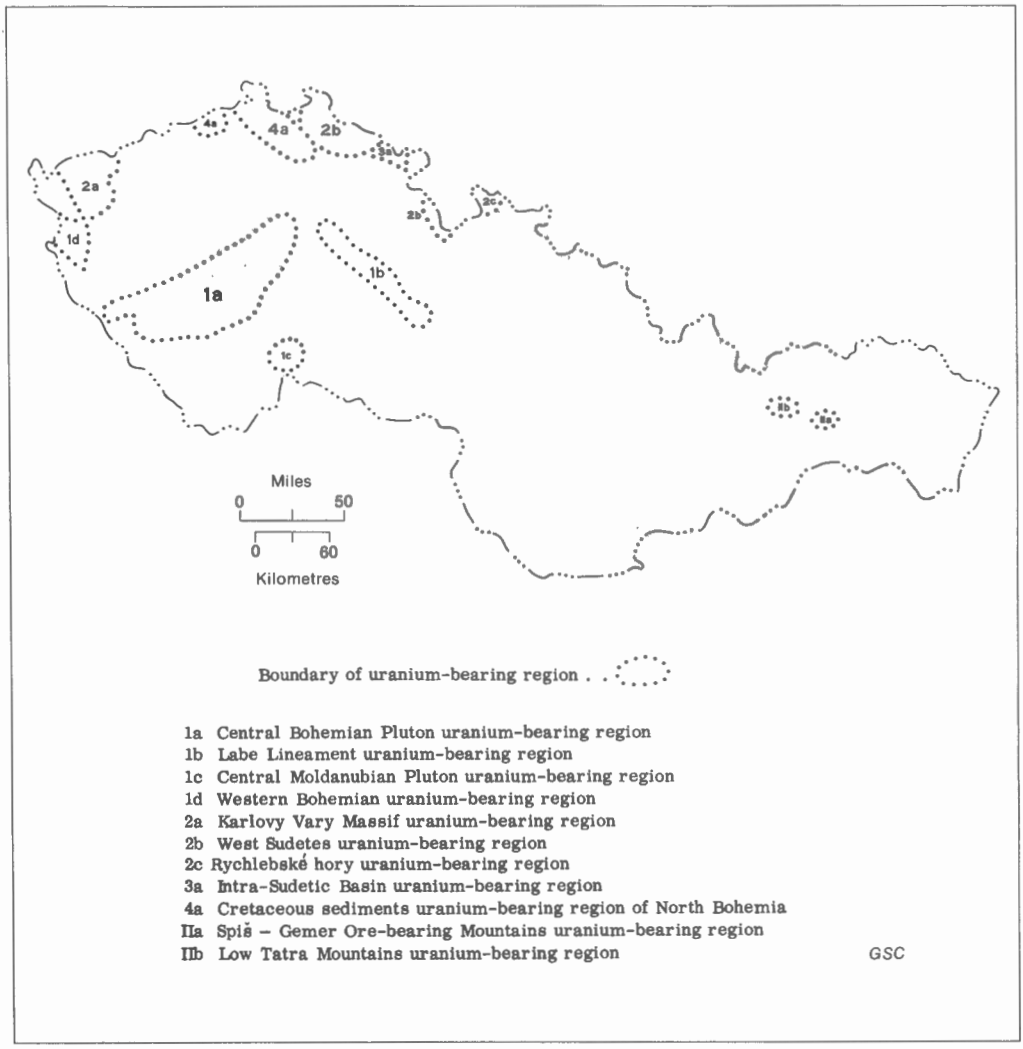


Figure 6. Uranium-bearing regions in Czechoslovakia (compiled by V. Ruzicka).

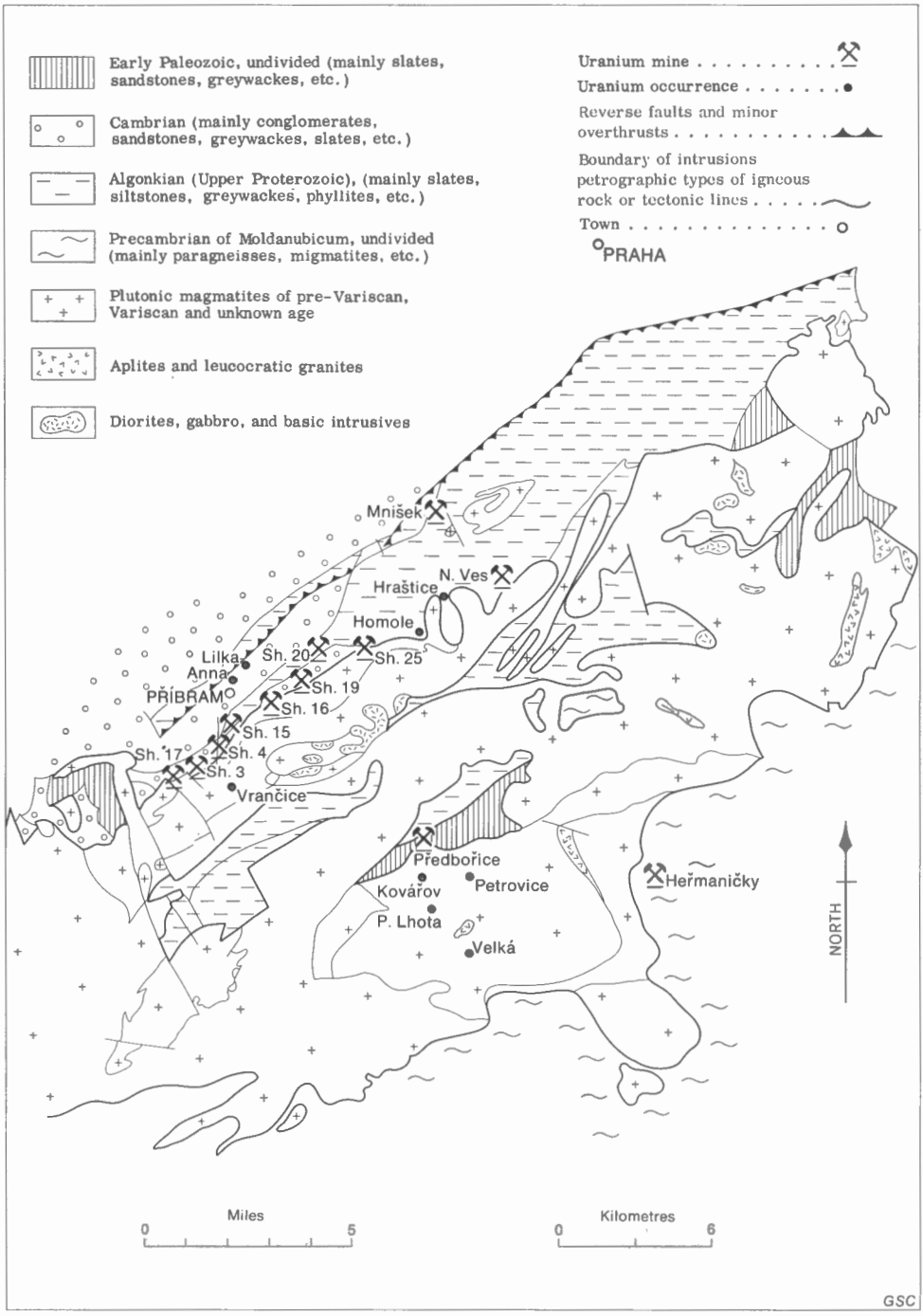


Figure 7. Central part of the Central Bohemian Pluton uranium-bearing region. (Base, "Geological map of Czechoslovakia, 1:500,000" by O. Fusan et al., compilers, Ustredni ustav geol., Prague, 1967.)

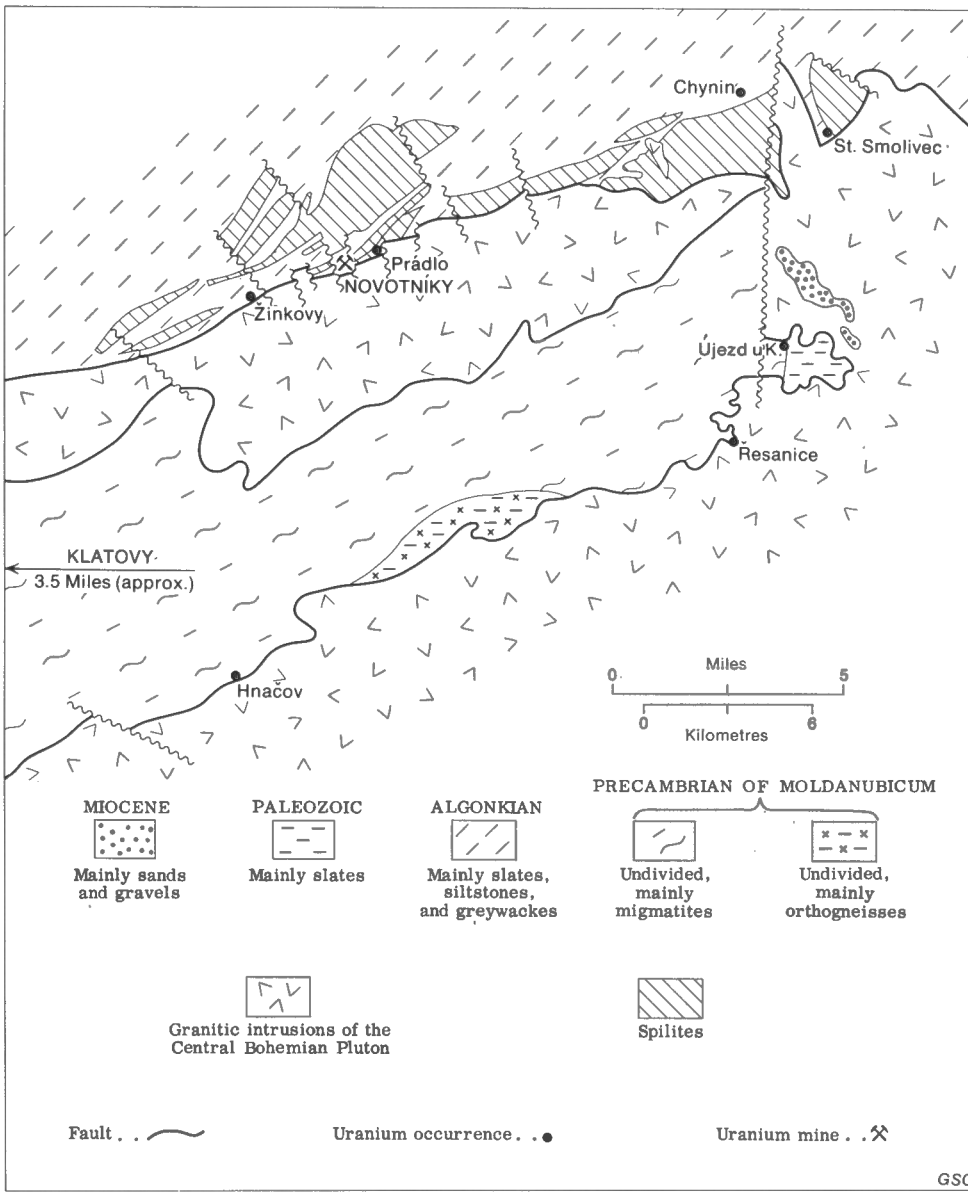


Figure 8. Southwestern part of the Central Bohemian Plutonuranium-bearing region (based on "Geological map 1:200,000" by L. Cepek et al., 1961).

The uranium hydrothermal deposits represent one specific zone and they represent the youngest event within the metallogenetic development of this region. The position of the uranium zone in relation to the Central Bohemian Pluton is shown in Figure 7 for the central part of Central Bohemian Pluton, and in Figure 8 for a small part of southwestern extension of this pluton. A.A. Malachov (1958) tried to explain by comparison of different areas of the Central Bohemian Pluton and its mantle the succession of magmatogenic and postmagmatic processes as follows (from the youngest to the oldest members):

(1) calcitic veins with or without sulphides of heavy metals,
(2) stibnite-barite-quartz mineralization,
(3) polymetallic veins with or without copper and barite,
(4) aplites and pegmatites,
(5) diorite intrusions,
(6) gold-bearing stibnite-quartz veins,
(7) gold-bearing arsenopyrite-quartz veins without tellurides,
(8) aplites and pegmatites,
(9) gold-bearing quartz veins and aplites, with tellurides,
(10) aplites and pegmatites,
(11) kersantites and spessartites (diabases?),
(12) aplitic-granites,
(13) molybdenum-bearing pegmatites,
(14) biotitic granodiorites.

There are two types (stages) of hydrothermal ore genesis; gold-bearing stage and polymetallic stage, which are separated from each other by the diorite intrusion.

For metallogenetic investigations it is very important to compare the Central Bohemian Pluton with the Karlovy Vary massif both of which have the uranium-bearing hydrothermal veins within their aureoles. The Central Bohemian Pluton is younger than the main orogenic movements of the Bretonian phase. The greater part of Central Bohemian Pluton is of Lower Carboniferous age, but the Karlovy Vary massif is a product of several intrusive phases, which took place probably between the upper Westphalian and Permian, and so later than those of Central Bohemian Pluton. It means that the magmatic centre has moved in general from southeast to northwest. An analogous feature can be seen within the postmagmatic hydrothermal processes, which correspond with the age determinations of metallic ore. For example the age determined for the main generation of pitchblende from the Příbram uranium deposits is about 270 million years (Hrubý and Šorf, 1968), whereas the age determinations of pitchblende from the Jachymov uranium deposit is about 227 million years (Dymkov, 1960).

Metallogenetic relations between uranium mineralization and volcanic rocks have been studied mineralogically by E. Drnzík (1965) and I. Rojkovič (1968) within the uranium deposit Novoveská Huta-Muráň in the Spiš-Gemer Ore-bearing Mountains. The complex U-Cu-Mo mineralization is bound mainly to the effusive-sedimentary complex and it is identical with the character of mineralization (U-Cu-Mo) in the quartz-porphyry dykes, to which the tuffs are related. The position of the uranium mineralization is shown in Figure 9.

The dependence of the ore deposits and their mineral contents on the surrounding igneous rocks, with which they are apparently genetically connected, is evident, according to Z. Pouba (1963), in the Rychlebské hory Mountains and Vysoký Jeseník Mountains. The mineral deposits are distributed and formed according to the development and movement of the magmatic centres. The ore mineralization belongs to two stages of Variscian magmatism, and the character of mineralization depends on the following factors:
(1) the geochemical evolution of the magmatic centres during the whole orogenesis,

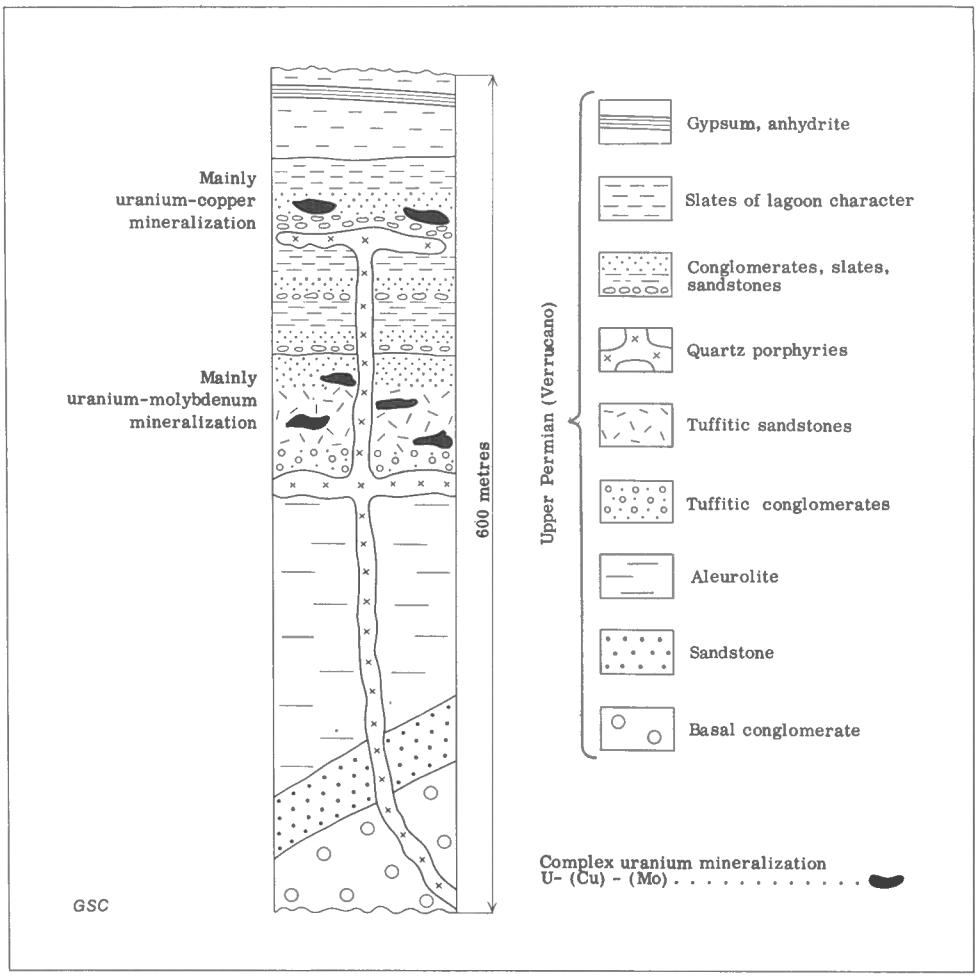


Figure 9. Schematical stratigraphical section of the uranium-bearing Permian beds within the Novoveska Huta–Muran deposit (after Zhukov, 1963, and Drnzik–Hudacek, 1963).

(2) the gradual movement of magmatic centres,
(3) the position of a tectonically advantageous zone for the origin of ore accumulations in different tectonic phases of the orogen.

The uranium mineralization is genetically related to the granodiorite of Javornik, which belongs to the first stage of the intra-orogenic and post-orogenic magmatism. Where the hydrothermal veins cut the metamorphosed sedimentary rocks, they are mineralized with pitchblende in those places where reducing or adsorbing conditions occurred.

THE LOCALIZATION OF URANIUM DEPOSITS IN RELATION TO TECTONIC FACTORS

Tectonic factors in relation to the location of uranium deposits and to the localization of uranium ore within the uranium deposits have been studied extensively by the geologists of Czechoslovakian uranium industry as a part of the research for the prognostic metallogenetic maps of Czechoslovakia. Analogous problems have been discussed on a broad scale during the investigations of the endogenous mineralization within the Bohemian Massif and the West Carpathians (e.g. Chrt et al., 1968; Ilavský, 1966).

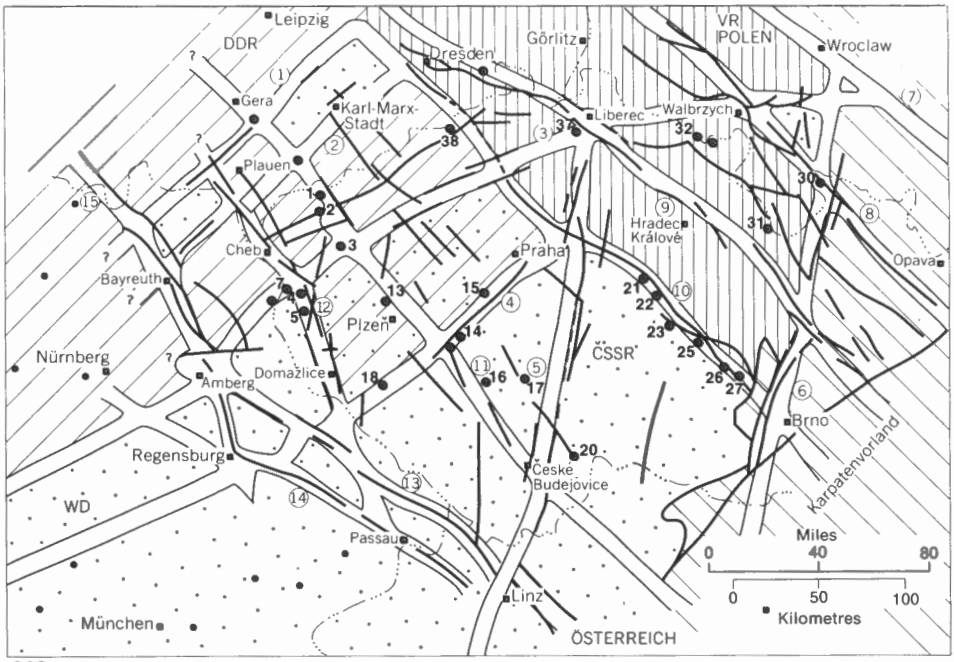
The tectonic development of the Bohemian Massif is characterized (as a part of the West European Variscan platform) structurally and genetically by very complicated features. The structural plan of the Bohemian Massif was in general influenced by the Assyntian tectonic framework, partly accomplished by the Caledonian elements. Deforming activity during the Variscan tectogenesis was more intense in the northwest, northeast, and east parts of the massif than in the central part. In later periods the massif mostly remained dry land, but here and there and from time to time was partly covered by an epicontinental sea and by freshwater lakes. The Bohemian Massif consists of the basement consolidated in Variscan times and of the Neoidic[1] platform cover. The basement of the Bohemian Massif can be divided into four structural layers: Moldanubian, Assyntian, Caledonian and Variscan. The platform cover can be divided into three principal structural stages, the lower, the middle and the upper, which correspond to three orthogeosynclinal stages of the West Carpathians (Máška, 1960, and Svoboda et al., 1966).

V.I. Kazanskij and others (in D.I. Shcherbakov and Vol'fson, editors, 1966) tried to explain the relation between the different structural stages and the endogenous uranium mineralization also within the Bohemian Massif. They stated that the most abundant endogenous uranium mineralization is located near the boundary between the lowest and the second structural stage, e.g. that the uranium mineralization is associated with the Precambrian metamorphosed rocks and with the early Paleozoic sediments. Less uranium mineralization is located in the upper stage of the basement, e.g. in the late Paleozoic sediments, and effusive rocks. But such conclusions need further verification.

A similar problem can be observed in the case of the relation between metallization and plicative or disjunctive tectonic activity. Within the largest uranium deposits the most favourable areas have an anticlinal or anticlinorial structure, which is cut by faults spatially related to the first order regional lineaments. Examples occur in the Jáchymov area, in the Příbram area, in the Rožná-Olší area and elsewhere.

The location of mineral deposits of endogenous origin along the extensive fault lines led to many analytical works done by the author, by the geologists of the Czechoslovakian uranium industry and by the scientists of

[1] Post-Variscan.



GSC

Saxony - Thuringian and Sudetic - Moravian zones

Moldanubian metallogenetic province

Lineaments . . . . . / /②

Main faults . . . . . .

Bore holes . . . . . .

Uranium deposits . . . . . ●26

Town . . . . . ■

LINEAMENTS

1 Northeast Saxony
2 Central Saxony
3 Ohárec
4 Central Bohemian (or Seam or Suture)
5 Blanice (or Furrow)
6 Boskovice (or Furrow)
7 Outer Sudetic
8 Sudetic Marginal
9 Lusatian
10 Labe
11 Gera - České Budějovice
12 Cheb - Domažlice
13 Bavarian
14 Danubian
15 Frankian

URANIUM DEPOSITS (Numbers refer to Figure 3)

1 Jáchymov	13 Lištany	20 O. Radouň	27 Olší
2 Hroznětín	14 Príbram	21 Bernardov	30 Javorník
3 Slavkov	15 Barrandien	22 Licomeřice	31 Orlické hory
4 Z. Chodov	16 Předbořice	23 Choteboř	32 Žacléř
5 Vítkov	17 Heřmaničky	25 Slavkovice	37 Hamr
7 Dylen	18 Dlažov	26 Rožná	38 Teplice

Figure 10. Distribution of uranium deposits within the Bohemian Massif in relation to lineaments and faults (after Chrt et al., 1968; compiled by V. Ruzicka).

some geological research centres in Middle Europe. A review of the topographical distribution of uranium deposits within the Bohemian Massif and selected fault lines (in some places hypothetical) is illustrated in Figure 10 (basic tectonic sketch compiled by Chrt et al., 1968):

Along lineament 11 (Gera-České Budějovice) there are located the post-magmatic hydrothermal uranium deposits: Jáchymov (1)[1], Příbram (14), Předbořice (16) and others. This lineament is represented locally as a thick zone or fault line, locally intruded by igneous rocks, locally geomorphologically predisposed to basins or grabens. Along the northwest prolongation of this lineament are other uranium deposits, Aue and Gera in East Germany, in the assumed southeast prolongation there are the Mecsek and Rhodopy uranium-bearing areas in Hungary and Bulgaria, respectively.

Along lineament 10 (Labe lineament) there are the following hydrothermal uranium deposits: Olší (27), Rožná (26), Slavkovice-Petrovice (25), Chotěboř (23), Licomeřice (22), Bernardov (21) and occurrences Litošice and Škrdlovice.

Along the lineament 12 there are the uranium deposits Zadní Chodov (4), Dyleň (7), and Vítkov II (5). Similarly in Figure 10 the alignment of many other uranium deposits can be seen.

The lineaments or fault lines are very often also boundaries of geological complexes or units. Therefore the margins of these units are favourable areas, in which uranium deposits are localized. This is the case within the metallogenetic province of the Bohemian Nucleus. The uranium deposits are located here at the margins of the katazonal metamorphosed complex of Moldanubicum, where this complex is in contact with slightly metamorphosed or unmetamorphosed complexes of Algonkian (Proterozoic) age. The uranium mineralization is confined mostly to carbonate veins or shear zones and the main uranium mineral is pitchblende, which is in solid or sooty form.

V. Sattran (1966) described other lineaments that are significant with respect to the location of deposits with polymetallic mineral associations:

1. The Blanice Furrow is a north-south lineament, probably of Assyntian origin. This lineament was repeatedly the locus of faulting movements, but especially during the Variscan orogenesis. The deposits with Pb-Zn-Ag-(Cu)[2] mineralization are related to this lineament.
2. The Central Bohemian lineament (or suture) with Au-Mo mineralization.
3. The Lužice and Labe lineaments with Cu mineralization.

The Central Bohemian lineament and the Labe lineaments are significant lines along which uranium deposits are also located.

A significant feature of the regional lineaments is their rejuvenation which can be observed also in the regeneration of the mineralization. Some examples of this will be described in a later section.

Favourable places for location of endogenous mineral deposits are the intersections of faults and lineaments, as, for example, the area of Příbram, where deposits of Pb-Zn-Ag and U lie at the intersection of the Gera-České Budějovice and the Central Bohemian lineaments. The Jáchymov deposits occur in the vicinity of the intersection of Gera-České Budějovice lineament (11)[2] and the Krušné hory (Erzgebirge) lineaments (3). The mineralization is mostly U-Bi-Co-Ni-Ag. Similarly the polymetallic deposit of Staré Ransko lies at the intersection of the Přibyslav zone and the Labe lineament. The crossing of the

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[1] Numbers in the brackets refer to localities on Figures 2 and 10.
[2] The brackets indicate that the metal may or may not be present.
[3] Numbers in brackets refer to numbers of lineaments in the Figure 10.

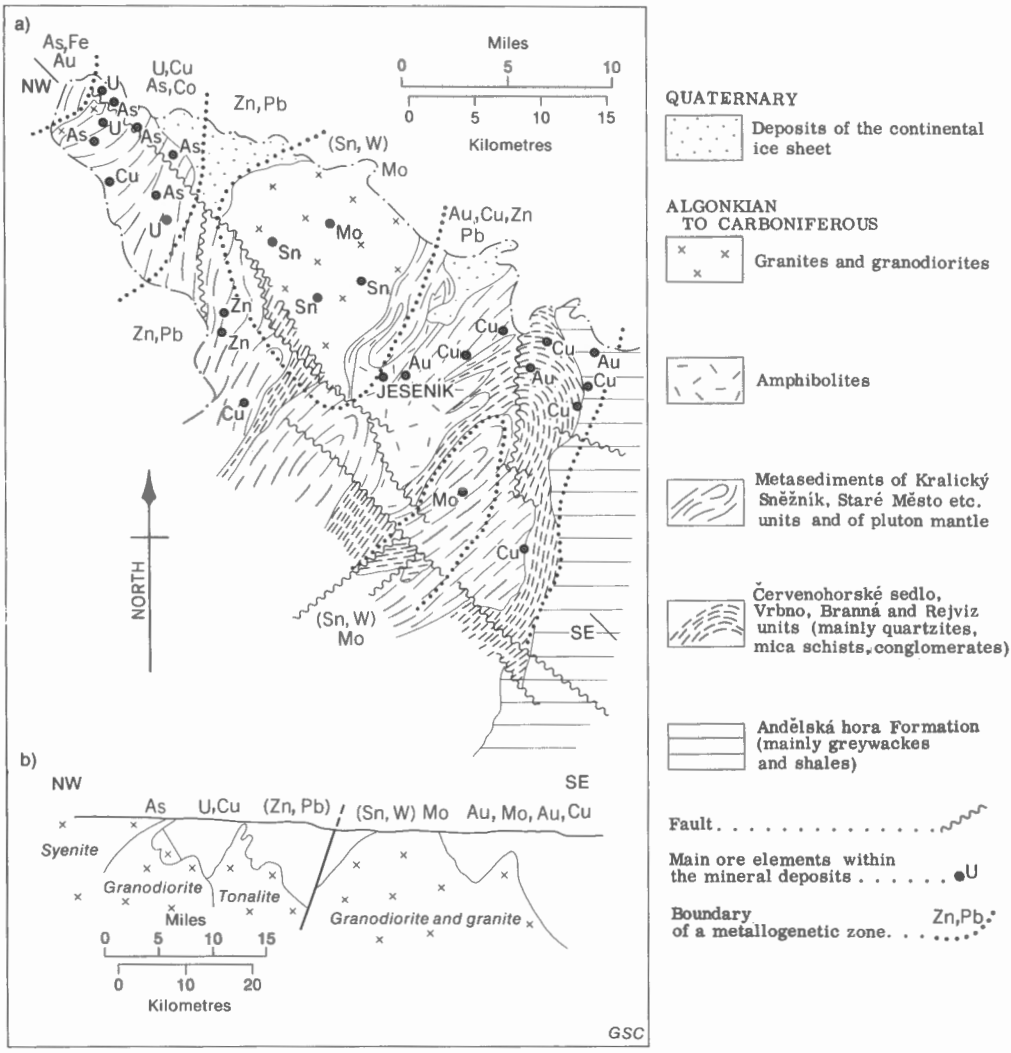

Figure 11. Geological sketch of the Rychlebske hory uranium-bearing region and the Vysoky Jesenik Mountains showing the distribution of mineral deposits (a), and schematical geological section west-east (b) comprising metallic elements mainly present within the deposits (after Pouba, 1963, and Pouba in Svoboda et al., 1966).

lineaments and of the lines, which are significant for localization of mineral deposits can be therefore used as criteria for prospecting.

J. Kutina (1968) observed the regularity in distribution of ore accumulations within the tectonic structures. These regularities have been observed in the ore districts of Příbram, Jihlava, Jáchymov and Kutná Hora in Czechoslovakia, in Scotland and in the western United States of America. This principle was verified in some uranium deposits and areas, such as Příbram, deposits along the Labe lineament, and in other places.

The relations between the tectonic factors and uranium deposits, or mineral deposits in general have been observed and described especially within the Bohemian Massif. Analogous investigations within the West Carpathians have not yet been done. Some aspects in this direction will be further discussed.

THE ZONING OF PARAGENETIC, CONSANGUINEOUS ELEMENTS AND MINERALS WITHIN THE REGIONS AND AREAS WITH ENDOGENOUS MINERAL DEPOSITS

In this section the most significant regions, within which the uranium mineralization is a part of the complex mineral zones are described. The principles of zonality have been verified and applied in a practical manner by J. Kutina, Z. Pouba, F. Mrňa, J.H. Bernard, and by the author.

Within the metallogenic subprovince of Krušné Hory (Erzgebirge) the principles of zonality have been studied by J. H. Bernard, F. Mrňa, D. Pavlů, J.F. Vogl, and M. Štemprok. Mrňa and Pavlů (1961) distinguished within the southwest part of this subprovince (the Jáchymov area) the following zones:

(1) in the northern part of this area there is a zone containing quartz veins with Bi-mineralization,
(2) in the northwestern part there exists a zone containing quartz-carbonate veins with Bi and sulpharsenides,
(3) in the middle of this area is the main mineralization represented by pitchblende and sulpharsenides (the "Jachymov zone"),
(4) in the southeastern part of this area, as in the northern part are predominantly quartz veins with Bi minerals,
(5) in the eastern part fluorite-barite veins are characteristic.

These zones are observed within the Bi-Co-Ni-Ag-U formation[1]. The zoning is affected by the lithological character of rocks and by the distance from the contact of the granitic pluton. In addition to the principles of regional zonation vertical zoning can be observed also. The Jáchymov area is a classical area with telescoping mineralization. The latest investigation verified the known principles of the vertical zoning and the following vertical zones within the "five-element-mineralization" have been observed: (1) in the upper parts there are mostly arsenides of the silver-paragenesis (sulpharsenide and sulphide stages), (2) in the middle part there are minerals of the Bi and U paragenesis, (3) in the lowest part the uranium mineralization predominates.

The abundance of uranium in the veins varies in a vertical direction, the richest parts being usually 150 to 400 metres above the granite contact.

Within the Sudetic-Moravian metallogenetic zone zoning is related to the magmatogenetic processes. The schematic picture of both magmatic and postmagmatic products are presented on Figure 11. According to Pouba (1963) the zone containing the uranium mineralization is genetically bound to granodioritic intrusions and it is paragenetically associated with Cu-As-Co

[1] So-called "five-element-formation".

mineralization. The uranium mineralization is accumulated within deposits and localities such as Javorník-Zálesí, Jelen, and Bílá Voda.

The relation between the evolution of the Variscan magmatism and the changing of mineralogical character of ore deposits has here an evident trend. According to Pouba (1963) the following events occurred:

1. pre-orogenic magmatism, which is represented mainly by diorite, gabbro-diorite[1] and gabbro, has associated Fe-(Cu) mineralization;
2. synorogenic magmatism, which is represented by quartz diorite and tonalite has associated Fe-(Cu)-Zn-Pb mineralization;
3. interorogenic and post-orogenic magmatism: stage 1, which is represented by granodiorite, syenite and monzonite; stage 2, which is represented by granodiorite; and stage 3, which is represented by granite and granodiorite, has a mineralogical association with Fe-Cu-As-Co-U-Zn-Pb-Sb, Au-Cu-Zn-Pb, and (Sn, W)-Mo-(Cu)-Au.

This type of zoning is called by Pouba (1963) polymagmatic zoning.

Within the metallogenetic area of the Central Bohemian pluton there is the following zoning in the Příbram mining district (see Fig. 12):

The first zone, in the endocontact[2] zone in the "border facies intrusion" of the Central Bohemian pluton mainly gold ore mineralization is present.

The second zone, in the nearest exocontact of the Central Bohemian pluton (in the northwest direction from the first zone) uranium mineralization is present with small amounts of Pb-Zn mineralization.

The third zone, which is within the Cambrian sediments northwesterly of zones 1 and 2 is mineralized with Pb-Zn-Ag.

The fourth zone is mineralized by Fe-Mn and Hg (see Fig. 13). The regional zoning within this part of the subprovince of Bohemian nucleus is schematically presented on Figure 13.

Zoning of the metallic hydrothermal deposits within the West Carpathians has been studied by Varček (1963), and Bernard (1963). Some uranium occurrences appear to fit into this zonal arrangement.

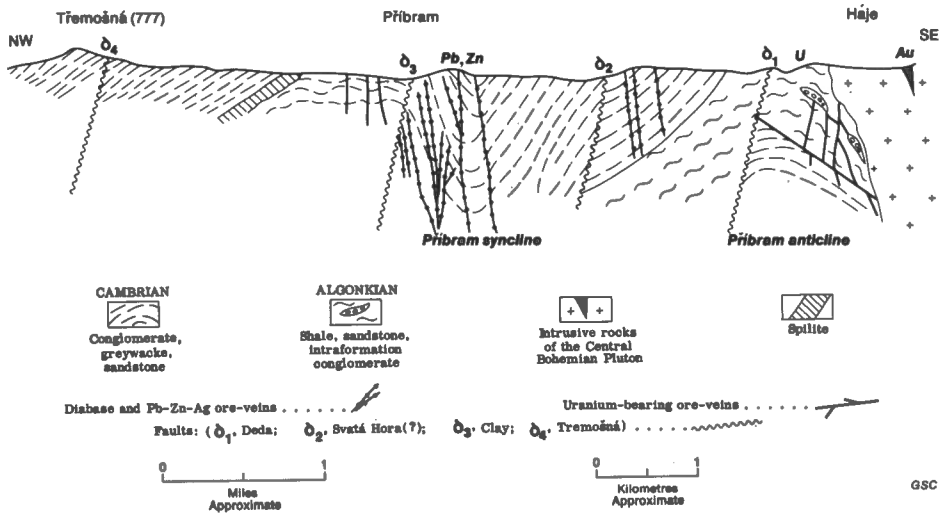

Figure 12. Schematical geological section through the Pribram area (after Kattner, 1926; compiled by V. Ruzicka).

SEDIMENTARY URANIUM DEPOSITS

A group of Czechoslovakian uranium deposits comprises epigenetic deposits in sediments, among which are (1) deposits in carbonaceous sediments, (2) deposits in sandstones, and (3) occurrences in graptolite shales. All these types have been formed under low temperature conditions and they are usually low grade.

Uranium deposits in carbonaceous sediments

The uranium mineralization of carbonaceous sediments is known in two geological units: In the Permian and Carboniferous coals, and in Tertiary lignites.

Uranium and vanadium concentrations in the Permo-Carboniferous sediments have been investigated by geologists of Czechoslovakian uranium industry and by others. Skoček (1967) stated that the uranium and vanadium concentrations of Stephanian and Autunian age are not syngenetic. The higher uranium-vanadium concentrations are the product of selective precipitation from solutions circulating through the sediments after their deposition. The migration of the two elements under exogenic conditions was favoured by warm and relatively dry climate that prevailed throughout the development of the terrestrial formations. Lepka (1967) came to similar conclusions for the Kladno-Slaný-Rakovník basin. The uranium was precipitated from the groundwaters containing $(2-8) \times 10^{-6}$ g U/l. The uranium content of the tuffaceous rocks averages 19 ppm U and is greater in sediments with higher contents of organic matter.

The uranium-bearing Tertiary sediments are mostly present in the Sokolov Basin, but partially also in the Cheb Basin. Some spots of uranium mineralization have also been found in the sediments of the Žitava Basin.

The uranium mineralization is mostly associated with the carbonaceous material as well as the sandstone, and loam beds are mineralized with uranium.

The deposits were formed under following conditions:

1. the underlying rocks are granitic rocks of Variscan magmatites,
2. the sediments are permeable to waters circulating from the granitic rocks down the dip,
3. the surface of the granitic contact is valley-shaped,
4. the sediments contain carbonaceous material, or tuffaceous material, or another kind of material that is able to adsorb the uranium dissolved in the circulating waters.

The uranium mineralization is usually associated with Be, Ge and Ti mineralization, and is represented by uraninite, uranium humates and secondary uranium minerals. Within the Tertiary sediments basaltic extrusives and tuffs may have a significant influence on the formation of uranium deposits. They may form hydraulical and geochemical environment favourable for ore deposition.

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[1] Gabbro with uralitized pyroxene. Plagioclase has basicity around An_{50}, also amphibole and pyroxene is present.

[2] i.e. in the igneous rocks near the contact.

Uranium deposits in sandstones

The uranium mineralization is related to the Mesozoic sediments mainly Cenomanian[1], but partly of Turonian[2] age. The most favourable sediments are those of freshwater origin of Lower and Middle Cenomanian in the Bohemian Cretaceous Basin. They usually fill depressions in the pre-Cretaceous basement, which is composed of Variscan granitoids or metasediments. According to Klein and Soukup (in Svoboda et al., 1966) the continental sedimentation was often of cyclic character, and was often interrupted by stream erosion. In places, the lower cycle began with basal conglomerate or breccia, followed upwards by pebbly or coarse-grained sandstone, and succeeded by finer-grained sandstone. The overlying complex is represented by coarse-grained sandy sediments with graded bedding. The top layers consist of claystone with finely disseminated carbonaceous material. The Lower Cenomanian sedimentation ended with claystone beds. The Upper Cenomanian beds are of brackish and marine character. The lower boundary of the marine Cenomanian is in places transgressive, and in places there are brackish sediments at the base. The sedimentation of the marine Cenomanian was usually sandy with clayey intercalations. Between the Cenomanian and Lower Turonian a transitional Cenomanian-Turonian succession of different lithological composition can be established. The main character of the Turonian is lithologically represented by quartz sandstone.

The tectonic development of the Cretaceous sediments was controlled by Saxonic[3] faults having mainly northwest and west-southwest trends. The earliest ones follow the Late Caledonian structures, but the latest ones follow the Early Variscan. Northerly trending faults, which are subordinate, follow the Late Variscan structures. The plicative structures within the uranium deposits are very slightly refolded. The gently folded anticlines and synclines are result of Early-Middle Tertiary boundary movements. These movements continued still in later Miocene and Pliocene tectonic phases of Saxonic tectogenesis.

The Saxonic tectonic movements are significant because they provided the locus for centres of volcanic activity. In the North Bohemian Cretaceous region volcanic activity is manifested by a large number of minor eruptions represented by extremely varied alkaline types (Svoboda et al., 1966).

The uranium deposits in the North Bohemian Cretaceous sediments are of epigenetic origin and they have been formed by uranium-bearing percolating artesian waters. Many geological, geochemical, hydrological and biological conditions were required to cause the formation of these deposits.

The localization of uranium deposits in the North Bohemian region was probably influenced by:

1. uranium-containing igneous, sedimentary and metamorphic rocks in the vicinity of the deposits, which as a result of their erosion, may be the source of soluble uranium compounds in the underground waters;
2. favourable sediments, which were sufficiently permeable to allow the percolation of waters, and which were able to form oxidizing and reducing conditions within themselves;
3. favourable tectonic structures both folds and faults, which could be the channels for the uranium-bearing solutions;

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[1] Lower Upper Cretaceous.
[2] Part of Upper Cretaceous following Cenomanian.
[3] Saxonic orogenetic movements started early in Mesozoic.

4. organic materials and microorganic compounds, which could be another favourable factor for the forming of uranium accumulations;
5. neoidic volcanic activity, which brought not only changes into the geochemical conditions, but also new tectonic, structural and textural features into the geological environment.

All these factors will be analyzed farther – in the chapter describing the main geological features of the roll type.

Uranium occurrences in graptolite shales

Radioactive occurrences are known in the Silurian sediments within the Bohemian Paleozoic Basin. Silurian greyish black graptolite shales are in sharp disconformable contact with grey and greenish grey silty shales and sandstones of Ordovician age. This sharp contact is influenced by Taconic orogenic phase (Svoboda et al., 1966). The uraniferous Silurian phase, which represents the Llandovery and Wenlock stages, occurs predominantly in the marginal parts of the Silurian synclinorium, particularly in its southern limb and in the brachysynclinal closure in the southwest. The most important part of this formation is the lower portion of these strata corresponding to the English Birkhill Series. These are greyish black micaceous graptolite shales containing locally chert interlayers, especially in the southwest of the basin (Ibidem.). Characteristic of this type of radioactive mineralization is the close relation of uranium accumulations to the northeasterly trending beds and faults.

DISTRIBUTION OF THE URANIUM DEPOSITS ACCORDING TO HOST ROCKS AND GEOLOGICAL FORMATIONS

Localization of the uranium deposits is schematically shown in Figure 14.

The main endogenous uranium deposits within the Bohemian Massif belong to the Precambrian and early Paleozoic host rocks. Another but smaller part of deposits belongs to the late Paleozoic host rocks. Kazanskiy et al. (in Shcherbakof and Vol'fson, editors, 1966) explain these features as localization of uranium deposits in folded regions within the "critical zone", e.g. that the upper boundary of uranium mineralization has been formed only a few hundreds metres under the earth's surface. The presence of the structurally lower complexes within this "critical zone" is usually caused by tectonic movements related with magmatic intrusions.

The hydrothermal uranium deposits are mainly located within metamorphic or basic rocks, or within rocks with pyritic and/or graphitic components. Metamorphic rocks are the most common host-rocks, especially amphibolites, chlorite and chlorite-epidote gneisses, graphitic and pyritic rocks, and paraschists.

Acidic host rocks are less favourable for localization of uranium deposits. Only a few deposits occur within the granitic or granodioritic host rocks, and other acidic rocks.

Both the character of hydrothermal solutions and lithological character of host-rocks influenced the ore-deposition. Within the uranium deposits of Krušné hory Mountains (Erzgebirge) the host rocks are controlling the deposition of uranium mineralization. The ore-veins of the uranium stage have been formed as fracture-fillings and they have often characteristic symmetrical crustification texture. The main gangue minerals are carbonates. Less abundant ones are quartz, fluorite and anhydrite. Hematite and adularia are present in small amounts. The main uranium ore mineral is pitchblende. Pyrite, arsenopyrite,

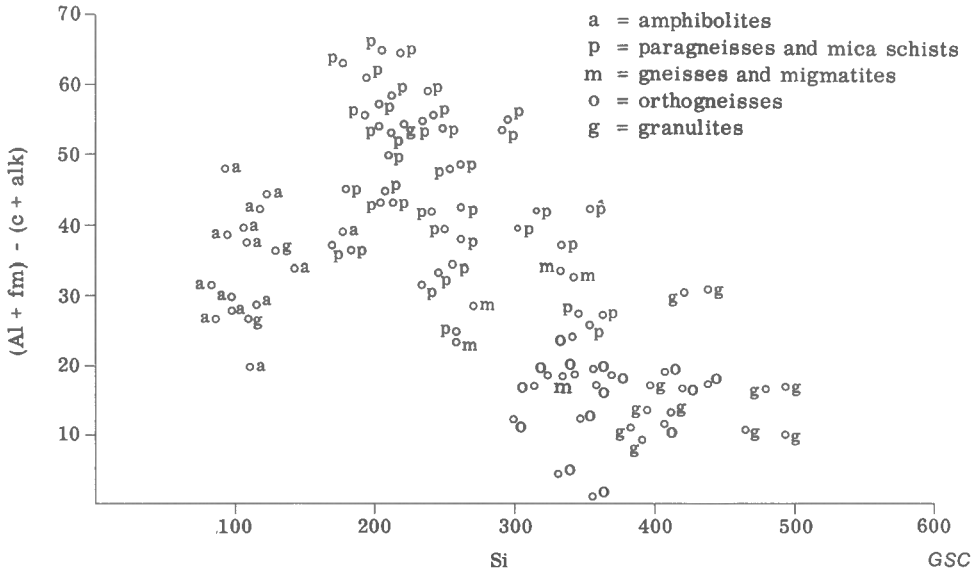

Figure 15. Chemical composition of the main Moldanubian rocks (after M. Suk in Svoboda et al., 1966). Niggli values in Simonen's projection.

chalcopyrite, galena and bismutite occur locally. The paragenesis of the principal gangue minerals is: adularia-quartz-fluorite-calcite. The main quantity of pitchblende has been deposited within the places, where chloritized pyritized biotite gneisses, amphibolites, skarns, and other basic or graphitic rocks are present. These host rocks are as a rule altered (Dymkov, 1960). The character of alteration will be described in a later section.

Chemical composition of the Moldanubian rocks is shown in Figure 15.

In the Příbram area the favourable host rocks of the uranium deposits are the sediments of the latest post-spilitic Late Algonkian (Eocambrian) Group. The petrographical character is determined by clastic sediments of a pronounced flysch nature, which are mostly shales, siltstones and greywackes. A typical feature of these sediments is the variable nature (especially vertically) of their structure and texture. The pyritized and hematitized host rocks are favourable for ore accumulation. The lithological control within these deposits is mostly of a regional character. The veins are mineralized with uranium only within the shaly sediments but are unmineralized in conglomerates of Algonkian and Cambrian ages, and within the granitic intrusions and related dyke rocks. However the structural factors that control ore deposition are more effective than the lithological and petrographical ones within the Algonkian sediments.

In the Dlažov deposit, located at the contact of Central Bohemian Pluton and its mantle rocks, the uranium mineralization is localized within the hydrothermal veins and veinlets with mainly calcite filling that contain pitchblende deposits and accumulations partly within the granodiorites and partly within the Algonkian slates. The fractures were caused by contraction during the cooling of the granodiorite intrusion.

Within the granitic pluton "Borský masiv" (Bor massif) the ore accumulations (see Fig. 16) are most abundant along the fractures in granodiorite, especially under the slightly dipping aplite dykes but they are absent

within paragneisses or basic xenoliths. The morphology of the orebodies is irregular. A significant feature is the chloritic alteration of granitic rocks, which can be used as a criterion for the exploration of the orebodies.

The lithological features are controlling factors within sedimentary epigenetic deposits will be described later.

THE ALTERATION OF HOST ROCKS

Problems of the alteration of the host rocks were studied initially by the research geologists of the Czechoslovakian uranium industry, but less has been published than in other countries. Dymkov (1960) described some examples from the Krušné hory area.

The initial stages of alteration of host rocks within the Krušné hory uranium deposits are represented by the formation of skarns and by biotitization. The biotite gneisses, because of their reducing characteristics of metasomatically formed pyrrhotite, pyrite, arsenopyrite and chalcopyrite are favourable for deposition of pitchblende within the veins cutting them. Within the same deposit it has been observed that the deposition of pitchblende is more abundant within those places where the veins cut through scapolitized gneisses. The other significant pre-uranium alteration of the host rocks is the pyritization and chloritization of amphibolites, tuffs and gneisses. According to Dymkov (1960) the graphitization which took place along the shear zones during the pre-uranium stage, has an important influence during the next stage which is characterized by the carbonate-uranium deposition. This uranium-bearing stage is followed by silicification, carbonatization and hematitization. The last is, as in other uranium deposits of hydrothermal origin, typical with its red in colour, hence known as "red alteration". The post-ore stages are characterized by sericitization, silicification and kaolinization. Within the granitic rocks there are metasomatic processes characterized by greizenization, albitization and silicification within the pre-uranium stages, as sericitization within the uranium-bearing stage and as sericitization and kaolinization within the post-uranium stages. The aureole of metasomatism is usually not too extensive, only a few metres from the veins. Barsukov and others in Vinogradov, editor (1963) tried on the basis of analyses of rock samples to determine the distribution of oxides of rock-forming elements within different host rocks (see Fig. 17 from the Krušné hory area).

THE LOCALIZATION OF URANIUM MINERALIZATION WITHIN THE BOHEMIAN MASSIF AND THE WEST CARPATHIANS IN CZECHOSLOVAKIA

The localization of selected occurrences with uranium mineralization in Czechoslovakia is shown in Figure 3.

From the metallogenetic point of view several regions with uranium mineralization can be distinguished:

the Central Bohemian Pluton region (1a)[1] with uranium deposits and occurrences in its mantle such as Příbram, Mníšek, Dlažov, Novotníky, Heřmaničky, and Předbořice as well as in its igneous rocks (Kovářov, Pechova Lhota, Velká and others);

the Labe Lineament region (1b) with uranium deposits and occurrences genetically related to the fault system of the Labe Lineament (Olší, Rožná, Slavkovice, Chotěboř, Předbořice, Bernardov deposits and others);

[1] The numbers in brackets refer to numbers of regions in Figure 6.

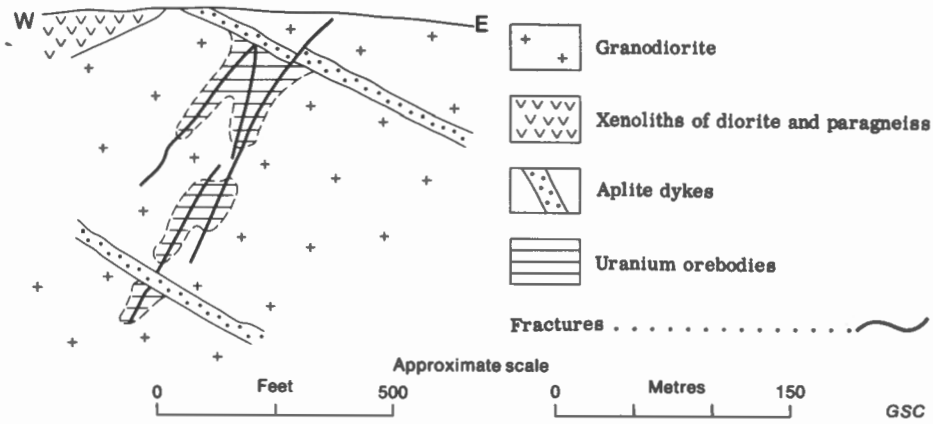

Figure 16. Schematical geological section of the Vitkov II deposit (after Vol'fson in Shcherbakov and Vol'fson ed., 1966).

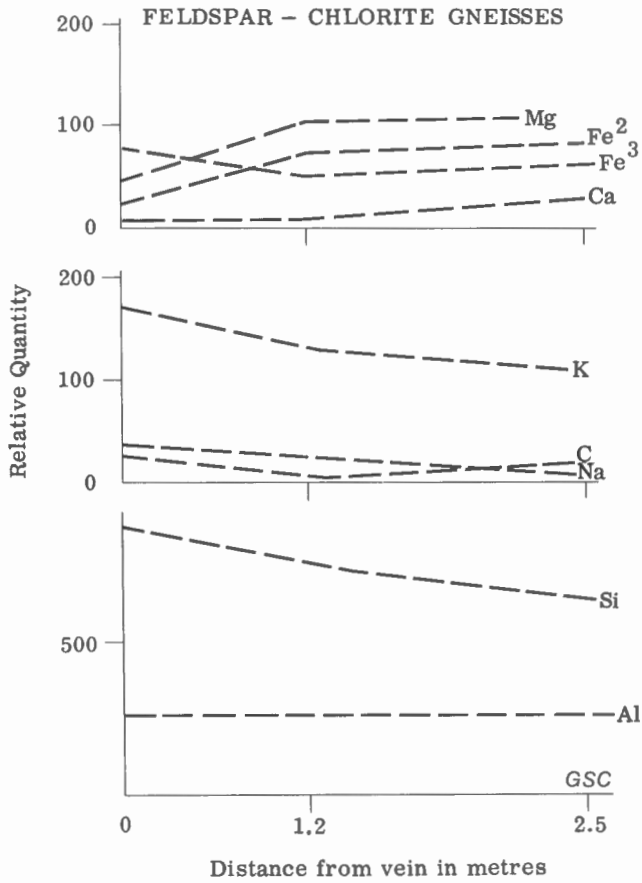

Figure 17.

Contents of rock-forming elements within the hydrothermally altered host rocks cut by uranium-bearing veins (Krusne hory (Erzgebirge)) (after Barsukov in Vinogradov ed., 1963).

the Central Moldanubian Pluton region (1c) with uranium mineralization in a tectonic fault zone within the mantle of the Central Moldanubian Pluton (Okrouhlá Radouň deposit);
the Western Bohemian region (1d) including the Bor Massif area, and the western part of the Moldanubian crystalline complexes. The uranium mineralization in this region is located in the Variscan igneous rocks (Vítkov II deposit), within their exocontact area (Anna deposit) or within the faults genetically related to the lineaments (Zadní Chodov deposit) and to the subsidiary faults (Dyleň deposit);
the Karlovy Vary Massif region (2a) with uranium mineralization within its igneous rocks (Fojtov, and Přebuz deposits), within its metamorphosed mantle rocks (Jáchymov and Slavkov deposits) or within the Neoide sediments (Hroznětín deposit);
the West Sudeten region (2b) Krkonoše and Orlické hory Mountain areas (Harrachov, Přehrada, Říčky, Kamenec deposits and others);
the Rychlebské hory region (2c) with uranium mineralization genetically related to the Variscan granitoids and tectonically related to fault structures (Javorník deposit and others);
the Intra-Sudetic Basin region (3a) with uranium mineralization within the Permo-Carboniferous sediments (Stachanov, Rybníček and other deposits);
the Cretaceous sediments region of North Bohemia (4a) with uranium deposits of roll type (Hamr deposit and Teplice occurrence);
the Spis-Gemer ore-bearing Mountains region (IIa) with the uranium mineralization within the Permian beds (Novoveská Huta-Muráň deposit);
the Low Tatra Mountains region (IIb) with the uranium mineralization in the Permo-Triassic beds.

In addition to the above mentioned regions other uranium occurrences are known. Uranium mineralization is known in the Ordovician and Silurian sediments of the Barrandian Basin, in the Carboniferous sediments of Central Bohemia (the Kladno-Rakovník district, the Plzeň district) and in other parts of Bohemian Massif and West Carpathians.

GEOLOGICAL FEATURES OF DIFFERENT AREAS

The Karlovy Vary Massif region (2a, Fig. 3) belongs to two various metallogenetic units to the Saxon-Thuringian and Sudetic-Moravian metallogenetic zone and its Krušné hory subprovince, and the area of post-Variscan platform covered by alkaline neovolcanics.

A predominant feature of this region is a large intrusion of granitoids of Variscan age.

The Krusne hory metallogenetic subprovince is located as a frontier mountain range in northwest Bohemia. It is formed of Proterozoic and early Paleozoic metamorphics and numerous granitoid massifs. It is composed of several geological units, which contain significant mineral deposits. With respect to uranium mineralization there are two important units, the Krušné hory Mountains (Krušné hory sensu stricto), and the Slavkovský les.

The Krušné hory Mountains unit constitute an anticlinorial zone built up prevalently of crystalline schists and granitoids. The crystalline complex has been formed during the Assynthian Orogeny and reactivated and consolidated during the Variscan Orogeny. During the Neoidic Epoch the complex has been partly covered by the post-Variscan platform cover. The metamorphosed complex can be divided into the central gneiss core and into the envelope of mica-schists and phyllites (Sattran, 1957). The gneiss complex and a part of the mica-schists are

ranged to the Algonkian. Part of the mica-schists and phyllites range from Eocambrian up to Cambrian ages. The central gneisses are divided into two groups: "Grey gneisses" and "Red gneisses" according to their petrographical and genetic characters. The mica-schists and phyllites vary greatly in composition. The graphitic-muscovite-biotite mica-schists with a pyritic admixture are characteristic host rocks to the Jáchymov uranium deposit. The Variscan tectogenesis welded the older crystalline complex with the Variscan epimetamorphics derived from Cambrian to Silurian sediments. The postmetamorphic Variscan granites were emplaced in several pulses. The ages of individual intrusions range from the end of the Namurian up to the Rotliegendes[1]. The magmatites were accompanied by a suite of hypabyssal and effusive rocks and by hydrothermal phenomena. The hydrothermal activity persisted into the late Permian (Svoboda et al., 1966).

The mineral deposits within the Krušné hory Mountains are of many types. The earliest formed, which comprise magnetite, occur in skarns. Tin and tungsten deposits occur in greisens. In the polymetallic hydrothermal veins within the Jáchymov area pitchblende is the most abundant mineral. Barite-fluorite veins are widely scattered throughout the whole area and represent the latest stages of hydrothermal mineralization. Other significant nonmetallic mineral resources are kaolin and lignite.

Within the Karlovy Vary Massif region three types of uranium deposits can be distinguished:

1. hydrothermal deposits within igneous rocks of the Karlovy Vary massif,
2. hydrothermal deposits within the mantle of the Karlovy Vary massif,
3. epigenetic deposits of low temperature origin within the Neoide sediments of Sokolov Basin.

Uranium deposits within the igneous rocks of the Karlovy Vary massif

Only two significant occurrences are known within the igneous rocks of the Karlovy Vary massif, the Přebuz-Rotava and the Fojtov.

The former is located near the southwest contact of the Karlovy Vary massif within the intrusion of "autometamorphosed (Erzgebirge) granites". Pitchblende mineralization is deposited very irregularly within quartz-carbonate veins, and within the oxidation zone is represented mainly by autunite and torbernite.

The latter occurrence, which is near the settlement of Nejdek, is represented by irregular orebodies along and within several fractures. The ore-mineralization is represented mainly by torbernite and metatorbernite. The genesis of this occurrence is probably hydrothermal, but certain features which are analogous to those of epigenetic deposits near Hroznetin suggests a low temperature origin is possible.

The hydrothermal deposits within the mantle of the Karlovy Vary massif

Two independent areas can be distinguished within this group of hydrothermal deposits, the Jáchymov area, and the Slavkov area. The characteristic features of these deposits have been studied by O. Pazdírek, E. G. Distanov, J. Fatková, F. Mrňa, N. Hladká, V. Sattran, Yu. Dymkov, V. Ruzicka and by others.

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[1] Namurian and Rotliegendes in West and Middle Europe correspond with Lower Pennsylvanian and Lower Permian in North America.

The Jachymov area

The uranium ore deposits within this area cover this space of about 35 square kilometres. The main rocks are represented by metasediments, which are cut by intrusive and extrusive rocks of different ages and of different petrographical compositions.

The metasediments are stratigraphically divided in the following sequence (from the oldest to the youngest): the Klinovec mica-schists; the Jáchymov mica-schists, amphibolites and lime silicate rocks; the Barbara Series, composed mainly of chloritic, biotitic, graphitic mica schists with pyrite; the Potůčky Series, comprising mainly phyllites interbedded with amphibolites.

These series were metamorphosed before the Variscan Orogeny. They are of Proterozoic to early Paleozoic age. The intensity of the metamorphism becomes weaker from south to north (Mrňa and Pavlů, 1963).

The magmatites are represented mainly by the granitoids of the Karlovy Vary massif, and its differentiated dyke rocks. Zoubek (1951, 1958) distinguished two significant main granitic intrusions within the Karlovy Vary massif, the Normal granite and the autometamorphic granite groups, the characteristics of which were mentioned earlier in this paper.

These two main groups of granitic intrusions preceded the gabbro-diorite and diorite intrusion. The later intrusive phase of the autometamorphic granite has been followed by the hydrothermal postmagmatic phase.

The age of the intrusions of the Normal granites is supposed (Svoboda et al., 1966) to be of Namurian and later, the age of the autometamorphic granite is supposed to be of Late Carboniferous to Rotliegendes[1] (Early Permian).

The youngest volcanic rocks there are the Tertiary volcanics represented within the Jáchymov area by differentiates of alkaline magma (nephelinite, leucitite, tephrite). The pyroclastics belong to the same volcanics.

The significant feature of the Jáchymov uranium deposits is their position within the mantle of the Karlovy Vary massif and also the morphology of this massif. The contact between the granitoids and the metasediments is concave and the metasediments represent a mantle of the granitic pluton composed mainly of the Autometamorphic granite group. No significant uranium mineralization has been found in connection with the Normal granite group.

There are two structurally different complexes within the Jáchymov area, a complicated and strongly folded series of gneisses (e.g. the Klínovec anticline) and a slightly folded series of phyllites.

The general strike of the Klínovec anticline is westerly. Its south limb is more folded than the north limb and its dip is asymmetric to the north limb. The phyllite series is folded into a synclinorium (Sattran, 1966). The most favourable structures for the formation of hydrothermal uranium-bearing veins are the faults related to the Klínovec anticline.

The fault pattern of the Jáchymov area is very complicated. The three main systems within the Klinovec anticline are the northwest, the east and, the northeast systems.

The northwest fault-system is part of the regionally extended "Nejdek-Crimmitschau" fault zone[2], along which the tectonic movement has

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[1] On the basis of absolute age determinations and geological criteria.
[2] A part of Gera-České Budějovice lineament.

been renewed several times. The Tertiary tectonic movements, which lasted from Miocene to Pliocene, used first of all the northeast-trending fault-systems.

The fracturing plan is closely related to the above mentioned structural plan. The opening of the vein-fractures followed immediately the latest phases of the granitic intrusions. These fractures most commonly trend northerly. They were opened during the mineralization-phases and so were mineralized by pitchblende. Sattran (1966) made an interesting comparison between the characteristic structural features of ore-veins and their mineral-filling. His conslusions are:

1. The northwest system of veins extends from 1 to 20 kilometres in length. It is characterized by shear zones, from 1 metre to 28 metres wide, and filled mostly by Fe-Mn mineralization. This system is supposed to be used as channels for the ore-bearing solutions.
2. The east system of veins extends mainly from 500 to 1,500 metres in length, and is characterized by faults (0.1 up to 0.5 metre thick) filled by fault clay or brecciated quartz. The mineralization of these veins is mostly at intersections with the north-trending veins only. The ore-forming elements are largely Ag, U, Bi, Zn, Co, Ni.
3. The northeast system of veins extends within short intervals only. Its mineral filling is very variable and it is represented mainly by fault clays, quartz or "five-element" mineralization.
4. The north system of veins represents the main system of uranium-bearing veins and veins formed during the pitchblende stage of mineralization. The thickness of veins is usually only a few centimetres, but in places may be as much as a few metres. The vein-filling is mainly quartz, carbonates and a suite of minerals listed in the chapter describing the mineralogical character of veins.

According to results of investigations of mineralization within the different types of veins it can be concluded that:

1. The northwest system of dislocations has two significant roles, both as a channel for the ore-bearing solutions and as a place for deposition of some amounts of ore-minerals.
2. The northeast system of dislocations was the main system used as ore-bringing channels.
3. The west system of dislocations and especially the large dislocations had a similar function as the northwest system.
4. The north system of dislocations acted as host-structures favourable for the deposition of the ore-minerals.

The mineralogical character of veins is developed according to development of ore-bearing solutions, which changed their chemical character in time and in space. This development of solutions occurred in several periods.

The mineral content of the ore-veins. The post-magmatic ore-forming hydrothermal processes took place mainly during and after the Variscan tectonic activity. The tectonic movements were renewed several times and the intensity of the tectonic activity decreased gradually. Mrňa and Pavlů (1963, 1967) distinguished six stages of the mineral formation with following succession:

1. The older sulphide stage which is developed mainly within the northeast and east vein and fault systems. This stage is represented by quartz and sulphides of As, Fe, Pb, Zn, Cu.
2. The quartz stage with the association of quartz, carbonates, fluorite and hematite. Quartz especially is very extensive throughout this stage and is represented by chalcedonic or typically smoky forms.
3. The pitchblende stage, the main products of this stage are dolomite, pitchblende, small amounts of fluorite, and pyrite. Pitchblende is often developed in typically colloform structure.
4. The arsenides stage is the most geochemically complicated stage of mineralization. Two main assemblages can be distinguished within this stage: arsenide-ore with native silver (1), and arsenide-ore with native bismuth (2). The main gangue mineral is quartz, with small amounts of carbonates. The first paragenetical association within the arsenide stage is represented by native silver, skutterudite, rammelsbergite, niccolite and partly safflorite and lollingite. The second paragenetical association is represented by native bismuth, skutterudite, safflorite, loellingite and rammelsbergite.
5. The sulpharsenides stage is characterized by the assemblage of native silver, proustite, pyrargyrite, realgar, loellingite and stibnite. The gangue minerals are carbonates.
6. The younger sulphide stage has abundant sulphides, principally pyrite, marcasite, galena, sphalerite, chalcopyrite, and bornite in a gangue of calcite.

The uranium mineralization is mainly present within the pitchblende stage, but the regenerated mineralization of uranium especially in the form of sooty pitchblende, is present also within the arsenides and young sulphide stages.

The main uranium-ore mineral is pitchblende, which has following chemical compositions.

Table 1

Partial analyses of pitchblende in per cent

	1	2	3	4[1]	5	6
U_3O_8	68.97	65.8	62.53	8.08	41.23	40.41
Pb	2.9	2.5	1.06	0.25	n.d.	n.d.
V_2O_5	0.24	1.1	0.02	2.91	0.014	0.10
Rare earths	2.15	0.25	2.1	n.d.	0.78	2.45

[1] Probably sooty form.

The spectrographic analyses of uranium ores show the following constituent elements (Table 2).

The structure of pitchblende is mostly colloform. It forms lenses, veins, and aggregates from microscopic size to several metres long and several centimetres wide (Table 3).

Table 2

more than 1.00%	-	U, Fe
1.00-0.1%	-	V, Yb, Cu, Pb, Zn, Sb, As
1.00-0.01%	-	Mn, Bi
0.1-0.1%	-	Ti, Th, Ag, P, Au, W, Y, Sc
less than 0.01%	-	Mo, Sn, Li, Be, Co, Ni, Ba, Sr, Tl, Ce

Table 3

Mineral-succession in the hydrothermal veins within the Jáchymov deposit (after Mrňa and Pavlů, 1963, 1967)

Stage	1	2	3	4		5	6
Mineral	sulphides	quartz	pitchblende	As and Ag minerals	As and Bi minerals	sulpharsenides	sulphides
Quartz	–	– – –		–	–		
Arsenopyrite	–						–
Pyrite	–	–	–				–
Galena	–						–
Sphalerite	–						–
Chalcopyrite	–						–
Bornite	–						
Ankerite		–					
Hematite		–					
Dolomite			–				
Pitchblende			–	—			
Fluorite			–				
Native silver				– –			
Native bismuth					–		
Skutterudite				– –	—		
Rammelsbergite				—	–		
Nicolite				—	–		
Safflorite				–	–		
Lollingite				–	–	–	
Gersdorfite				–			
Bismuthite					–		
Native arsenic					–	–	
Proustite						–	
Pyrargyrite						–	
Argentite						–	
Sternbergite						–	
Stephanite						– –	
Stibnite						–	
Realgar							–
Tennantite							–
Calcite							—

Lithological and structural control of uranium mineralization. The general features of lithological and structural control have been described above. Localization of mineralization within deposits is so dependent upon three main factors:
1. favourable host rocks, especially their lithological composition,
2. favourable structures, especially their morphology and their position,
3. favourable mineralogical and geochemical environment.

The lithological control is one of the very important factors that can be used as a criterion during prospecting, exploration and mining. The most favourable host rocks for the deposition uranium-ore minerals are: amphibolites, biotitic, pyritic, and graphitic gneisses, erlans[1], chloritized and pyritized biotitic mica schists, and skarns (especially amphibole-pyroxene).

Unfavourable host-rocks are: granitic rocks, quartz-sericitic gneisses, and muscovitic paragneisses.

Favourable faults and fractures in which pitchblende was deposited are those that were open during the mineralization phase, especially those parts that were opened the widest. The pitchblende lenses are located at intersections with other faults or in branch faults and fractures. Favourable factors for deposition of pitchblende are also the distance from the granite contact surface, the distance from the intrusive dykes, those places where the fractures change their dip or trend, those places where the veins cut the anticlinorial structures, and those places where the veins cut favourable host rocks.

Favourable mineralogical and geochemical environments for the deposition of uranium minerals within the vein-fractures. Because of polyascendent character of vein-mineralization the previous stages of mineralization, their metasomatic effects and their geochemical features, favourable places for deposition of pitchblende within the veins have been formed. Dymkov (1960) stated that most pitchblende was deposited simultaneously with carbonates within the geochemical environment where pH is 8.35. The transportation of uranium ions within the solutions was in their U^6 form. The precipitation of U_3O_8 from solution was caused by such reducing ions as Fe^2, S or C contained in minerals from previous stages or in rock-forming minerals within the host-rocks.

Decrepitation tests have shown, that the temperature within the pitchblende stage was between 370 and 470°C which agrees with such temperature determinations made on similar veins elsewhere (Mrňa and Pavlů, 1967).

Temperature conditions as well as the geochemical processes are the main reason for mineral zoning within the deposit. The regional features of zoning have been described above, but there is also a more detailed zoning within individual veins. The position of mineral accumulation in relation to the granite contact surface and/or to the earth's surface is important. According to Mrňa and Pavlů (1967), and to geological documentation done by the author, the mineral-associations belonging to the oldest stages are, as a rule, close to the granite surface (i.e. in the deepest parts of veins). There quartz is the most abundant gangue mineral but locally there is much fluorite. With increasing distance from the granite surface the abundance of carbonates

[1] Contact metamorphosed rock containing mainly calcium silicates, plagioclase, biotite, etc.

becomes greater and of quartz lesser. This is especially true within the northerly-trending veins. The following mineral associations have been observed in the veins:

upper part - carbonates, pitchblende, native silver, skutterudite, rammelsbergite

middle part - carbonates, some quartz, pitchblende, native bismuth, rammelsbergite, skutterudite

lower part - quartz, native bismuth, skutterudite, safflorite, pitchblende, some carbonates.

These veins, which have been formed polyascendently, have as a rule the most extensive pitchblende zone, within which the arsenides with native bismuth form the deeper parts and the arsenides with native silver form the upper parts of veins.

In the Jáchymov area the uranium (pitchblende) mineralization is the most extensive and most abundant. A number of veins have monoascendental and monominerallic mineralization, represented by pitchblende as ore, and dolomite as gangue, minerals.

Genesis of the uranium deposits within the Jachymov area. The characteristic features of the uranium mineralization can be a basis for an hypothesis for the origin of these deposits. These are:

1. The deposits are localized within a metallogenetic province, where endogenic magmatic and postmagmatic processes formed many metallic deposits of different types.
2. The deposits are localized within an area where different orogenies formed the geological structure of favourable environment. The Variscan Orogeny is the most significant epoch within the forming-processes of the deposits.
3. The deposits are located within or close to the old regional tectonic lineaments, along or within which other large ore deposits are located.
4. The deposits are located within the mantle of the granitic pluton and especially within those parts that are close to the younger differentiates of intrusions.
5. The deposits are represented by hydrothermal veins, which have been mineralized in several stages by hydrothermal solutions, and which had differing chemical characteristics, differing temperatures and differing gas pressures. The hydrothermal solutions reacted with the host rocks as well as with the products from previous stages of mineralization. Within the hydrothermal veins can be found those with polyascendent as well as those with monoascendent character of mineralization.
6. The close relations between the lithological, structural and mineralogical factors and the localization of the uranium ore.
7. The metasomatic and alteration effects following the hydrothermal processes.
8. The development of chemical, physical and topical[1] conditions during the time and space of ore-formation. Different generations of mineralization and several generations of uranium-ore-forming processes have been identified.
9. The question of the source of uranium mineralization which is however not yet unambiguously solved. Higher contents of uranium have been found in

[1] In original sense of this word, meaning positional.

both intrusive granitic rocks as well as in the metasediments. Either the theory of hydrothermal ascension or that of lateral secretion can be applied. But much more probable in the opinion of author, is that both autometamorphic granite and metasediments played significant roles during the formation of these deposits.

The genesis of the complex mineralization within the Jáchymov and Erzgebirge area has been studied by many authors, among whom are Betechtin (1953), Baumann (1967), and Mrňa and Pavlů (1961, 1963, 1967).

It may be generally accepted that the fractures were formed mainly during the late Variscan tectonic movements and filled in before the Tertiary volcanism. The absolute age of pitchblende roughly ranges the postmagmatic phases of granitic magmatites. The absolute age of pitchblende within its first and maximum generation as obtained by various investigators averages around 220 to 230 million years (Legierski, 1966: 230 to 260 million years; Vinogradov, 1959: 180 million years; Leutwein, 1957: 260 to 220 million years)[1]. The age of granitic magmatites is about 320 million years for the "Normal granite" and 260 to 280 million years for the "Autometamorphic granite" (Smejkal, 1960, 1964). The hydrothermal solutions had several pulses with six main mineralization stages. The uranium-bearing solutions had great amounts of U, Fe, Mg, Ca and CO_2, minor amounts of SiO_2 and F, and traces of V and rare earths. Mrňa and Pavlů (1963, 1967) suggested the following chemical reaction causing the precipitation of pitchblende from the uranium-bearing solutions:

$$90\ Mg^{2} + 45\ (UO_2)\ (CO_3)_3^{4} + 2\ FeS_2 + 94\ CaCO_3$$

$$15\ U_3O_8 + Fe_2O_3 + 4\ CaSO_4 + 49\ CO_2 + 90\ CaMg\ (CO_3)_2$$

This formula explains also the red alteration caused by hematite as well as the presence of dolomite, the main gangue mineral accompanying the accumulations of pitchblende. Anhydrite and gypsum are known especially from the deposits surrounding the north part of Karlovy Vary massif, and Krušné hory pluton in particular. Both favourable structural and lithological conditions mentioned previously affected the deposition of pitchblende. Uranium contained in host rocks probably also affected the deposition of uranium minerals. Pitchblende has been at least twice regenerated and regenerations have been confirmed by pitchblende age determinations: of 160 to 60 million years and of 30 to 5 million years. The products of other stages of metallic mineralization, that is the arsenides stage and the sulpharsenides stages, have been deposited mainly within the same veins as the products of the pitchblende stage. The metallic elements of these stages are as a rule associated with the products of the previous stages and therefore the paragenesis is called Bi-Co-Ni-Ag-U (or "five-element") formation, although this type of deposit has several different stages and several different paragenetic associations. The paleomagnetic investigations done during recent years pointed to a very young origin for some ores especially the Co-Ni mineralization (Krs, Vondrová, 1965), which is accepted as result of the alkaline volcanism in the Tertiary. The author of this report supposes that these results testify to processes, which accompanied the Tertiary tectogenesis and which took

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[1] In Mrna and Pavlu (1967).

part in remobilization, redistribution and redeposition or regeneration of the previous mineral associations without the need for great quantities of new uranium-bearing solutions.

The Horní Slavkov (or Slavkov) area

This area (see Fig. 3) is a part of the Slavkovský les Mountains region, which consists of the metamorphic complex and of the granitic rocks belonging to the Karlovy Vary massif. According to Holubec (in Svoboda et al., 1966) the predominant part of metamorphics is regarded as Algonkian to Silurian. The metasediments are folded in a megaanticlinorium, so that both the core and the younger envelope can be distinguished. The axis of the anticlinorium has a northeast trend. The Algonkian complex was metamorphosed during the Assynthian Orogeny, but the Paleozoic formations were folded and metamorphosed during the Variscan Orogeny. The intrusion of the Karlovy Vary granite massif took place probably in the Middle Carboniferous and ended in the Stephanian. This magmatism was followed by post-magmatic hydrothermal processes, as in the Jachymov area. Movements along the earlier faults were renewed by the Saxonic tectonics, mainly within the Laramide phase.

The Slavkov core is represented mainly by biotite-sillimanite gneiss, biotite- and migmatitic biotite-muscovite gneiss and biotite- or biotite-muscovite orthogneiss with aplitic gneiss. In some places there are interbedded amphibolite, amphibole gneiss and skarn. The gneisses are commonly sericitized.

The envelope complex of the Slavkovsky les is represented by several stratigraphical formations of varied rock composition. The stratigraphic and tectonic features are masked by post-kinematic alteration at the contact with intrusive igneous rocks.

The granitoids of the Karlovy Vary massif are characterized, as in the Jáchymov area, by two groups: the older Normal granite and the younger Autometamorphic granite. The Autometamorphic granite is distinguished by pneumatolitic and hydrothermal alterations e.g. albitization, kaolinization, sericitization, and greisenization. The intrusions of the Autometamorphic granites are accompanied by a consanguineous dyke suite and by the above distinctive hydrothermal processes.

The post-metamorphic faults and the related fracturing formed favourable loci for ore deposition. The general trend of the main fault structures is northwest to west-northwest. The movements on these faults have been repeated many times. Another system of faults is northeast-trending, which corresponds with the "Krušné hory fault" system.

Two main groups of ore-mineral associations are characteristic for this area:

1. pneumatolytic hydrothermal deposits with paragenetical association of Sn-W-Li-Mo ore minerals, and
2. hydrothermal deposits in which mainly pitchblende is deposited within the veins accompanied by arsenides of silver and bismuth.

The pneumatolytic-hydrothermal deposits are of greisen origin. They are composed of zinnwaldite, cassiterite, wolframite, arsenopyrite, chalcopyrite, sphalerite, molybdenite and bismuth minerals (a) as ore-minerals within the upper parts of greisen stocks and of mainly tin mineralization, and (b) within the deeper part of these stocks, which are represented here as kaolinized and weakly greisenized granites.

The hydrothermal deposits (2) are more extensive than the deposits of the first group (1). Their position is analogous to the position of deposits within the Jachymov area. The hydrothermal vein deposits are located within the metasediments, among which paragneisses and amphibole gneisses are the most favourable host rocks for ore deposition. The orthogneisses are much less favourable host rocks for ore deposition and the uranium mineralization is practically absent where the veins cut these rocks. The mantle rocks of Karlovy Vary granite massif comprise a rest-block (roof pendant) above the dish-shaped surface of the granite pluton.

The mineralization occurred within several stages. The products of the pitchblende-dolomite stage are relatively much more abundant than those of the other stages. Quartz predominates over carbonate, and the quartz stages are less mineralized than the others. The main uranium mineral is pitchblende and it is accompanied by dolomite, ankerite, calcite, siderite, fluorite, and pyrite, but these minerals are more irregularly distributed and less abundant than pitchblende. Hematitization is the predominant alteration both of the carbonates and of the host rocks. The fluorite in the vicinity of pitchblende mineralization is mostly dark purple. Unlike the Jachymov mineral associations there are few quartz veins containing wolframite and belonging to the first group of ore formations within the Slavkov deposits (Mrňa and Pavlů, 1967).

In the Horní Slavkov area the lithological and structural control of ore localization especially of uranium mineralization can be expressed by the following conclusions.

The favourable host-rocks are amphibolites, commonly interlayered with paragneisses, amphibole gneisses, biotite gneisses, and paragneisses of various compositions.

The unfavourable host-rocks are orthogneisses of different composition, quartzite, migmatitic biotite-muscovite gneiss, aplitic gneiss, and granite, granite-porphyry and dykes related to granitic intrusions.

The favourable structures are northwest- to north-trending fractures, especially in places where they change in thickness, dip or strike and where they cut metasediments that contain pyrite, biotite, basic minerals and graphitic material.

The third group of uranium deposits within the Karlovy Vary granite massif region is represented by sedimentary epigenetic types of deposits.

The uranium deposits and occurrences are known mainly within the Sokolov Basin and partly within the Cheb Basin.

The Sokolov Basin is a part of the Krušné hory tectonic graben built mainly by continental sediments of Tertiary age. The basement of the basin is composed mainly of igneous rocks of Karlovy Vary massif but partly of schists.

The sediments of the Sokolov Basin were formed in two sedimentation stages and five lithostratigraphical formations can be distinguished, from oldest to youngest as follows (Svoboda et al., 1966):

Oligocene basal clastics representing the first stage.

Miocene sediments as the second stage represented by four lithostratigraphical formations, the Josef seam Formation (mainly coal seam), the Volcanogenic Series (tuffites, tuffs, agglomerates), the Main-seam Formation (mainly coal seam), and Cypris claystone (mainly kaolinitic clays, coaly clays, claystones, and sandy layers).

The sediments were faulted repeatedly and the main tectonic system is represented by two trends, northeast and northwest. The synsedimentary movements occurred along these main systems with less intensity than the post-sedimentary ones.

The uranium deposits are located mainly within those parts of Sokolov Basin, where this lies on the basement comprising Autometamorphic granites of Karlovy Vary granite massif. The second important feature of localization of these deposits is their position within the stratigraphical sequence. Most of the deposits are within the lignitic and/or bentonitic beds of Volcanogenic Series and Main-seam Formation. The third feature of significance in ore deposition is the presence of favourable hydrogeological conditions.

The following types of deposits are within this area:

1. uranium-bearing lignites (Odeř deposit), where the uranium mineralization occurs together with Ge,
2. uranium-bearing lignitic-bentonitic beds (Hájek and Ruprechtov deposits), where the uranium mineralization occurs in association with berylium,
3. sandy-detrital uranium-bearing accumulations (Domino deposit).

The origin of these ore deposits is explained as epigenetic, whereby the uranium-bearing solutions of low temperature have been transported from weathered uranium-containing material through permeable beds that contained reducing constituents, causing uranium ions to be precipitated or adsorbed. Only secondary uranium minerals megascopically developed have been found within these deposits. X-ray analyses identified uraninite as well as uranium humates. Other minerals present are sulphides, hematite, and hydrated iron oxides, and hydromicas in minor quantities (Civín and Procházka, 1967).

The Central Bohemian Pluton region

Within this region (1a, Fig. 6) the following groups of uranium deposits may be distinguished:

(a) deposits in the mantle of the granitic pluton which can be subdivided into deposits located within the northwestern part of the exocontact built up of the Algonkian sediments, deposits located within the southeastern part of the exocontact built up of the Moldanubian metamorphosed rocks, and deposits located within the so-called 'islets' (roof pendants), which are built up of Paleozoic rocks,

(b) deposits and occurrences within the igneous rocks of the Central Bohemian Pluton.

The Central Bohemian Pluton uranium-bearing region is a part of the Moldanubian Metallogenetic Zone and of the subprovince of the "Bohemian nucleus". The border of this region corresponds roughly with the delimitation set by Bernard (1964) and Sattran et al. (1966). This uranium-bearing region occupies the area of Central Bohemian Pluton, the southeast part of the Barrandien area and a part of the Moldanubicum. From the metallogenetic point of view this region is mainly characterized by the associations of Au, Sb, Fe, As, Pb, Zn, Ag, and U and by the associations: Pb-Zn-(Ag)-(Cu), U-(Pb)-(Zn)-(As), Au-sulphides, quartz-Sb, and others which are less significant. The common features of this metallogenetic unit are:

1. the subordinate abundance of pyrite and arsenopyrite,
2. the two different generations of sphalerite both with characteristic traces of Ag, Ga, Ge, Hg, Sb, Sn and In,

3. the presence of barite as a gangue mineral,
4. the lower temperature of mineralization, especially within the Pb-Zn-Ag-Cu association.

Because of the predominant character of the Central Bohemian Pluton igneous rocks it is necessary to start with the characteristics of these and then characterize the mantle-parts.

The Central Bohemian Pluton was formed after the tectonic movements of the Bretonian phase of the Variscan. It consists of several intrusions representing several petrographic types of igneous rocks.

Kodym (in Svoboda et al., 1966) distinguished the following groups of plutonic rocks within the Central Bohemian Pluton, from oldest to youngest:

older cataclastic granodiorites (east margin),
basic rocks (northeast part),
granodiorites (islets and north margin),
biotite- and amphibole-biotite granodiorites (central and west parts),
amphibole-biotite and pyroxene-biotite granites and syenodiorites (southeast part),
contaminated muscovite-bearing granodiorites with cordierite (different parts),
biotite adamellite with muscovite (northeast part),
diopside-bearing plutonic and hypabyssal rocks formed by assimilation of erlans and limestones (different parts).

Dykes and sills are abundant and their composition is extremely varied. Examples are leucocratic rocks (granite, aplite, pegmatite), basic granodiorite porphyrites[1], porphyries, and lamporphyres. Several groups of intrusions are followed by post-magmatic products, especially those of the hydrothermal phase.

The above mentioned list of plutonic rocks is in order of succession. Their absolute age has been determined by Smejkal (1960) and by the Geochemical Institute of the Academy of Sciences of the U.S.S.R. (Svoboda et al., 1966).

Table 4

Facies	Age (in million years)
Amphibole-biotite granodiorite	417
Amphibole-biotite granodiorite	371
Two-mica granite	370
Biotite granodiorite	367
Two-mica granite	359
Biotite granodiorite	353
Pyroxene-biotite syenite	343
Melanocratic series of syenite	330
Marginal biotite granite	324
Porphyritic granodiorite	290
Amphibole-biotite granite	285

[1] Term used in Europe for (a) effusive rock (paleovolcanic), and (b) for dyke rocks (in such case the name of the original intrusive rock is accompanied).

The mantle-rocks of the Central Bohemian Pluton are mainly represented by the early Paleozoic, Algonkian and Moldanubian complexes. Permian and Cretaceous sediments occur only at the northeast border of the pluton. According Svoboda et al. (1966) they are characterized as follows.

The early Paleozoic and Algonkian complexes form the northwest and central parts of the mantle, whereas the Moldanubian ones form the south and southeast parts.

The Moldanubian part of the mantle belongs mainly to the Varied Group[1] of Moldanubicum. This group originated from sediments of different composition, which vary stratigraphically and regionally. Two series can be distinguished within the Varied Group (Chernyshev, Timofeev and others, unpublished), the lower part, which is characterized by amphibolites, and the upper part, which is characterized by limestones.

In accordance with the regional division of the Varied Group the east, southeast, and south parts of the mantle belong to the Sušice-Votice unit. This unit is built up of biotite paragneiss, amphibolite and quartzite. Locally limestone is present.

The northwest and central part of the mantle belong to Proterozoic and early Paleozoic complexes. The Proterozoic complex was folded by the Assyntian tectogenesis accompanied by metamorphism of the Algonkian rocks. The Algonkian may be subdivided into Prespilitic, Spilitic, and Postspilitic (or Eocambrian) Algonkian. The early Paleozoic rocks rest unconformably on the Algonkian. The Central Bohemian Eocambrian is limited only to the southeast of the Barrandian Basin, occurring in the area intervening between its early Paleozoic part and the Central Bohemian Pluton with the Algonkian mantle. Along the boundary with the Central Bohemian Pluton the Eocambrian sediments, which consist of banded silty shales, siltstones, greywackes with intercalated greywacke-conglomerates, are contact metamorphosed into biotite- and biotite-cordierite hornfelses and spotted schists.

An interesting suggestion is that the material comprising the Eocambrian sediments has been transported chiefly from the southeast, that is from the (hypothetical) lineament area, which later controlled intrusion of the granitic plutons.

The Proterozoic orogenic cycle, which terminated the Algonkian geosynclinal regime, was followed by the deposition of Cambrian molassoid sediments. They were deposited in a partly continental and partly marine environment. The Cambrian here consist of conglomerate, quartzose sandstone, arkose, greywacke and minor slate. The Ordovician and Silurian complexes are products of geosynclinal sedimentation. According to Havlíček (in Svoboda et al., 1966) two Ordovician intrageosynclines were formed, one in the north, and the other in the south. The latter is represented by the "Islets zone" resting on the Central Bohemian Pluton. The Silurian sedimentation started with greyish black graptolite shales. The development of the Silurian complexes is however extremely varied.

The early Paleozoic volcanism culminated in the Upper Cambrian.

It is interesting, that the porphyries and porphyrities of the Křivoklát-Rokycany Belt are located at the intersection of the northeasterly-trending fault system (parallel to the Krušné hory strike and parallel to the

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[1] Varied Group (unlike the Monotonous Group) is mainly represented by paragneisses with intercalated amphibolites, marbles, erlans, quartzites, graphitic gneisses, and graphite.

Middle Bohemian seam), and of the hypothetical northwest trending tectonic zones, Gera-Rožmitál, Annaberg-Krásná Hora, and Marienberg-Tábor (nomenclature accordingly to Chrt, Bolduan et al., 1966).

The tectonic structures of the Central Bohemian Pluton region are controlled by the main structural plan of the Bohemian Massif. The plutonic body is elongated in a northeast direction, which is also the direction of the contact between the Moldanubicum and the Barrandian Algonkian. Postgranitic faults of Variscan and Saxonian age are frequent. They follow the main trends, northwest, northeast, and north.

These faults are often accompanied by porphyry and porphyrite dykes and the fractures of higher orders are in some places affected by postmagmatic, usually hydrothermal, processes (Kodym in Svoboda et al., 1966).

The Barrandian part of the mantle is structurally controlled by two most significant orogenies, the Assyntian and the Variscan. The first orogeny in addition to its influence on the development of sediments is significant because it was accompanied by basic spilite magmatism. The second orogeny is represented by very strong folding, faulting, and magmatic processes, which terminated with the intrusion of the Central Bohemian Pluton. The three systems of plicative and disjunctive tectonic structures northwest, northeast and north continued to develop into the late Paleozoic. From this time to the Quaternary the Barrandian underwent an epeirogenic development disturbed only by movements along the northwest-trending faults (Svoboda in Svoboda et al., 1966).

The Moldanubian part of the mantle underwent a very complicated tectonic development. The gneisses form several brachyanticlines and brachysynclines the direction of which changes rapidly regionally following a sigmoidal trend. Faults follow the general trends, except locally.

The mineral deposits within the area of the Central Bohemian Pluton may be ranged into the three main groups (Odehnal and Polak in Svoboda, 1966):

1. the oldest group of syngenetic metamorphic and metamorphogenic deposits associated with the Moldanubian crystalline rocks,
2. the epigenetic, prevalently vein deposits of the Variscan metallogenetic period and the Variscan and earlier granitoids,
3. the supergene deposits formed by disintegration of Moldanubian rocks and granite massifs.

The first and the third groups belong to the Central Bohemian Pluton mainly spatially and only partly genetically; the second group is mainly genetically related to the pluton.

The second group is the most important. Different types of metallic deposits and different mineral associations may be distinguished, and on this basis are divided into the following groups:

1. pegmatite dykes penetrating the granite bodies and their mantle, and containing Be, Th, Nb, and Ta minerals,
2. hydrothermal veins related generally to the Variscan metallogenetic period and distributed in both endocontact and exocontact zones of the Central Bohemian Pluton.

These may be subdivided as follows:

(a) quartz veins with Au, W and other metals,
(b) Pb-Zn-(Ag) bearing veins, locally containing Cu-minerals, comprise significant deposits mainly developed in the Algonkian and Cambrian rocks,
(c) U-bearing vein deposits developed within the mantle rocks, and U occurrences related to the fractures within the granitic rocks,
(d) Au-Sb veins following mylonitized and altered lamporphyre veins in granodiorites and metamorphics.

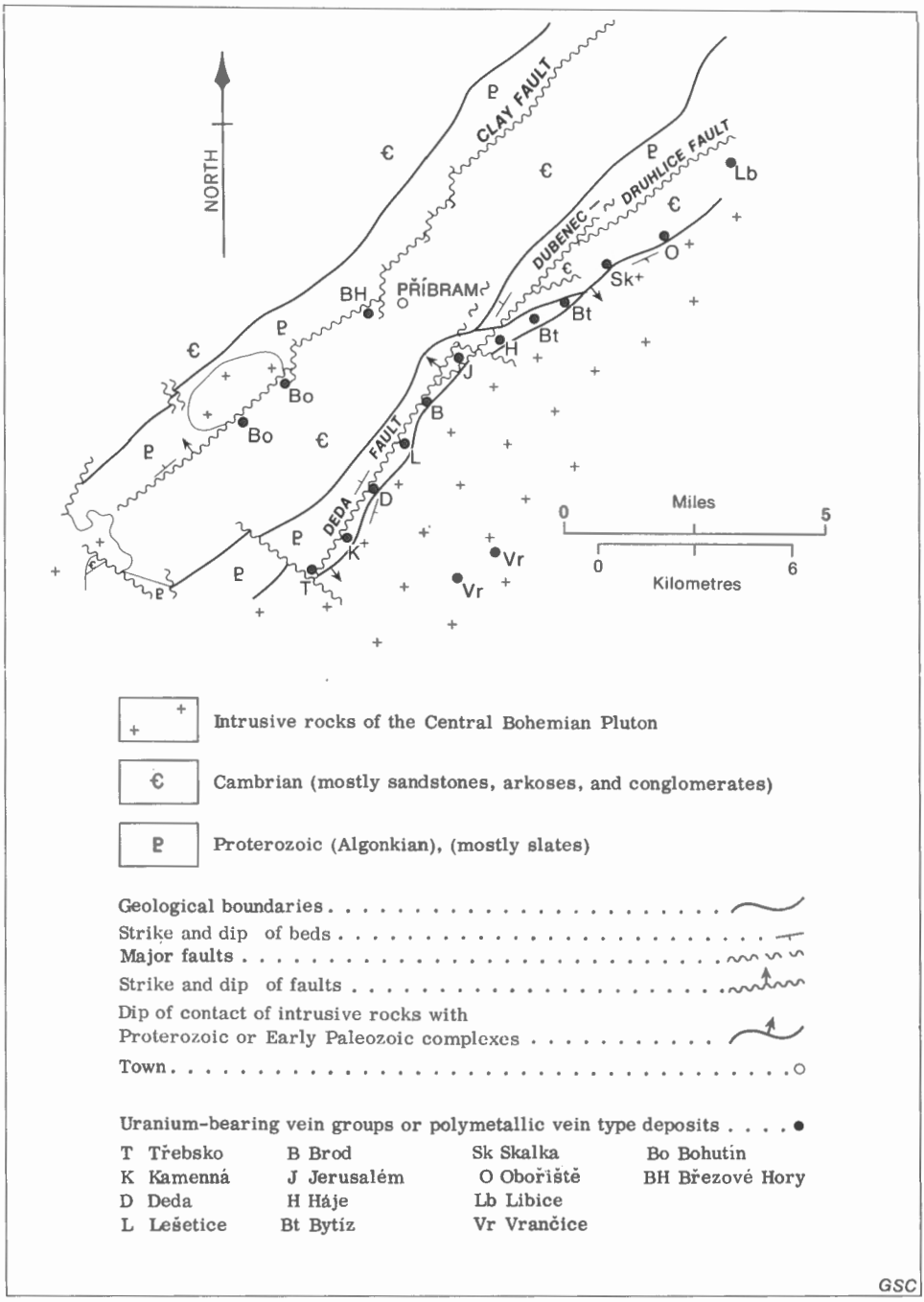

Figure 20. Geological sketch of the Příbram ore district (on the basis of a map by Pisa in Bernard et al., 1967).

Published geological literature on the uranium deposits and occurrences is sparse. Some problems have been mentioned by Mrňa (1967), Hrubý and Sorf (1958), Bernard (1967), Vondrova (1963), Malachov (1958), Svoboda et al. (1966), Kotek, Šorf, Zikmund (1966), Chrt et al. (1966), and Sattran et al. (1966).

The distribution of uranium deposits and occurrences is shown in Figures 1, 3, and 7.

In the uranium-bearing area of the Central Bohemian Pluton the following groups of uranium deposits occur (see Fig. 7):

1. deposits located within the exocontact mantle zone along the northwest margin, comprising the Příbram deposits (including Vrančice near in the endocontact zone), the Nová Ves deposit, the Mníšek deposit, the Novotníky deposit, and the Dlažov deposit;
2. deposits located within the exocontact mantle zone along the east, southeast and south margins, including the Heřmaničky, Ustaleč, and Damětice deposits, and other occurrences within the mantle of Chanovice and Klatovy apophyses of pluton;
3. deposit located within Sedlčany-Krásná Hora metamorphic islet, the Předbořice deposit;
4. occurrences within the igneous rocks of the Central Bohemian Pluton, such as Kovářov, Pechova Lhota, Velká, and Petrovice.

The Příbram deposits (The Příbram ore district, see Fig. 20)

The Příbram deposits occupy the mantle zone of Central Bohemian Pluton built up of Barrandian Proterozoic and early Paleozoic complexes. The Paleozoic rocks were affected by Variscan Orogeny, in the course of which the previously folded Proterozoic sediments have also been reworked. The Barrandian synclinorium trends mainly southwest, and is dislocated by sets of faults that strike northeast, north, and northwest.

The uranium mineralization occurs in two main types of veins, in carbonate veins with pitchblende and less sulphides, and in quartz-carbonate veins with Pb-Zn-(Ag)-(Cu).

The Pribram ore district is built up of Eocambrian sediments called by Kettner (1915, 1926) the "post-spilitic series" because they rest up on Algonkian spilitic rocks.

The geologists of the Czechoslovakian uranium industry have divided the spilitic series into four units, the member with spilitic volcanism, the tuffaceous sediments member, the member with acidic effusions and volcanogenic sediments, and the silicified black shales member with tuffaceous material. The post-spilitic series is divided into the lower member, in which pelitic sediments are predominant, the middle member comprising coarse sediments including conglomerates, and the upper member comprising mainly pelitic material with minor conglomerates. Between the latter series and the overlying Cambrian complex is an unconformity. The Cambrian sediments have varied facies (Kotek, Šorf, and Zikmund, 1966).

Folds in the Pribram ore district trend roughly 55 degrees. Close to the contact with Central Bohemian Pluton the Algonkian sediments are folded into "Příbram anticline". The Cambrian sediments are folded into "Příbram syncline".

Within the Příbram area there are three fault systems. The first, which trends northeast, consists of prominent faults, the Clay Fault, along which the Algonkian sediments are thrust southeasterly over the Cambrian,

and the Dědovská porucha, or Děda Fault and its northeastern extension, the Dubenec-Druhlice Fault. The second, which trend northwesterly and comprises faults from the Gera-České Budejovice, Annaberg-Krásna Hora, and Marienberg-Tábor lineaments. The third, which trends northerly and subordinately easterly, is related to the northeast-trending faults.

The Pribram uranium deposit is represented by hydrothermal veins, which form individual vein groups (see Fig. 20), e.g. Třebsko (T)[1], Kamenná (K), Děda (D), Lešetice (L), Brod (B), Jerusalém (J), Háje (H), Bytíz (Bt), Skalka (Sk), Obořiště (Ob), and Libice (Lb).

Within these vein groups distinctive "vein-knots"[2] are formed as spatially and tectonically related vein formations. Such separate vein-knots are distributed mainly between the Děda Fault and the Dubenec-Druhlice Fault and the contact of Central Bohemian Pluton.

Several of these knots contain blind orebodies, which start and end at different depths. Vein-knots have ore-mineralization accumulated within scattered orebodies. Morphologically the orebodies have following shapes: regularly scattered lenses (L-1, Bt-4), irregularly scattered lenses (B-34), ore chimneys (L-25), ore bunches (Bt-25), ore stockworks (Bt-22) and many others.

The sequence of vein mineralization in the Pribram uranium ore district is trifold. The first stage is polymetallic in which siderite, quartz, sphalerite, Ni-Co minerals, galena, dolomitic carbonate, and arsenopyrite were deposited. In the second stage calcite, dolomite, ankerite, pitchblende, and later calcite were formed, and finally in the post-ore stage, mainly calcite was deposited. Those stages are developed either in separate veins or superimposed within the same veins (Mrňa and Pavlů, 1967).

The carbonate vein-filling is classified into five generations (Brodin, Petroš, Prokeš, and others, unpublished papers) in which the first two generations and the last one are not connected with uranium mineralization, which mainly accompanies the third and the fourth generations of carbonates. The different generations of carbonates can be distinguished by means of their fundamental chemical and physical features also and therefore this classification can be used as a practical criterion for the geological exploration of the ore-deposits. Sulphides are present mainly in the first (polymetallic) stage of mineralization, but rarely in the second stage, carbonate-pitchblende stage. Within the third (calcitic) stage of mineralization irregularly disseminated pyrite is present. Uranium mineralization is present both as pitchblende and as uranoan-anthraxolite, but the later is much less abundant.

The uranium-bearing anthraxolite mineralization is a product of the later phases of the hydrothermal processes. The hydrothermal solutions acquired their organic matter probably from the underlying carbonaceous shales. The metasomatic processes affected the primary pitchblende mineralization especially along the shear zones. Similar phenomena were described by B. V. Brodin and Yu. M. Dymkov (1964).

Close to the veins the surrounding rocks are more or less altered, depending mainly on the degree of cataclasis and the composition of the hydrothermal fluids. As a rule, chloritization, sericitization, and hematitization

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[1] Letters in brackets are symbols used for designation of individual vein groups.

[2] The term vein-knot is used for complicated vein systems.

are evident locally for only a short distance from the veins, but in places up to several metres. Hematitization is most common around pitchblende accumulations within the carbonate vein-filling.

Localization of the uranium mineralization within the Příbram ore district. The localization of the uranium mineralization within this district is controlled structurally and lithologically. The mantle sediments containing the hydrothermal uranium ore-veins are folded into an asymmetric anticline, the southeast limb dipping 20 to 40 degrees southeast while the dip of the northwest is as steep as 60 degrees northwest. The uranium mineralization within the ore-veins is mainly localized within the southeast anticlinal limb but other structurally favourable places are where the anticline forms local brachyanticlinal folds or closures (Bt-4) or where the anticlinal axis has virgations (Bt-4). Because of the domal character of contact surface of the Central Bohemian Pluton the ore-mineralization becomes richer close to these domal structures (B-34, L-25, Bt-25, and others). As in the Jáchymov area the fissures that opened during the pitchblende-carbonate mineralization stage are favourable for the ore-deposition. The most favourable places are where the fissures are ramified, intersected by other veins or faults, or in the vicinity of dykes and sills (Bt-4, L-1, Bt-22, and many others). Several analytical and statistical investigations have been done comparing different geological factors with the quantity of uranium metal. The results have shown a very close correlation between the total thickness of veins, together with their branches on a certain level. One vein in particular shows the correlation very distinctively; the wider the vein, the greater the quantity of uranium metal. There is also locally a direct relationship between the quantity of carbonates of the third and fourth generations and the quantity of the uranium, but the opposite is true of fifth generation carbonate. The quantity of ore varies inversely with the thickness, and size of pebbles, of enclosing conglomerates.

The identification of different generations of carbonates has been used to trace the migration of ore-bearing solutions. For example it was found that the mineralizing solutions started in the vicinity of the granite contact, ascended roughly vertically, then migrated at an incline, and finally horizontally.

Structural control, especially the morphology of fissures as well as the physical-mechanical features of host rocks is the chief factor influencing the localization of ore mineralization.

Interesting results have been obtained from investigations of the temperatures of formation of gangue minerals. The decrepitation method used for the reconstruction of temperature conditions during different periods of migration has shown that a very close relationship exists between ore deposition and the original temperatures, and this is one of several factors used for the evaluation of laws influencing the localization of ore. Unfortunately the results of these investigations within the Příbram area have not been published.

Carbonates influenced by hydrothermal solutions have been investigated by the thermoluminescent method. This method gave also excellent results, but interpretation is very difficult and has to be very carefully applied to solve the question of the genesis of the ore deposits.

The Pb-Zn-Ag-(Cu) mineral association which also contains uranium mineralization occurs in the Březové Hory and Vrančice deposits as well as in the Příbram district.

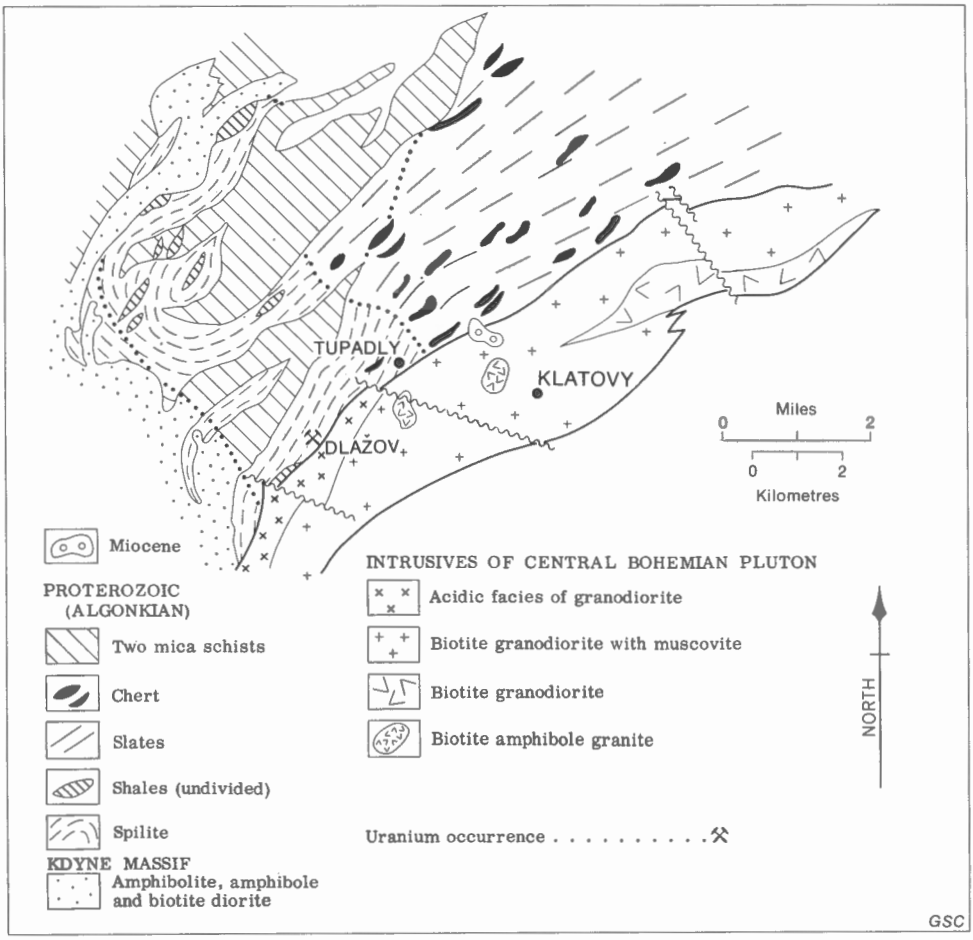

Figure 21. Geological sketch and localization of uranium mineralization along the Klatovy Apophysis of the Central Bohemian Pluton (based on "Geological map 1:200,000" by L. Cepek et al., 1961).

The polyascendent Pb-Zn-Ag mineralization of the Březové Hory deposits (see Fig. 20) originated during four main stages (Bernard et al., 1967): (1) (polymetallic)-galena-sphalerite, (2) (polymetallic)-sulphoantimonides, (3) stibnite, and (4) carbonate. In the course of these stages twelve monoascendent mineralization processes may be distinguished. Unlike the Příbram uranium ore-field the direction of ascent of ore-bearing hydrothermal solutions is supposed to be from the vicinity of the Clay Fault zone. The zonal distribution of hydrothermal mineralization in the vertical and horizontal sense is controlled particularly by the tectonic development of individual vein systems. The uranium mineralization belongs here to the latest (twelfth) period of mineral introduction, which is characterized by the association of chlorite, dolomite (second generation), calcite (third generation), pyrite (fifth generation), chalcopyrite (second generation), calcite (fourth generation), and within the Bohutín deposit only kaolinite which belongs to the carbonate main stage. The uranium mineralization is represented by pitchblende accumulations mainly within the upper parts of single veins (Václav, Jánská, Černojamská and other veins within the Lill Mine)(Píša, 1966).

The Vrancice deposit

The Vrančice deposit (Fig. 20) is situated in the rocks of the Central Bohemian Pluton represented by biotite granodiorite and partly by aplitic granite. The polymetallic ore veins are represented by Pb-Zn-Ag-Cu minerals with two associations, in the second of which several generations may occur (Bernard et al., 1967):

1. arsenopyrite, pyrite, quartz, sphalerite, pyrrhotite, ankerite, jamesonite, galena, and calcite, and
2. quartz, hematite, Ni-minerals, sphalerite, siderite, quartz, bournonite, tetrahedrite, barite; galena, chalcopyrite, bornite, chalcocite; quartz, willemite, calcite, native silver; calcite, goethite, and other minerals.

The pitchblende mineralization is localized mainly in the marginal zone of one of the main veins at a depth of about 300 metres beneath the present earth's surface. The gangue mineral is mainly carbonate here.

The uranium-ore Mníšek and Nová Ves deposits (see Fig. 7) and other occurrences northeast of the Pribram area are spatially related to the northeast-trending faults (Clay Fault and other parallel-trending faults) where they are intersected by the northwest-trending systems. The uranium mineralization accumulated within carbonate veins and shear zones and is represented by pitchblende, partly in the sooty form, especially in Mníšek deposit.

Southwest of the Příbram area there are Novotníky, Dlažov and other deposits and occurrences (Figs. 8, 21) of hydrothermal vein type belonging to the young carbonate stage of mineralization, spatially and genetically related to the granitic intrusions of Central Bohemian Pluton. The Dlažov deposit especially shows a very close relation to the tectonic development of the contact zone of the Klatovy Apophysis of Central Bohemian Pluton. The vein filling is localized within contraction fissures and it is accompanied by pitchblende mineralization.

The group of deposits located within the exocontact mantle zone along the east, southeast and south margins of the Central Bohemian Pluton

are located within the Varied Group of the Moldanubian complex, are spatially related to the igenous rocks of Central Bohemian Pluton, and are controlled by the disjunctive tectonic structures.

Several deposits and occurrences have been explored and mined, among which the Heřmaničky, the Ustaleč deposit and the Damětice deposits are of special geological interest. Their origin is related to the post-magmatic processes of the Central Bohemian Pluton. Redistribution of uranium mineralization occurred during the later geological periods especially within the Heřmaničky deposit. As within other deposits, the uranium mineralization is often confined to graphitic shear zones.

The uranium deposit and occurrences within the igneous rocks and the Paleozoic metamorphosed islets belong to a distinctive system of deep tectonics manifested in the Central Bohemian Pluton. The fault structures are concentrated (Zikmund, 1966) in several zones forming a belt about 12 kilometres wide, striking 340 degrees which adjoins an analogous belt trending 300 degrees. These individual zones were followed for a distance of about 35 kilometres but they are believed to be much longer. The zones were affected by hydrothermal processes that in many places formed orebodies. Their influence on the localization of polymetallic and uranium mineralization is observable in the Předbořice, Kovářov, and Pechova Lhota deposits and Velká, Petrovice and other occurrences. The zones are interpreted as the surface manifestations of the tectonics of the deeper structural level. This belt of tectonic zones coincides with the regionally extended northwest trending lineaments along which are located the Aue, Jáchymov, Příbram and other hydrothermal polymetallic and uranium deposits, and the uranium-bearing structures are parallel with those within the exocontact zone of the Central Bohemian Pluton, which are filled with mineral associations belonging to the carbonate-pitchblende stage of hydrothermal mineralization.

The Labe Lineament region

This region (Ib, Fig. 6) is a part of the Moldanubian metallogenetic zone and its subprovince of the Bohemian nucleus. The region contains several geological formations of several ages, which contain uranium deposits spatially related to the disjunctive tectonic system of Labe Lineament.

The Labe Lineament is considered by Máška (in Buday et al., 1960) as the northeast boundary of the Tepla-Moldanubian block. This boundary is represented by transitional zones between the Tepla-Moldanubian block and the area of more intensive Variscan tectogenesis. Geologists of the Czechoslovakian uranium industry verified this opinion and subsequently traced this lineament farther to the southeast.

The uranium deposits and occurrences are located and distributed within a belt that coincides with the margin of katazonal metamorphosed complexes of Moldanubicum and which lies adjacent to the outer phyllites, Svratka anticline and the Železné hory unit. In addition the uranium deposits and occurrences are spatially related to the Labe Lineament and distributed within the favourable rocks of the Železné hory Mountains. Therefore this region may be divided into a southeast area, which is represented mainly by metamorphic rocks of the Moldanubian Varied Group and a northwest area, which is represented by various complexes.

The southeast part of the Labe Lineament region

All uranium deposits and occurrences are located within paragneisses intercalated with amphibolites and quartzites in the lower part of the group and with metamorphosed limestones in the upper. A significant feature of these metamorphic rocks in relation to the uranium mineralization is the presence of graphitic and pyritic gneisses.

The main deposits known up to 1968 occupied both the northeast and southwest limbs of a refolded mega-anticline, which is disrupted by faults following the main Labe Lineament direction and by transverse faults. Both these systems comprise shear-zones, which carry uranium mineralization.

Within this area are the Rožná, Olši, Slavkovice-Petrovice, Chotěboř and Jasenice uranium deposits, and the Veselíčko and Škrdlovice occurrences.

Localization of all these deposits and occurrences was controlled by the following structural and lithological factors:

1. shear-zones and fissures tectonically related to the Labe Lineament;
2. flexures, intersections and broadings of shear-zones and faults and fissures;
3. the junctions of the main structures and their branches or of the structures of different orders, especially within the Rozna and Olsi deposits.

Generally the mineralization in the Rožná and Olší deposits is developed in three main stages, the oldest, consisting of quartz-hematite or carbonate-hematite with sulphides, the middle, comprising carbonate, pitchblende, graphite, hematite, chlorite and some metallic minerals, and the latest (post-ore) stage, consisting of quartz, hematite, carbonates and pyrite. The middle stage is followed by chloritization of host rocks. The carbonate vein-filling is characteristic for the subsidiary fissures and narrow fractures whereas the fundamental shear zones carry fine dispersed uranium mineralization within the graphitic, chloritic and partly pyritic brecciated and mylonitized material of the surrounding rocks.

Uranium mineralization is distributed within a tectonically disturbed part of Moldanubian Varied Group. Within the Rožná deposit this group is represented mainly by plagioclase-biotite paragneiss and amphibolite. The surrounding rocks are distintly chloritized and carbonatized. In the central part of this deposit four main ore-bearing zones are present:

The R-1 zone which is the main zone, trends and is subjacent to other ore zones. It dips south-southwest and reaches locally a thickness of 20 to 30 metres.

The R-2 zone which joins the R-1 zone from the northwest and above.

The R-3 zone which is also located above the R-1 zone.

The R-4 zone which also joins the R-1 zone on the south.

There are several subordinate zones and veins which together form a mining district.

The mineral succession may be observed mainly within the flanks of the deposit where carbonate veins are developed, whereas within the central part the ore zones are strongly crushed, brecciated and mylonitized and the ore mineralization is finely disseminated and as a rule represented by sooty or microscopic pitchblende.

Within such carbonate-pitchblende veins Boitsov (1966) identified six generations of carbonates.

Calcites of the first three generations were formed before the pitchblende, which formed simultaneously with calcite of the fourth generation.

Calcite of the fifth and sixth generations formed simultaneously with the second generation of pitchblende and with selenides.

Table 5

Paragenesis of vein minerals
(after Boitsov, 1966)

	1 to 3	4	5	6
Calcite	x x x	x	x	x
Pitchblende		x	x	
Berzelianite			x	
Umangite			x	
Eucairite			x	
Clausthalite			x	
Hematite			x	
Chalcocite				x
Bornite				x
Chalcopyrite				x

The composition of the uranium-bearing hydrothermal solutions, originally rich in CO_2, gradually changed composition increasing the oxidation potential and iron content, so that pitchblende could no longer be deposited. Then the ore-bearing solutions again changed and deposited pitchblende together with selenides. Finally selenium became less abundant than sulphur, and this caused deposition of chalcocite, bornite and finally chalcopyrite. The first stage of pitchblende mineralization is much more distinctly developed than the second stage.

The fact that the youngest stage of mineralization is usually developed at the margins of a deposit is a useful exploration tool.

Unlike the uranium deposits within the classical areas of Jáchymov and Příbram, granitoids in the southeast part of the Labe Lineament are scarce. A possible relationship may exist between the intrusions of latest Variscan granites (especially the two-mica granites) and their postmagmatic hydrothermal processes and the polymetallic mineralization of Pb-Zn-(Ag)-(Cu), U-Se-Cu, and Sb associations (Vondrová, 1963; Sattran, 1963; Hrubý-Šorf, 1968).

The northwestern part of the Labe Lineament region

The distribution of uranium deposits and occurrences is controlled by northwest-trending faults, which are related to the Labe Lineament. The common feature of this group of deposits is the character of uranium mineralization. Most of these deposits and occurrences are mineralized by uranium-bearing anthraxolite and only as an exception by sooty or massive pitchblende.

Within this area there are geological features similar to those at Pribram, that are favourable for forming a uranium-anthraxolite type of

mineralization. Distinctive hydrothermal alterations occur within and along the shear-zones as well as within vein-fissures, the surrounding rocks are mainly carbonaceous shale, and the uranium-anthraxolite mineralization is probably a result of metasomatic processes, which affected the primary pitchblende mineralization.

The representative deposits of Bernardov, Licomeřice-Březinka and such occurrences as Zdechovice and Rudov underwent analogous ore-forming processes, which are characteristic for both the Labe Lineament and the Central Bohemian Pluton uranium-bearing regions.

The Central Moldanubian Pluton region

This region (1c, Fig. 6) is less favourable for uranium than the regions above mentioned (1a and 1b), although it is represented by a plutonic body and its mantle.

The plutonic magmatites have following succession (Svoboda et al., 1966) (from the oldest to the youngest ones): (1) olivine-bearing rocks, (2) gabbros, (3) amphibolite-biotite diorites, (4) granites of 'Weinsberg' and 'Rastenberg' type, (5) granites of 'Mauthausen' type, (6) the Freistadt granodiorite, and (7) the Eisgarn granite.

The intrusions of the Moldanubian Pluton are petrographically related to the intrusions of the Central Bohemian Pluton. The absolute age determinations indicated Variscan age (260 to 390 million years). The greater part of these intrusions should be regarded as true intrusion and a minor part may be regarded as being due to granitization processes.

The uranium deposit within this area is located in the mantle of the central massif, which in this part is mainly composed of two-mica granite, which represents a younger differentiate enriched in volatiles and causing distinctive metasomatism. The Okrouhlá Radouň deposit is closely related to the northerly-trending shear zones, which are strong mylonitized and affected by chloritization, graphitization and carbonatization. Uranium mineralization is represented mainly by sooty pitchblende, usually finely dispersed within the zones, in lenses of irregular shape. Sulphides of iron and copper are present as small specks only.

The Western Bohemian region

This region (1d, Fig. 6) belongs to the Moldanubian metallogenetic zone and its subprovince of the Bohemian nucleus, as defined by Sattran et al. (1966). In this region the characteristic metallic elements are U, Pb, Zn, Sb and Cu.

The Western Bohemian Group of uranium deposits occurs in the Variscan intrusions of the Bor massif and its mantle, and the metamorphics of the Domažlice Crystalline Complex.

In the Bor massif and its mantle, the Vítkov I, Vítkov II, and Anna uranium deposits, and the Bor occurrence are found, and in the Domažlice Complex, the Zadní Chodov and Dyleň deposits occur.

The Variscan intrusions of the Bor massif are represented by medium-grained, porphyritic biotite-granite containing bodies of nonporphyritic biotite-granite or amphibole-quartz diorite. Dykes of tourmaline granite and aplite are significant intrusions of the later phases.

Three sets of faults are important in relation to the deposition of ore deposits: the north-northwest trending direction of Marianské Lázně fault and Zadní Chodov faults, the northwest trending Tři Sekery fault, and north trending fractures and fissures.

Characteristic features of the Vítkov II deposit were described in the chapter "Distribution of the uranium deposits according to host rocks and geological formations".

The Vítkov I deposit lies along the contact zone of the Bor massif and within the northern extension of ore-controlling fractures. This deposit differs from the Vítkov II deposit mainly in that the main veins contain quartz and carbonate gangue minerals which are lacking in the Vítkov II deposit.

In the mantle of the Bor massif the uranium mineralization is spatially controlled by Marianské Lázně fault. The hydrothermal carbonate-quartz veins in the Sv. Anna deposit carry pitchblende and arsenides of cobalt, nickel and silver. This ore-mineralization corresponds roughly to the pitchblende and arsenide stages within the Jáchymov area, but the development of these stages is much poorer.

The Zadní Chodov fault, which occurs within the western exocontact of the Bor massif in prevalently biotite-gneisses is an important ore-controlling structural factor in the Zadní Chodov uranium deposit. The uranium ore-mineralization is confined to shear-zones that are strongly mylonitized, graphitized, carbonatized and chloritized. The ore mineral is finely disseminated sooty pitchblende. The structural and morphological character of the uranium-bearing shear zones is analogous with that in the southeast area of Labe Lineament region.

The West Sudeten region

Two main areas (2b, Fig. 6) may be distinguished within this region, the area of Krkonoše-Jizerské hory granite massif and its mantle, and the Orlické hory area.

The Krkonoše-Jizerské hory massif may be Upper Carboniferous in age. It has its own pneumatolytic-hydrothermal aureole built up of magnetite skarns, polymetallic skarns and hydrothermal veins, containing Ag-Cu, U and fluorite-barite (Svoboda et al., 1966).

The Orlické hory area is affected by uranium mineralization only within fault-zones, as in Kamenec occurrence, or in products of weak hydrothermal activity in association with Pb-Zn minerals.

The Rychlebske hory region

This region (2c, Figs. 6, 11) belongs to the Sudetic-Moravian metallogenetic zone and specifically to its Sudetic subprovince.

The Rychlebské hory region has similar geological features as the Krušné hory and West Sudeten regions have. They are:

1. Within the region there are Variscan massifs containing several intrusions presumably of post-Bretonian age. Within the ore-aureole of these granitic intrusions there are mainly hydrothermal deposits corresponding to different stages of development of the magmatism.

2. The region is tectonically favourable for uranium mineralization of hydrothermal origin and the localization of uranium deposits and occurrences is structurally controlled mainly by northwest-trending faults, along which the movements have been repeated several times and which have the character of regional lineaments similar to those controlling the distribution of uranium deposits within other parts of Bohemian massif.
3. Lithologically favourable host rocks are represented by gneisses intercalated by amphibolites and erlans. The gneisses are often migmatitized.

Uranium deposits and occurrences are represented by hydrothermal carbonate-veins carrying mainly pitchblende mineralization. The copper mineralization, which consists mainly of chalcopyrite and bornite, is within irregularly-shaped carbonate bodies and stockworks, and partly in veins. Similar, but much smaller bodies also carry uranium-pitchblende mineralization, which is very finely disseminated within the orebodies, as in Javorník deposit.

The Spiš-Gemer Ore-bearing Mountains region

This region (IIa, Fig. 6) belongs to the heterogenous polycyclic province of the West Carpathians and to the middle metallogenetic stage of the Inner West-Carpathians respectively.

The fundamental geological features and mineralogical-geochemical characteristics have been reported by Drnzík-Hudáček (1963), Zhukov (1963), Drnzík (1965), Mahel-Buday (1968), Adámek (1966), Rojkovič (1968) and others.

The uranium deposits within this region differ substantially from those within the Bohemian Massif. They are paragenetically related to the effusive-sedimentary complex and especially with the tuffite units genetically related to quartz-porphyry extrusions (see Fig. 22).

The ore-bearing sediments are of Permian age, and lie unconformably on Middle Carboniferous sediments. The stratigraphic column (see Fig. 9) is: conglomerates, sandstones and aleurolites[1]; effusive-sedimentary complex with: the upper effusive-sedimentary horizon, the horizon of 'varied' sediments, the lower effusive-sedimentary horizon; basal conglomerates.

The series is folded into the Huta anticline and Hnilčík syncline. A disjunctive tectonic is developed extensively, but is later than the ore-forming processes.

As can be seen in the above column, volcanic activity took place during two stages. It was followed by pneumatolytic and hydatogenic processes, which formed the ore-mineralization, which is apparently syngenetic. Uranium is in association with Cu and Mo and deposits occurring in tuffites, quartz porphyries, or arkosic shales, porphyroids, and tuffs can be minerographically distinguished (Rojkovič, 1968).

The ore-minerals in tuffites are represented by pitchblende, sooty pitchblende, molybdenite, chalcopyrite, tenantite-tetrahedrite, galena, sphalerite, arsenopyrite, ilmenite, magnetite, hematite, covellite, and the secondary minerals, autunite, torbernite, and tyuyamunite. Those in quartz-porphyries are represented by pitchblende, sooty pitchblende, chalcopyrite, tenantite-tetrahedrite, pyrite, sphalerite and molybdenite.

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[1] Term used in Eastern Europe for siltstone.

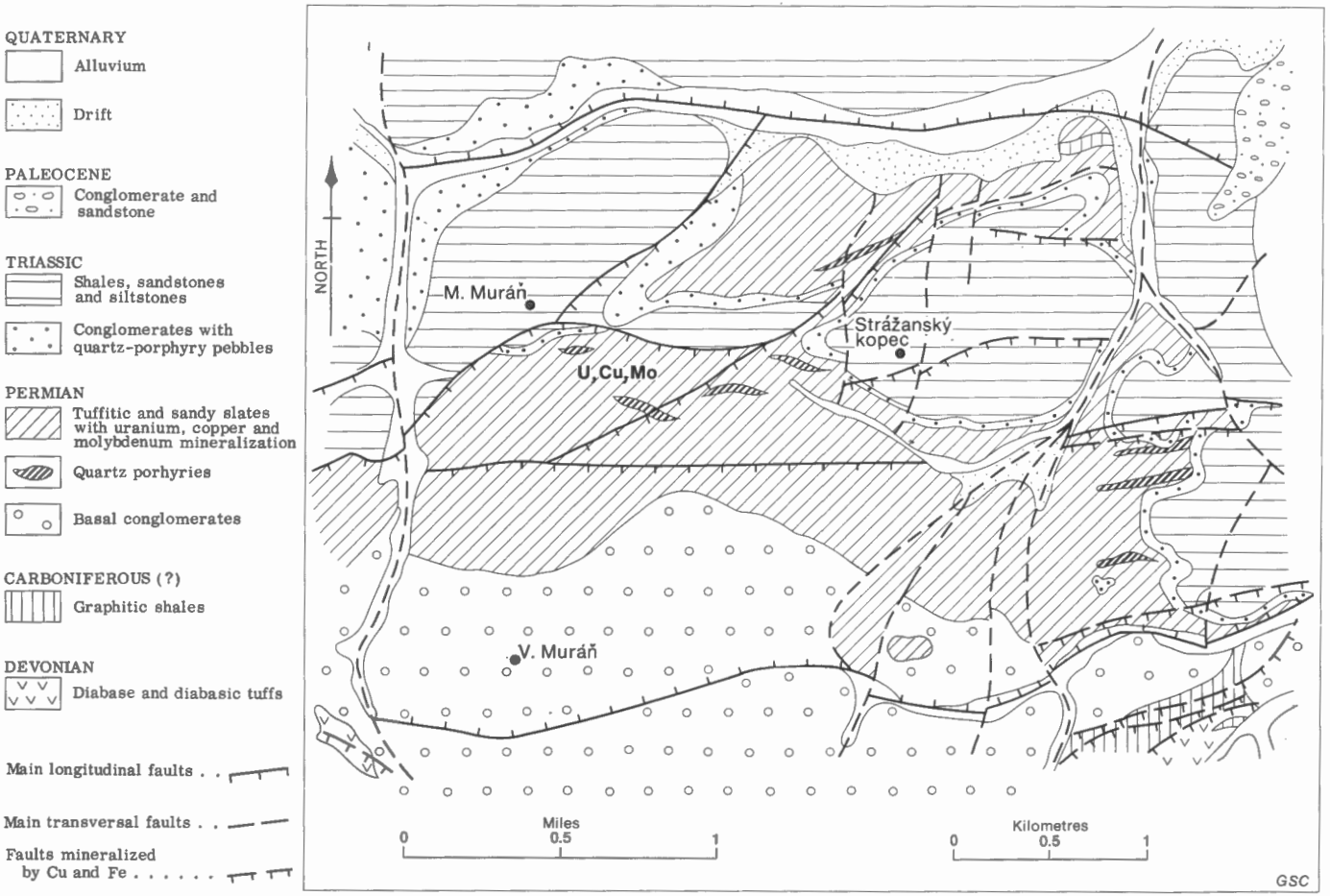

Figure 22. Geological sketch of the Novoveska Huta-Muran uranium deposit (after Drnzik-Hudacek, 1963).

The third type of mineralization is developed as sooty pitchblende, which is known in Eastern Europe as uranium black, and in submicroscopic dispersions.

The ore-mineralization is not accompanied by alteration of the host rocks, but the effects of metamorphism have been reported by Rojkovic (1968), who considers that the quartz-porphyry volcanism was accompanied with hydrothermal activity and exhalatory activity, which occurred during the sedimentation of tuffaceous rocks. The hydrogen sulphide exhalations caused precipitation of ore elements, the source of which were quartz-porphyries. Subsequent metamorphic processes caused local mobilization, migration and accumulation of ore-elements.

The Novoveská Huta and Muráň uranium deposits are the main representatives of this type. The Hnilcik and Haniskova occurrences are located on the flanks of the main area. Zhukov (1963a) listed eight localities of the volcanic activity within the Spiš-Gemer Ore-bearing Mountains, but only the above mentioned deposits were known until the middle of 1968.

The Low Tatra Mountains region

The second region within the metallogenetic province of West Carpathians (IIb, Fig. 6) is underlain by Permian up to Lower Triassic sediments of the Čierny Vah series of the Lower Tatra.

Uranium mineralization occurs in Permain sandstones of continental-lagoonal origin containing carbonized plant remains. These sandstone beds are covered with volcanics, which are generally supposed to be of Lower Triassic age, but Biely (1962) believes them to be Permian. Besides uranium mineralization, present mainly as torbernite, the following elements have been reported (Afanasjev-Drnzík, 1967):

Table 6

Pb	- 0.03-0.06% (up to 2.00% in the organic matter)
Ag	- 0.1 to 0.3%
V	- 0.1 to 0.3%
Mo	- up to 0.02%
Cu	- 0.06%

The ore-minerals are represented by pyrite, chalcopyrite and galena, the two last being in tiny carbonate veinlets.

The uranium mineralization associated with the copper mineralization is present also in sandstone beds which have a lower carbon content than those that contain mainly uranium.

Origin of the uranium-ore accumulations of this type is apparently epigenetic.

The Čierný Váh, Kravany, Štiavník uranium deposits and occurrences have been studied for several years because of their intricate tectonic pattern.

The Intra-Sudetic Basin region

This region (3a, Fig. 6) belongs metallogenetically to the area of Permo-Carboniferous molasse sediments, which carry the uranium mineralization within the Plzeň Basin, Kladno-Slaný-Rakovník Basin and Žacléř-Svatoňovice Basin (or Intra-Sudetic Basin).

A part of the Intra-Sudetic Basin belongs to Czechoslovakia, the rest to Poland. This basin is located amidst crystalline massifs and it is of the intermontane depression type (Svoboda et al., 1966).

The uranium mineralization, which is epigenetic, is localized within bituminous coal seams and partly within their overlying and subjacent beds which are composed mainly of sandstone. It is associated with vanadium, copper, and germanium, which locally reaches a high concentration.

The Stachanov, Rybníček and Chvaleč deposits and some other occurrences contain uranium mineralization.

The Cretaceous sediments region of North Bohemia

The geological features of the Bohemican Cretaceous Basin (4a, Fig. 6) have been described in the general part of this paper.

In the Bohemian Massif the Upper Cretaceous is represented (within this region) by sediments of Cenomanian, Lower and Upper Turonian, Coniacian and Lower Santonian ages.

Roll-type uranium mineralization occurs in the Hamr and the Teplice areas.

The Hamr area is located in the vicinity of the Hamr Lake and Ceska Lipa. The uranium mineralization is mainly confined to fluviolacustrine sediments, which are in general almost flat-lying, the dips being only 5 to 10 degrees. The sediments are dislocated by faults of northwest and west-southwest directions, subordinately with faults of north and north-northwest directions. The fault lines originated during the early period of Saxonic tectogenesis and they influenced movements during the Tertiary. During the same period the Cretaceous sediments were warped into recumbent folds (Klein and Soukup in Svoboda et al., 1966).

The uranium mineralization is developed within sedimentary units, within which some orebodies are extensive, but others are interrupted. The thickness of the orebodies varies greatly.

Characteristic features of the localization of uranium mineralization within the Hamr area are:

1. The uranium mineralization is developed mainly in those places, where coarse-grained sandstones are intercalated by siltstones and covered by mudstone.
2. The ore-accumulations are concentrated within the local depressions and usually they occur near the bottom of the sedimentary basin.
3. Near basaltic dykes and pipes the boundaries of the orebodies are locally parallel to the igneous contacts showing the influence of such bodies.
4. Uranium mineralization occurs at the contact between altered and unaltered clastic sediments. The alteration of sandstone is usually represented by oxidation of rock-forming minerals.
5. The distribution of uranium ore is influenced by hydraulic features of artesian water and by the original chemical composition of uranium-bearing

solutions penetrating the reducing environment of the host rocks. The hydraulics were influenced by faults.

6. Fractionation of uranium isotopes U^{238}, U^{235} and U^{234} has been observed, but the results have not been published. The investigations show that the uranium-bearing solutions penetrated not only peneconcordantly with the sediments, but also vertically both upward and downward.
7. Microbiological processes aided in the precipitation of the ore.

The genesis of the Hamr deposit may be explained as follows. The main sources of uranium were the acidic igneous rocks of the Lusatian granite massif and the rocks within its mantle. The uranium-bearing solutions were represented by artesian waters, containing 5.10^{-5}g/l U or more and having a positive redox potential values (Eh plus 200 mV or more). The reduction of uranium oxides took place where negative values of redox potential occurred (Eh minus 100 mV and less).

The oxidation of sulphides probably proceeded according to the equation (Vinogradov, editor, 1963):

$$FeS_2 + 11\ H_2O = Fe\ (OH)_3 + 2\ SO_4 + 19H + 15\bar{e}$$

where Eh and pH of pyrite were in the following relation:

$$Eh = +0.412 + 0.008 \log (SO_4^{2-}) - 0.076\ pH.$$

The precipitation of uranium from solution proceeded according to the equation (Vinogradov, editor, 1963):

$$UO_2OH^+ + H^+ + H_2O + 2\bar{e} = U\ (OH)_4$$

where $Eh = 0.334 + 0.03 \log (UO_2OH^+) - 0.03\ pH$.

Reducing agents were pyrite and other sulphides, organic (carbonaceous) material, hydrogen sulphide, and perhaps other substances.

These physical-chemical and chemical reactions proceeded within geological conditions favourable for leaching, transportation, and deposition of uranium components.

The Teplice area (see Figs. 3, 6) within the North Bohemian Cretaceous sediments region is similar geologically to the Hamr area. Čadek and Malkovský (1963) reported the low-temperature mineralization on the basis of their own geochemical investigations as an example of a recent till subrecent mineralization. Unlike the Hamr area however the mineralization is present not only within the Cenomanian sediments, but also within the Turonian. The uranium mineralization is present as uranium blacks (sooty pitchblende) and it is accompanied by galena, pyrite, sphalerite, quartz, fluorite and barite.

The mineralization of above mentioned character occupies a large area.

The main areas of uranium mineralization have been reported, but there are further areas favourable for uranium mineralization and uranium deposits.

PART II

EAST EUROPEAN URANIUM DEPOSITS

Several types of uranium deposits that occur in East European countries have been described in the geological literature. Those developed within Czechoslovakia were mentioned in the previous chapter. A description of genetic types of uranium deposits from other East European countries is the subject of this chapter. For comparison purposes only characteristic types of uranium deposits were selected. The description is based on geological publications, such as those by A.G. Betechtin, F.I. Vol'fson, D.Ya. Surazhskij, V.N. Kotlyar, A.P. Vinogradov, D.I. Shcherbakov, V.I. Smirnov, M.M. Konstantinov, E.Ya. Kulikova, G.B. Naumov, V.I. Danchev, K. Viragh, J. Kiss, A. Morawiecki, P.D. Ilev as well as on this author's opinions.

EAST GERMANY

Uranium mineralization in the western part of Eastern Europe beyond Czechoslovakia (i.e. in East Germany) belongs to the Saxothuringian metallogenetic zone. The geological development of this zone underwent three significant geotectonical periods: (1) pre-Variscan (Assyntic) geosynclinal period, (2) Variscan geosynclinal period, and (3) post-Variscan (Alpidic) platform period. The second period (Variscan) comprised four geological and metallogenetic phases: (a) initial stage (Ordovician to Middle Devonian; O_1-D_2[1]), (b) early stage (Upper Devonian and Dinantian; Lower Carboniferous), (c) medium stage (uppermost Dinantian and Silesian; mainly Upper Carboniferous; C_2), and (d) final stage (Stephanian; uppermost Pennsylvanian and Lower Permian; C_2-P_1)(Loetzsch, 1968).

According to this division different types of uranium mineralization can be distinguished: the endogenous pitchblende mineralization confined to hydrothermal veins spatially connected with an Upper Carboniferous and Lower Permian intrusive complex (developed mainly in Erzgebirge), i.e. stage (2d); the sedimentary-metamorphogenic mineralization confined to the metamorphosed complexes of the earliest stages (2b) of the Variscan period; uranium mineralization confined to bituminous coal seams (Freital); and uranium mineralization in sedimentary formations of Permian (P_2), Triassic (T_1) and Cretaceous (C_2) age, i.e. from the post-Variscan (Alpidic) platform period (3). It is also assumed that a part of the pitchblende mineralization might also be formed during the third (platform) period as result of Alpidic fault-block movements.

The Saxothuringian area is a part of the Bohemian massif. Characteristic features of this area are similar to those mentioned in the description of the metallogenetic characteristics of uranium deposits within the Bohemian massif. The following significant genetical types of uranium deposits which occur within the East German territory will be mentioned.

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[1] Symbols coincide with the European stratigraphic nomenclature symbols.

The hydrothermal pitchblende mineralization is reported from known mining districts, such as Freiberg, Marienberg, Annaberg, Johanngeorgenstadt and Schneeberg as well as from other localities in West Erzgebirge (Dymkov, 1960; Vinogradov, editor, 1963; Harlass and Schuetzel, 1965).

The geological features of mineral deposits of the hydrothermal pitchblende type are partly similar to those in Jachymov area mentioned in Part I. Most of them occur within contact metamorphosed sedimentary and volcanic complexes near granitic plutons. The distribution of these deposits is structurally controlled by a regional fault system and lineaments as well as by fault and fracture systems related to the latter. One of such controlling lineaments (the Nejdek-Crimmitschau zone) appears to be a part of the Gera-České Budějovice lineament, the significance of which was also mentioned.

The prevalent rock complexes, in which the uranium deposits occur, are represented by gneisses and schists which are often interbedded with dolomitized limestones, skarns, amphibolites and quartzites. They are believed to be of Lower Cambrian age. They are overlain by quartz-sericite-chlorite schists interbedded with quartzites, amphibolites and lenses of massive sulphides. These are in turn overlain by Ordovician shales and schists and by Silurian carbonaceous shales. The Devonian complexes are represented by limy and clayey sediments contact metamorphosed into biotite schists with skarns and sulphide lenses. The upper complexes are composed of metadiabase and amphibolite intercalated with carbonaceous and pyroxene-feldspar rocks.

The most favourable host rocks for uranium mineralization are represented by Cambrian skarns and amphibolites, or by pyritic chlorite-sericite schists and by carbonaceous shales, skarns and amphibolites of Silurian and Devonian age (Yanishevskiy and Konstantinov, 1960).

Uranium mineralization is mainly developed in two separate stages: the quartz-pitchblende-calcite, and the dolomite-selenides stages, which are significant parts of the broad mineral assemblages within the metallogenetic sequence. Harlass and Schuetzel (1965) distinguished the following main mineralization stages within the West Erzgebirge area: (1) the skarn stage (with iron and boron mineralization), (2) the quartz-wolframite-cassiterite stage, (3) the quartz-sulphidic stage (with quartz, chlorite, fluorite, arsenopyrite, pyrite, pyrrhotite, sphalerite, stannite, chalcopyrite, bornite and galena), (4) the quartz-pitchblende-calcite stage (with quartz, fluorite, pitchblende, hematite, coffinite, calcite, anhydrite and gypsum), (5) dolomite-selenides stage with quartz, fluorite, pitchblende (both massive and sooty), dolomite, clausthalite, umangite, goethite and sparse sulphides, (6) the arsenides stage (with quartz, barite, fluorite, siderite, dolomite, kaolinite, native silver, native bismuth, niccolite, skutterudite, loellingite, rammelsbergite, safflorite, redeposited selenides, pitchblende (both massive and sooty), coffinite and sparse sulphides, (7) the silver-sulphides stage, (8) quartz stage with iron and manganese mineralization.

The mineral sequence within the two, (4) and (5), main uranium-bearing stages is (after Harlass and Schuetzel, 1965) as follows:

Table 7

Mineral	The quartz-pichblende-calcite	The dolomite-selenides
Quartz	———	
Fluorite	———	———
Hematite	——— — ——— ———	——— — ———
Coffinite	— ——— ———	
Pitchblende	— ——— - ———	——— ———
Calcite	———	
Anhydrite, gypsum	———	———
Sulphides	— ——— — ———	
Dolomite		———
Goethite		- ——— ——— - — -
Selenides		———

Uranium was probably transported in hydrothermal solutions as a uranylcarbonate complex and precipitated as a result of (a) rapidly changed pH and Eh within solutions (with participation of wall-rock mineral components), (b) decreased temperature of solutions, (c) decreased CO_2 content and pressure.

The sedimentary metamorphic mineralization is confined to lower Paleozoic complexes which are folded, faulted, and metamorphosed. The host-rocks are represented by argillaceous, micaceous and black shales and dolomitized limestones. A significant feature is the presence of graptolitic members within the Paleozoic complexes as well as other organic material and a considerably quantity of pyrite. Uranium mineralization is represented mainly by pitchblende which commonly occurs in the sooty form.

An analogous type of uranium mineralization has been described by Getseva (1958) from an anonymous deposit and Surazhskiy (1960) as his thirteenth type of uranium deposits.

According to these authors the distribution, character and paragenesis of uranium mineralization indicate the following fundamental minerogenetic processes:

1. The original accumulation of uranium is supposed to be syngenetic with sedimentation of productive beds during the beginning stage of geosynclinal development. The accumulation of uranium during this stage took place from very dilute solutions under adsorbing and reducing environmental conditions.
2. This accumulation continued also during the diagenetic processes.
3. The metamorphic processes were represented (a) by recrystallization and dehydration of the rock-forming components, carbonization and polymerization of organic material, and the complete destruction of its adsorption bond with uranium, (b) by migration of uranium-bearing solutions and metasomatic replacement of rocks by pitchblende near reducing agents, and (c) by forming of secretionary veins. The metamorphic processes took place during the middle and final stages of geosynclinal development.

The first stage of metamorphism (3a) is characterized by such products as dolomite-calcite, sericite, pyrite, graphite and quartz, the second (3b) by pitchblende, marcasite, and humic material, and the third (3c) by

dolomite, chalcopyrite, marcasite, pyrite, quartz, graphite, pyrobitumen, kaolinite, barite and pitchblende. It stands to reason that the mineral products are dependent on the character of the original rocks.

The uranium mineralization in bituminous coals was reported by Ziehr (1961) from the vicinity of Freital.

The coal seams belong to the Lower Permian and they are irregularly mineralized by uranium, tin, germanium, molybdenum, pyrite, galena, sphalerite and copper. Such minerals are quartz, pyrite, chalcopyrite, bornite, covellite, fahlerz, and galena, which are finely disseminated, are confined to the combustible shales as well as to the fissure filling.

Uranium mineralization of the post-Variscan platform period is mainly confined to the sedimentary formations of Upper Permian, Lower Triassic and Upper Cretaceous.

Pietzsch (1963) reported uranium enrichments in sediments especially within the Zechstein Formation of Ronneburg area.

The Upper Cretaceous uraniferous sediments mentioned by Loetzsch (1968) may comprise a type of uranium mineralization similar to those in Cretaceous sediments elsewhere in the Bohemian Massif. Such favourable loci for infiltration type (roll type) of uranium mineralization are developed in Cenomanian sediments in the Elbtal ore-district which is in the vicinity of Dresden, and elsewhere.

POLAND

Uranium mineralization in Poland was reported by Morawiecki (1960). It is genetically related to igneous rocks as well as to sediments such as Silurian shales, Carboniferous conglomerates, sandstones and coal seams, Permian and Triassic sandstones and Cretaceous sediments. The most common primary uranium minerals are uraninite and pitchblende.

In the hydrothermal type of mineralization uraninite, pitchblende and sooty pitchblende are accompanied by schroeckingerite, autunite, sklodovskite, uranophane and uranium carbonates, phosphates and silicates as well as pyrite, pyrrhotite, marcasite, galena, sphalerite, arsenopyrite, chalcopyrite, bornite, tetrahedrite, loellingite, native arsenic, bismuthite, quartz, magnetite, hematite, fluorite, barite and calcite.

In sediments uranium mineralization is represented by sooty pitchblende and secondary uranium minerals accompanied by pyrite, marcasite, calcite, limonite, galena, gypsum and barite. Uranium in phosphorites, coals and clays does not occur in mineral form.

HUNGARY

Uranium mineralization in Hungary is developed in Permian sediments of the Permian-Triassic anticline in the western part of Mecsek Mountains (Barabas and Kiss, 1958).

It occurs in the terrigenous sediments of Upper Permian age (Barabas and Virag, 1966). These sediments are built up of arkosic sandstones, and siltstones with clayey-carbonate matrix and of thin-bedded argillites. The beds subjacent to the mineralized zone are composed mainly of muddy sediments. The beds overlying that zone comprise mainly fluviatile sediments. The productive zone has a transitional character.

The subjacent beds are characterized by a lower oxidizing-reducing potential (Eh), whereas the overlying ones have high Eh values. The ore-bearing zone is composed of rocks with various $Fe^{2+}:Fe^{3+}$ ratio.

The minerogenetic processes had an epigenetic character, whereby mobilization of uranium took place within the overlying "red" beds under oxidizing conditions. Uranium was then transported by low temperature waters and again precipitated under reducing conditions within the middle transitional strata.

The uranium minerals present are uranium oxides, silicates, uranyl-hydroxide, and in smaller amounts carbonates, sulphates and phosphates, accompanied by galena, chalcopyrite and traces of other sulphides.

The age of uranium mineralization is believed to be Upper Jurassic and Lower Cretaceous, but some younger mineralized spots, especially along cracks and fissures, are known.

BULGARIA AND ROUMANIA

Uranium mineralization in Bulgaria and Roumania has rarely been reported. Bain (1950) listed occurrences of oxidized uranium minerals at Goten or Bukhovo near Sophia and at Strelchna, the latter represented by autunite associated with pegmatites. But in both countries there are favourable areas for both endogenous and exogenous types of uranium deposits. Such areas are for example Rhodopy Mountains in Bulgaria and Bihor Mountains in Roumania. Favourable areas for sedimentary types of deposits are those with terrigenous clastic sediments.

An interesting type of uranium deposit of exogenetic origin was mentioned by Danchev et al. (1969). Uranium mineralization of this type is represented mainly by finely disseminated sooty and hydrated pitchblende associated as a rule with quartz and carbonized organic remains. The ore-bearing rocks are represented by sandstones; less uranium mineralization occurs in siltstones, and fine pelitic (clayey) sediments are as a rule barren. The overwhelming quantity of uranium ore is represented by fine-grained sandstone.

The minerogenetic processes are assumed to be: within the sandstone-siltstone facies (all alluvial-lacustrine) the diagenetic processes took part in uranium accumulation, whereas within the coarse-grained sandstone facies (alluvial) the main part of uranium was concentrated during the exodiagenetic and epigenetic stages.

U.S.S.R.

Uranium mineralization within the mineral deposits in the U.S.S.R. is developed in several genetic types. Such types were described in Vol'fson, editor (1968), by Sapozhnikov and Viselkina (1962), Alekseeva and Polupanova (1959), Pavlov et al. (1968), Gotman and Zubrev (1963), Kotlyar (1961) and Korolev and Miguta (1961). Uranium mineralization occurs in various geological regions and it is confined to certain geological formations.

The radioactive and rare element mineralization is confined to Cambrian conglomerates. Distribution of uranium mineralization is also controlled by fault systems of the lower structural level. It is developed

within the border facies of an iron-ore deposit. A titanium-phosphate-uranium type occurs in basic paleovolcanics, and a pitchblende-sulphides type in acidic paleovolcanics. Uranium-bearing apatites are also known. Uranium mineralization is also developed within the volcanogenetic complexes of the liparite (rhyolite) formation. A pitchblende-quartz association occurs in granitoids, pitchblende-carbonate in the felsite porphyries, pitchblende-fluorite in greisens. Also pitchblende-arsenides and uranium-molybdenum associations were reported.

Thorium-uranium occurrences are spatially related to the basic intrusions within the activated platforms.

Uranium deposits of roll type are confined to Mesozoic clastic sediments, exogenetic deposits are associated with red continental beds, uranium mineralization occurs in clay with fish bone detritus and uranium mineralization is found in bitumens, lignites and coals.

The geological-mineralogical features useful for comparison within selected types of uranium deposits will be mentioned farther.

Radioactive mineralization in conglomerates within the shield region

Radioactive uraniferous conglomerates are within Cambrian complexes unconformably overlying the Precambrian basement which is composed of microcline granite, schists and gneisses. Mineralogical and chemical composition of the radioactive conglomerate coincides roughly with the composition of microcline granite. Three types of conglomerates may be distinguished: (a) monomictic quartz-pebble conglomerate composed mainly of vein quartz pebbles, (b) oligomictic, composed of quartz and granite pebbles, and (c) polymictic with pebbles of quartz, quartzite, granite and schist. The most productive uranium-bearing zone is represented by monomictic quartz-pebble conglomerate (Shcherbin in Vol'fson, editor, 1968).

The uranium-bearing zone comprises three types of orebodies: (a) stratiform and lenticular confined to conglomeratic rocks, (b) veinlets confined to conglomeratic rocks and to the contact zone between them and the adjacent quartzites, and (c) irregular bodies with disseminated and massive ore confined to conglomerates affected by shearing and metasomatism. The last type is developed only sporadically.

Ore mineralization in the (a) type is developed within the conglomerate matrix only. It is represented by microcline, malacon (altered zircon), thorite, uranothorite, allanite, ilmenite, rutile, brannerite(?), hematite, magnetite, secondary autunite, with minor titanium-tantalum-niobates, priorite, monazite, xenotime, pyrite and chalcopyrite. Mineralization in (b) veinlets is represented by quartz, ilmenite, hematite, thorite, uranothorite and zircon. The third, type (c), is represented mainly by allanite.

Generally uranium is contained in brannerite, allanite, autunite, thorite, thorianite, uranothorite, and hyalite.

The origin of the uranium mineralization seems to be similar to that in the Elliot Lake area. However, the metamorphic and particularly the hydrothermal processes, affected the uranium mineralization (after the diagenetic stage of uranium-bearing conglomerates) and caused partially its redistribution (Shcherbin in Vol'fson, editor, 1968).

The ratios between some ore elements in the uraniferous conglomerates, which occur adjacent to granites are shown in the following table (after Shcherbin in Vol'fson, editor, 1968):

Table 8

U : Th	Ta : Nb	RE:Th
3:1 - 1:10	1:10	2:1

Uranium deposits related to the fault systems of the lower structural level within the shield regions

Two types of uranium mineralization may be recognized here: (1) the hydrothermal formed during several stages, and (2) the uranium-bearing albitites.

The hydrothermal uranium mineralization of the first type is developed within a mineralized zone composed of effusive sedimentary rocks of Proterozoic age enclosed between two regional faults to which subsidiary faults and fractures are tectonically related. Uranium mineralization is structurally and lithologically controlled. The main structural features controlling the localization of uranium mineralization are represented by cross-faults and with them related pinnate tension joints. Favourable host rocks are represented by Proterozoic trachytic porphyries, granites and by terrigenous sandstones.

The mineralization occurred during four stages: (a) apatite-uranium, (b) quartz-sulphide, (c) pitchblende-fluorite, and (d) quartz-carbonate.

Mineralogically the first (a) stage is represented by francolite, finely dispersed uranium minerals, brannerite, uranium-titanate, quartz and hematite. The host-rock alteration of this stage is represented by albitization, silicification, and phosphatic alteration. During the second (b) stage dissemination of pyrite, chalcopyrite, arsenopyrite, as well as formation of quartz-sulphidic veinlets, silicification and chloritization occurred. The third (c) stage comprises pitchblende, fluorite, quartz, hematite, molybdenite and galena. During this stage silicification, hematitization and chloritization of host rocks took place. The fourth (d) stage comprises minerals such as quartz, carbonate, fluorite, hematite, and chlorite. Uranium minerals are absent.

The uranium mineralization within this deposit is believed to be related to the Mesozoic movements that took place along the existing fault and fracture systems, along which the movements were rejuvenated (Seminskiy in Vol'fson, editor, 1968).

Uranium-bearing albitites as a product of metasomatic processes, which occurred preferentially in places where the regional fault systems were opened, are localized within zones of intense cataclasis of granites and pegmatites (Kazakov et al. in Vol'fson, editor, 1968).

Uranium mineralization confined to the border facies of iron ore deposits ("iron-uranium formation")

Uranium mineralization occurs in quartzites and in similar rocks of the Precambrian (Proterozoic). The host rocks are migmatitized, altered by aegirinization, rhodusitization, albitization and carbonatization, and they carry also hematite-magnetite mineralization.

The orebodies are represented by several morphological and mineralogical types with following features: (a) stratiform bodies within albitites comprising uraninite, magnetite, hematite, aegirine, rhodusite, malacon, pitchblende, uranium silicate, aragonite and graphite; (b) lenticular accumulations of magnetite, hematite, carbonate and uraninite with local spots containing aegirine, albite and rhodusite; (c) irregular accumulations of albite, dolomite, and uraninite, accompanied by pyrite, galena, or marcasite, and quartz; (d) irregular accumulations of albite, amphibole, aegirine and malacon.

The magnetite-uraninite-carbonate and pitchblende-sulphides ores were formed under mesothermal conditions (Kotlyar, 1961; Surazhskiy, 1960).

Types of pitchblende mineralization

Tananaeva (in Vol'fson, 1968) mentioned two main groups of characteristic genetic types of uranium mineralization in which pitchblende is the chief uranium mineral, the U.S.S.R. uranium deposits: (1) pitchblende-carbonate group, and (2) pitchblende-fluorite group.

The first (1) group comprises following associations:

(a) The pitchblende-calcite-iron oxides association which occurs in host rocks of various age and composition. The characteristic features of this association are: the general mineral sequence with three stages: (I) calcite I (or quartz) + hematite (+adularia); (II) native copper (or bismuth) + pitchblende; (III) calcite II + sulphides or hematite and/or goethite. The characteristic host-rock alterations are hematitization, sericitization and carbonatization.

(b) Calcite-sulphides-pitchblende association with Fe, Cu, Pb, Zn, As, Ag, Bi, Sb sulphides, or pitchblende with polymetallic sulphides and molybdenite, or pitchblende-molybdenite association. Within these types several subtypes such as galena-pitchblende, galena-molybdenite-pitchblende, and sphalerite-molybdenite-pitchblende ores may be distinguished.

(c) Pitchblende-molybdenite association, which belongs to the most characteristic genetic types of hydrothermal uranium deposits in U.S.S.R. It occurs mostly in acidic effusives and their tuffs, but also (rarely) within granitoids and granites of early and late Paleozoic age. The main minerals are molybdenite, pitchblende, and commonly pyrite and marcasite. The gangue minerals are sericite and quartz, but rarely chlorite and calcite. But carbonatization (especially of diabase and diorite porphyry dykes) is developed as a rule in the vicinity of molybdenite-pitchblende veinlets. The following mineral sequence was observed: (I) molybdenite + pitchblende + sericite, (II) galena + pyrite or marcasite + pitchblende + quartz, (III) calcite + goethite.

(d) Pitchblende-arsenides mineralization. A deposit with this mineral association occurs within the contact zone between gabbro-monzonite (Middle Carboniferous) and syenite (younger) intrusions (Strelcov in Vol'fson, 1968).

Five periods of mineralization developed within separate vein groups can be distinguished within the deposit: (1) pyrite-quartz veins, (2) quartz-barite veins, (3) veins with pitchblende, arsenides and native metals, (4) calcite-ankerite and quartz-calcite veins with sulphides, and (5) prehnite-calcite and zeolites-calcite veinlets. The mineral sequence within the veins of the (1), (3) and (4) groups is shown on Table 9. In the table the mineralization of pyrite-quartz veins is represented by the first stage, the pitchblende-arsenides mineralization is represented by the second to thirteenth stages, and the mineralization of quartz-calcite veins with sulphides is represented by stages fourteen to eighteen.

The pitchblende mineralization is developed in four stages. In one stage it is associated with native silver and native bismuth only, but not with arsenides; in a later stage it is paragentically developed with coffinite.

In group (2) of the deposits the pitchblende is associated with fluorite and iron oxides or hydroalumosilicates and iron sulphides. The typical alteration of host rocks is argillization and fluoritization, but no hematitization.

Table 9

Mineral sequence within a deposit
with pitchblende-arsenides mineralization
(after Strel'cov in Vol'fson, 1968)

Mineral/Stage	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Pyrite	—														—			
Pitchblende			—	—					—	—								
Native silver				—														
Native bismuth				—													—	
Rammelsbergite					—		—											
Chloantite					—													
Smaltite					—													
Niccolite						—												
Gersdorffite								—										
Safflorite								—										
Coffinite									—									
Arsenic and antimony (n.)												—						
Loellingite													—					
Sphalerite																—		
Galena																	—	
Chalcopyrite															—			
Tetrahedrite																	—	
Bismuthite																	—	
Quartz	—										—			—				
Calcite		—																—
Dolomite													—					

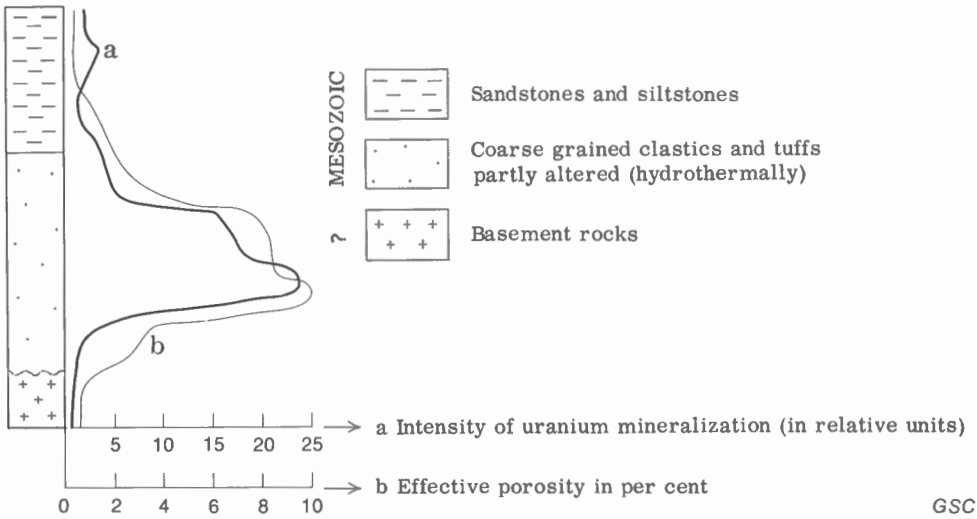

Figure 23. Relation between intensity of mineralization and porosity of rocks in a uranium deposit confined to Mesozoic complexes (U.S.S.R.) (after Pelmenev in Vol'fson, 1968).

Epigenetic uranium mineralization in sandstones

Distribution of uranium and other elements in Cretaceous deposits of the southern Aral Sea region was reported by Pavlov et al. (1968). A comparison of U, Cu, Ni, Pb, Cr, Ti, Zr and Ge, plotted separately for some arenaceous but mostly pelitic formations showed that the argillaceous formations comprise higher concentrations of these elements than the arenaceous ones. The highest uranium contents in Cenomanian pelitic rocks were attributed to the presence of boron compounds associated with uranium. The distribution of the above elements in various stratigraphic members is the result of differentiation, which was minor in Neocomian, increased in Aptian and reached a maximum in Albian formations, then it sharply decreased in Cenomanian and increased in Turonian and Senonian sediments. Pavlov et al. explained these changes as a result of chemical leaching of rocks. In this case the leached components might be deposited elsewhere. As may be concluded from the geological studies the Mesozoic complexes within the Aral Sea area and adjacent areas were favourable for formation of epigenetic types of uranium deposits similar to those in the Colorado Plateau.

Pel'menev (in Vol'fson, editor, 1968) correlated intensity of mineralization with physical-mechanical features of rocks and uranium deposit confined to Mesozoic complexes. He verified the correlation between the intensity of mineralization and the porosity of host-rocks (see Fig. 23). The favourable host rocks occur within the basal suite above the granitoid basement. The uranium-bearing rocks are represented by sandstones, partially cemented gravels, tuffs and conglomerates porosity of which reaches 8-12 per cent. Localization of uranium mineralization is controlled structurally by fault and fracture systems.

Mineralization and host-rock alteration processes occurred within this type of deposit during three stages: (1) formation of quartz, kaolinite, hydromicas, carbonates and pyrite, (2) formation of pitchblende, coffinite, pyrite, native arsenic, hydromicas and carbonates, and (3) formation of dickite, quartz, carbonates, minor barite, sphalerite, realgar, pyrite and other minerals.

Other types

Exogenetic uranium mineralization confined to Tertiary and Quaternary terrigenous sediments was mentioned by Korolev and Miguta (1961). Most of the uranium in sandstone is confined to its clayey fraction. Within the sandy fraction the uranium mineralization is confined to the grains of effusives and feldspar.

Sapozhnikov and Viselkina (1962) reported uranium mineralization in Neogene sediments represented by conglomerates, pink and grey sandstones, siltstones, clays and limestones. Uranium mineralization in this case is confined mainly to red-brown and red sandstones. Within the oxidation zone the most common uranium-bearing mineral is tyuyamunite, but within the cementation and primary zone it is sooty pitchblende and rarely pitchblende. The genesis of this type of deposit is supposed to be a result of syngenetic uranium accumulation in clastic sediments and its subsequent redeposition during diagenesis as well as during later weathering processes.

Gotman and Zubrev (1963) mentioned uranium mineralization in clays with fish-bone detritus, accompanied by phosphorus, iron, nickel, cobalt, molybdenum, rare-earths and gold. Uranium and rare-earths are sorbed by phosphate compounds of fish-bone detritus.

Uranium mineralization confined to hard bitumen within red beds in the U.S.S.R. was reported by Ermakov et al. (in Vol'fson, editor, 1968). Uranium bound to hard black bitumen occurs in sandstones. The distribution of orebodies is structurally controlled. The uranium-bearing black hard bitumen is accompanied by other types of bitumens as well as by iron and molybdenum disulphides. The post-ore mineralization is represented by lead, zinc and mercury sulphides, pyrite, calcite and fluorite.

As mentioned previously, several other types of uranium deposits and mineralization were reported from the U.S.S.R. and other East European countries. They will be considered when comparing the Canadian and East European uranium deposits in Part IV.

PART III

CANADIAN URANIUM DEPOSITS

INTRODUCTION

Canadian uranium deposits have been extensively described in the world geological literature. These geological works belong to the basic thesaurus of radiogeology but the variety and the importance of these deposits are so colossal that they may be an object of investigations for many generations.

It is not possible in this paper to list all publications and all scientists who participated in the geological investigations of the Canadian uranium deposits. Among the Canadian scientists who have made important contributions are, A.H. Lang, A.W. Jolliffe, S.M. Roscoe, L.P. Tremblay, H.V. Ellsworth, L.S. Beck, E.E.N. Smith and many others. From other countries a few geologists can be mentioned here, e.g. J.W. Gabelman, R.D. Nininger, V.N. Kotlyar and others.

For purposes of comparison of these deposits with the uranium deposits in the other parts of the world, a short description of geological features will be given. First of all the regularities of distribution of deposits and the laws of geological control in uranium mineralization will be analyzed, followed by the description of separate uranium areas and deposits.

Localization of uranium deposits and mineralization in Canada

Within recognized Canadian main natural regions (Lang, 1961) the uranium deposits and mineralization are distributed irregularly, but distinctive uranium-bearing areas can be distinguished (see Fig. 24).

The Canadian Cordilleran region (1)[1], which is geologically characterized by a northwest-trending fold belt, contains, so far as known small uranium deposits only. Known occurrences and deposits are distributed within the northwestern part (1a), middle (1b) and southeastern part (1c) of Canadian Cordillera.

Within the Plains (2) extensive uranium mineralization is known in the Cypress Hills area (2a).

The overwhelming number of uranium deposits and occurrences known in Canada are distributed within the Canadian Shield (3), which is often designated throughout the world as distinctive uranium metallogenetic province (Konstantinov, Kulikova, 1960), within which metallogenetic uranium subprovinces and zones are distributed. In this report the following uranium-bearing areas are mentioned: the Great Bear Lake area (3a), the Great Slave Lake area (3b), the Beaverlodge area (3c), the Athabasca basin area (3d), the Wollaston Lake area (3e), the group of occurrences within the southern part of Churchill (Structural) Province (3f), the group of occurrences within the western part of Superior (Structural) Province (3g), the Port Arthur (now Thunder Bay) area (3h), the Elliot Lake area (3i), the group of uranium occurrences within the southeastern part of Superior (Structural) Province distributed near the Grenville Front (3j), the Makkovik-Seal Lake area (3k) and the deposits and occurrences within the Grenville (Structural) Province (3l).

The uranium occurrences within the Canadian Appalachian region (4) form a separate group of localities.

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[1] Numbers in brackets correspond with numbers on Figure 24.

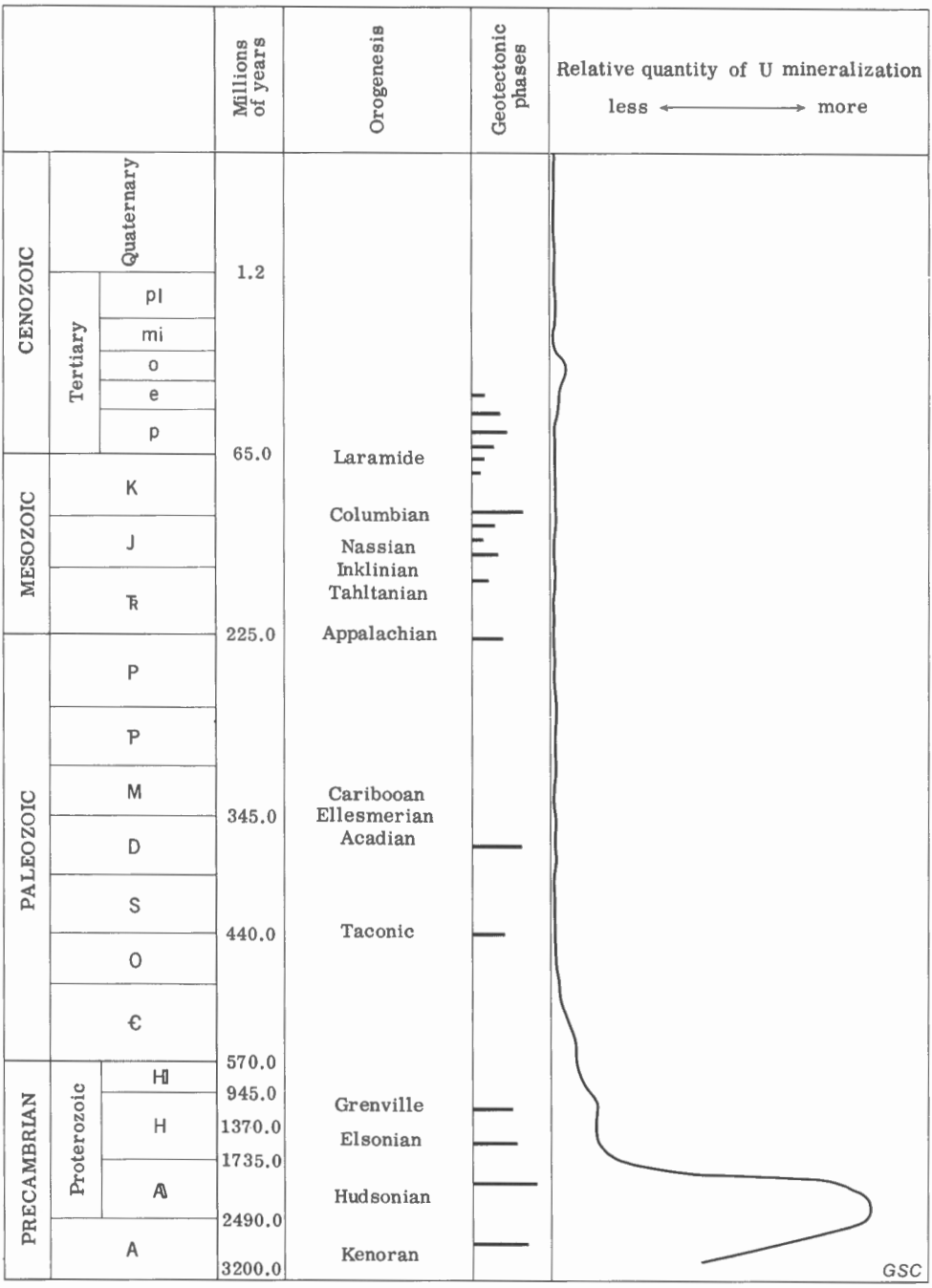

Figure 25. Occurrence of uranium mineralization in Canada according to the age of the host rocks. (Ore resources exploited and unexploited. Estimation made by V. Ruzicka on the basis of various sources, 1.1.1970.)

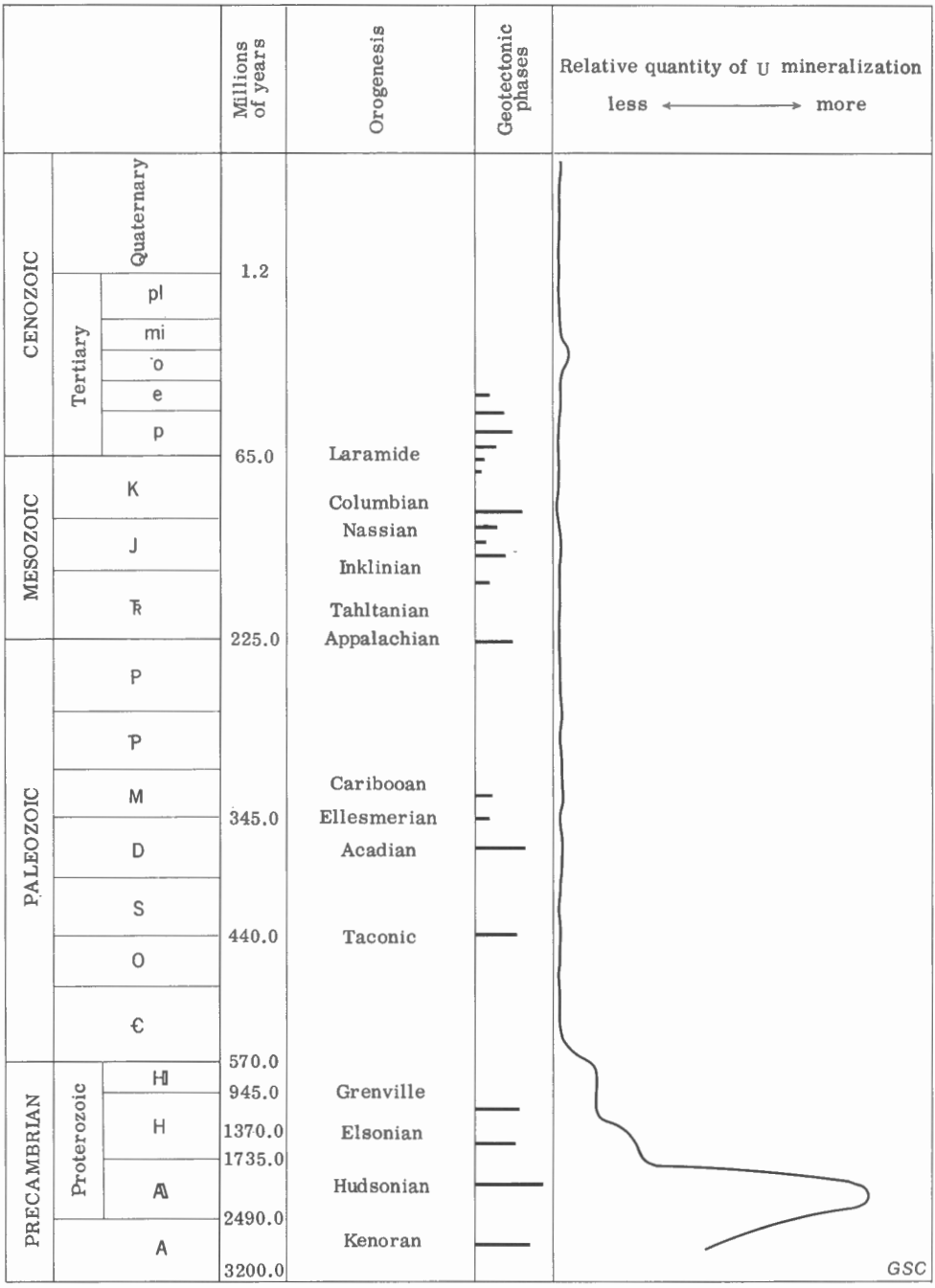

Figure 26. Occurrence of uranium mineralization in Canada according to the absolute age of the mineralization (representation). (Ore resources exploited and unexploited. Estimation made by V. Ruzicka on the basis of various sources, 1.1.1970.)

Within the Inuitian region (5) no uranium deposit is known at the present time, but a radioactive anomaly was identified in a specimen from Triassic beds from Ellesmere Island by the author of this paper.

In addition many radioactive anomalies and occurrences, which occur elsewhere than in mentioned uranium-bearing areas, are known in Canada.

Many geological factors can be investigated as controlling the occurrence of mineral deposits. As mentioned by P.C. Badgley (1965) the following factors may be important: (1) stage in the tectonic cycle, (2) proximity to igneous rocks, (3) proximity to major and minor structures, (4) correct level of erosion, (5) particular geological period and degree of regeneration of ore deposits, (6) favourable lithological units, and (7) favourable metallogenetic content in the earth's upper mantle which has prevailed since early in the earth's history. Some of these factors are more important in one district than in another. Kotlyar (1961) suggested the following regularities in the distribution of uranium deposits:

1. Uranium deposits are distributed within uraniferous metallogenetic provinces and belts. This distribution is probably influenced by primary endogenous processes. The uraniferous provinces and belts are confined to vast regional geotectonic units of the first order and they trend analogously with them.
2. Two types of uraniferous provinces and belts can be distinguished: (a) those that are confined to the Precambrian fold zones within the shields, and (b) those that are confined to Phanerozoic fold zones.
3. Each province has its own special features according to its geotectonical development.
4. Most of the uraniferous provinces and belts are affected by complicated geotectonic development (mainly expressed by repeated tectonic movements) and by the development of various types of deposits and mineralization which were formed during several stages.

Regularities in distribution of Canadian uranium deposits and uranium mineralization in Canada are mentioned from different aspects and for various areas by many Canadian geologists. A.H. Lang et al. (1962) discussed this question according to different types of deposits, their relations to metallogenetic provinces and subprovinces and their relations to rock types. S.C. Robinson (1958) concluded that although the major factor controlling the type of deposit is a genetic process, marked differences in type may also be due to structures in, and type of, host rock. He pointed to evidence of more than one period of mineralization. His genetic classification of Canadian uranium deposits together with other geological factors is an excellent tool for searching for regularities in distribution of uranium mineralization in Canada.

The author of this present paper has made an attempt to discuss some regularities in distribution of uranium mineralization in Canada from various aspects which were: relationships of geochronological positions of various mineralization periods and the orogenetic phases within tectonic cycles, structural control in the distribution of uranium deposits and mineralization, lithological control, proximity of different types of deposits to igneous rocks, distribution of genetic types of uranium deposits, and distribution of uranium deposits and mineralization within metallogenetic units and mineral assemblages within uranium-bearing areas.

Analysis of relationship between geochronological positions of mineralization periods and the orogenetic phases

The absolute age determinations of uranium minerals made possible several conclusions in the metallogenetic studies. For example the

absolute age determinations of uranium minerals from Witwatersrand defined the value of 3,100 m.y., which is close to the absolute age of monazite (3,160 m.y.) contained in detritus from the Dominion Formation and close to granitoids from the crystalline basement (3,200 m.y.), (Shcherbakov and Vol'fson, editors, 1966).

In Canada the absolute age determinations of uranium mineralization within uranium deposits fully confirmed the previous conclusions about various periods of mineralization and in many cases helped to solve the genesis of ore deposits (see Fig. 27).

The formation of uraninite belongs to the earliest periods of uranium mineralization (2,500 to 2,600 m.y.), (Roscoe, 1969) in Elliot Lake area. The uraniferous conglomerates containing that uraninite were formed during Huronian sedimentation, which closely followed the Kenoran Orogeny. The potassium-argon ages determined on orogenic micas from the Superior Province range from 2,230 to 2,730 m.y. with the maximal frequency at about 2,500 m.y. (Lowdon, 1961; Stockwell, 1964).

The interval between the Kenoran and Hudsonian Orogenies comprises two other periods of uranium mineralization, which have been identified; both of these periods are developed within the Churchill Province. The uranium mineralization there is confined to pegmatites and mafic portions of metasediments (V. Koeppel, 1968). The first period, which appears to correspond with the period of granitization, metamorphism and metasomatism of the Tazin Group, embraces the interval around 2,200 m.y. The second one, which is characterized by similar features, took place around 1,920-1,930 m.y. As mentioned by Stockwell (in Lowdon, 1961) a fair number of apparently reliable potassium-argon determinations fall within the range of 1,850 and 2,200 m.y., which apparently indicates a continuing orogenic activity (between the Kenoran and Hudsonian Orogenies).

The Hudsonian Orogeny with the peak at about 1,735 m.y. was accompanied by pitchblende mineralization within the Beaverlodge area. The first stage of epigenetic uranium mineralization within this area took place around 1,780 m.y. (Koeppel, 1968). The start of the Hudsonian Orogeny is roughly 1,850 m.y. (Stockwell in Lowdon, 1961).

According to Jory (1964) the uranium mineralization in the Great Bear Lake area occupies the interval between the Hudsonian and Grenville Orogenies. The isotopic data of pitchblende are grouped around 1,400-1,450 m.y. and to the interval from 1,200 to 1,300 m.y., although a few are only around 1,100 m.y. It is interesting that the first two groups coincide in time with Stockwell's proposed Elsonian Orogeny, which took place 1,280 to 1,460 m.y. The significance of the Elsonian Orogeny seems to be dubious for this part of Canadian Shield (King, 1969), although its evidence is present within the Nain and Southern Provinces. The above mentioned period is also evident as the Mazatzal Orogeny (1,120 to 1,540 m.y.) in the southwestern United States.

The next younger period of uranium mineralization ranges from 880 to 1,100 m.y. During this period the uranium mineralization in Beaverlodge, Great Bear Lake and Bancroft areas took place. According to Koeppel (1968) the first reworking of uranium epigenetic deposits in Beaverlodge area took place at this time (U-Pb age determination on pitchblende of Beaverlodge area shows the value 1,125 $\pm$ 20 m.y.). Robinson (1960) reported several age determinations of the uranium mineralization from Bancroft area and concluded, that the uranium deposits in the western half of the Grenville Province are generally similar in both type and

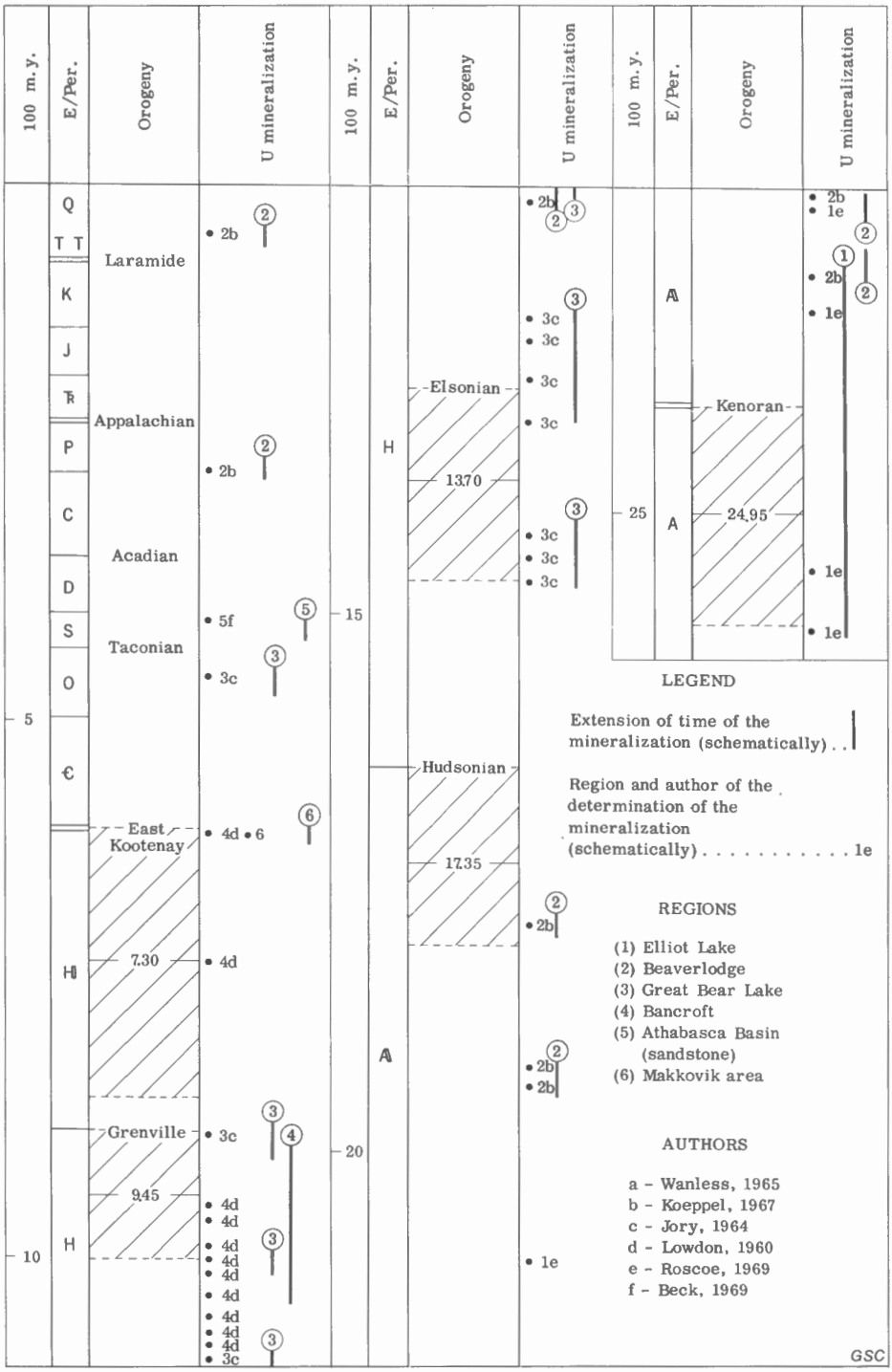

Figure 27. Ages of mineralization in Canadian uranium deposits.

age. This suggests a genetic relationship according to their distribution around granite intrusions and their similarity of age. The uraninite-thorianite ages are in the range 950 to 1,070 m.y. The uranium deposits in the Bancroft area are probably of the same age as the granite intrusions except for the Faraday granite, which is older. A similar value has been obtained on uraninite from Lac Pieds des Monts, Quebec (G.S.C. sample 59-86; 990 ± 20 m.y.; in Lowdon, 1960, 1961).

The above mentioned interval with uranium mineralization is also characteristic for the Grenville Orogeny. Most potassium-argon age determinations from the Grenville Province fall within the range of 800 to 1,100 m.y. (Stockwell in Lowdon, 1961).

During the above mentioned periods of uranium mineralization most of the uranium ores were formed, but the further periods of uranium mineralization appear to be related to orogenetic phases elsewhere. For example within the Beaverlodge area two more stages of uranium mineralization should be mentioned. The earlier coincides with the epeirogenetic uplift of the Canadian Shield and is synchronous with the main phase of uranium mineralization within several European uranium deposits related to the Variscan Orogeny. The absolute age of pitchblende from the Beaverlodge area belonging to this stage has been identified as 270 ± 20 m.y. (Koeppel, 1968). Roughly the same period of uranium mineralization occupies the "Group II" reported by Robinson (1955, p. 89). The ages of epigenetic deposits from the Beaverlodge area of the "Group II" vary around 290 m.y. (from 235 to 365). These ages are analogous with those of late Paleozoic orogenies. The latest stage of uranium mineralization within the Beaverlodge area occupies the interval from 100 m.y. ago to the recent time. It is characterized as the third reworking period of epigenetic uranium deposits.

Within the Great Bear Lake area the Paleozoic periods of uranium mineralization are also evident, but this question needs to be further investigated.

It is evident that the correlations between separate phases of the tectonic cycle and the periods of uranium mineralization can be done within genetically corresponding events only; on the other hand the age determinations of uranium mineralization, which are a sensitive indicator of several geological processes, can be successfully used in solving some geochronological and metallogenetic questions.

A diagram illustrating the geochronological position of various mineralization periods and the orogenetic phases within selected tectonic cycles is presented in Figure 27.

An interesting picture is provided by the chronological arrangement of uranium mineralization according to its absolute age and to its quantity[1]. The overwhelming quantity of uranium resources in workable deposits known at the present time occurs in the Precambrian Shield, but the absolute age determinations were done on samples from the main uranium deposits within the Canadian Shield, and new data may alter the diagram.

It is also interesting to note that the later stages of mineralization belong mostly to the rejuvenated generations of the originally Precambrian uranium mineralization.

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[1] The estimation comprises roughly the relative quantity of uranium ores recovered and recoverable.

Structural control in the distribution of uranium deposits and mineralization

Most endogenous uranium deposits are structurally controlled by lineaments and regional tectonic systems, and their distribution indicates some regularities.

There are excellent examples of structural control in the distribution of uranium deposits within the Canadian Shield. Some controlling features can be observed also within the Canadian Cordillera.

In selected uranium-bearing areas the following structural features and regularities in localization of uranium deposits can be distinguished.

The Great Bear Lake uranium-bearing area (3a on Fig. 24) is characterized by northeast-trending structures, including both folding and primarily fundamental fracturing.

The Early Proterozoic rocks within the Great Bear Lake uraniferous area have been folded during the Hudsonian Orogeny. The folding and the granitic intrusions took place during the late Aphebian. Of the same age the major lineaments are developed in this area. As mentioned by Lord (1951) these lineaments are very common features, and some, perhaps many, of them may mark other unrecognized faults of various magnitudes. The lineaments are roughly parallel and trend northeast (e.g. faults following Tilchuse River, Cameron Bay, Sloan River and Fault River). They are spaced about 12 miles apart (Campbell, 1955). This system of lineaments is one of the significant factors controlling the localization of uranium deposits on a regional scale within this area and uranium mineralization within deposits. Several times the rocks of Great Bear Lake area have been affected by tensional stresses, which initiated faults and fractures in various directions tectonically related to the northeasterly trending system. Among these fractures some of the southeasterly trending ones have been occupied by diabase dykes. The diabase dykes are of several different ages within the area. The earliest diabase preceded the pitchblende mineralization. The latest diabase is younger than the pitchblende mineralization (R. Murphy, 1948). The pitchblende mineralization within the Eldorado and Echo Bay mines is structurally controlled by vein-junctions as well as by diabase dykes (see Fig. 31). It is possible that such fracture systems analogous to the later ones, were controlling the localization of uranium deposits on a regional scale. Fahrig and Wanless (1963) pointed out the significance of diabase dyke swarms of the Canadian Shield. For example dyke swarm No. 7 extends over an area more than 1,000 miles long and locally more than 600 miles wide. In addition the age determinations of these diabases, although scarce, showed rough coincidence with the ages of the pitchblende mineralization. Thus, if this hypothesis were valid, the structurally favourable loci for localization of uranium deposits within the Great Bear Lake uraniferous area might be the intersections of northeasterly-trending lineaments with the fault and fracture systems, which have caused the opening of fractures simultaneously with the mineralization periods. The diabase dyke swarms and their intersections with the northeast systems can be the factor leading to discovery of other such places along the fundamental lineaments.

The distribution of uranium deposits and mineralization within the Beaverlodge area is also closely related to the structural features of the geological formations.

The basement complex is here characterized by northeasterly trending structures, which were imparted by the Hudsonian Orogeny. The Proterozoic cover (Martin Formation) is folded in broad folds, which have roughly parallel trends to those in the basement.

As mentioned by Beck (1967), Tremblay (1968) and by others, two generations of faults can be distinguished here: (1) the early faults confined to the basement complex and (2) the late faults commonly associated with the earlier ones. The fundamental northeasterly-trending faults of the basement were formed during the Hudsonian Orogeny and they are analogous with those within the Great Bear Lake area. They are also an important factor controlling the localization of uranium vein deposits.

Also other systems of faults and fractures, which are the results of multiple stresses and relaxations, control the localization of uranium mineralization. The intersections and joints of such systems are especially favourable for the setting of endogenous uranium deposits.

The Ace, Fay and Verna deposits are located along the St. Louis Fault, the Gunnar deposit is located close to the intersection of Zeemel, Iso and St. Mary's Channel Faults; an analogous setting of deposits can be observed along the Boom Lake Fault, Black Bay Fault, Crackingstone Fault, ABC Fault, Fish Hook Fault and along others.

It is also interesting to analyze the position and occurrence of orebodies within the Fay, Ace and Verna deposits. As illustrated in Griffith (1967, Fig. 97) the main orebodies are elongated in roughly parallel obliquely dipping directions. This morphological feature is structurally controlled by the junctions of St. Louis Fault with northwesterly-trending ABC, Larum and Radiore Faults. The continuation of the northwesterly-trending fault system can be found also outside of the above mentioned deposits. For example the ABC Fault has been identified in the northwestern extension cutting the Martin Formation; the Fish Hook Fault is developed southeasterly following this system. It is also interesting that roughly parallel directions are common to the several fracture systems, which have been intruded later by the diabase dykes within the Athabasca Basin. According to Fahrig (1961) the diabase dykes there are of Keweenawan age. These major fault systems are developed as regional structures that cut across belts of folding as well as intervening areas of granitic, igneous, and metamorphic rocks. The close relationship between the dykes of diabase and many of the faults implies (Byers in Stevenson, editor, 1962) that the fractures probably extend down to the base of the granitic layer of the crust.

If this conclusion is correct, and if we accept that movements along these faults have been many times repeated, then the presence of faults and fractures which were active during the mineralization periods might be also a significant structural factor controlling the localization of uranium deposits and mineralization also in the wide regional scale. (For the interpretation of this idea see Fig. 27.)

The northeasterly-striking fault systems are also important structural factors controlling the localization of uranium deposits in other uraniferous areas within the Canadian Shield. In the Great Slave Lake area (3b, Fig. 24) the Rayrock deposit is localized and spatially related to Marian River Fault; the northwest-striking system is present within this deposit and has a close relation to uranium mineralization (A. H. Lang et al., 1962).

The recently discovered deposit (3e, Fig. 24), the Rabbit Lake deposit in the Wollaston Lake uraniferous area is localized within the

northeasterly-trending fault system. The uranium mineralization is structurally controlled within this deposit. It is also interesting that the setting of this deposit coincides roughly with the hypothetical intersection of the northeasterly-trending fault system and the prolongation of southeasterly-trending diabase dykes intruding the sediments of the Athabasca Formation (Geological Map of Canada, Geol. Surv. Can., Map 1250A, Tectonic Map of Canada, Geol. Surv. Can., Map 1251A, King, 1969, and Fig. 24).

A possible relationship between the northeasterly-trending fault system of the Huron-Mistassini lineament (Grenville Front) and the epigenetic ore deposits in the Timiskaming area was mentioned by Lang (in Stevenson, 1962). The further extension of the Grenville Front to the Labrador coast was suggested by Robinson (1956). If this is correct, then several similar structural features within both Timiskaming and Makkovik-Seal Lake areas might be related to the Grenville Front and the distribution of several uranium occurrences arranged in an analogously trending zone explained. Beavan (1958) supposed that faults, at least those of the set striking northeast, might be the most probable loci for substantial ore deposits in the Kaipokok-Makkovik uranium area. The exploration work done by British Newfoundland Exploration Limited recently verified his supposition and showed further relationships between the roughly northeasterly-trending structures and the setting of uranium mineralization. As reported by Little and Ruzicka (1970) the pitchblende-bearing veins and disseminations that have been recently discovered occur mainly in a zone of tuff, quartzite, and argillite that extends southwestward from the Kitts deposit.

Some of the previously mentioned fold belts and fault systems within the Canadian Shield were grouped by Shcheglov (1968) as phenomena that are characteristic for the so-called regions of autonomous activization. Among several world examples of such regions he mentioned the Great Bear Lake, the Beaverlodge areas and the big tectonic zones in Quebec. He supposed that the processes of the autonomous activization represent an especial group of planetary structures confined to continents. This group is characterized by certain sedimentary, magmatic and ore formations. Such characteristics may lead to conclusions that the extent of the above mentioned structures within the Canadian Shield may be much wider than known. It can be supposed that the fault systems controlling the distribution of uranium deposits and mineralization may be extended beyond their presently known limits. For example on the Tectonic Map of North America (King, 1969) the East Arm Fault is traced southwesterly as transcurrent fault across Alberta Basin. Similarly Haites (1960) believed that transcurrent faults in Western Canada, particularly in the Interior Plains, are more common than was formerly assumed and that they constitute an important element of the fabric of this geological realm. Thus they can lead to discovery of new deposits.

Lithological control in localization of uranium deposits and mineralization

Regularities in localization of uranium deposits and mineralization in relation to lithological character of host rocks depend upon geochemical processes forming deposits. Therefore some regularities will be investigated according to the genetic types of deposits in this chapter.

A genetic classification of Canadian uranium deposits proposed by Robinson (1958) comprises the following types of Canadian uranium deposits: (1) granites, syenites, (2) pegmatites, (3) metasomatic deposits (general and fenites), (4) hydrothermal deposits, (5) placers, (6) conglomerates, (7) sandstones, (8) phosphate deposits, (9) carbonaceous deposits, (10) gossan cappings and (11) deposit traversed by meteoric waters. Little (1968) recognized (1) pegmatitic type, (2) vein and replacement type, (3) fenites, (4) conglomerates, (5) sandstones and (6) lignitic measures. Within this classification, which comprises the main types of deposits in North America, three types are most developed in Canada: pegmatites, veins and replacements, and conglomerates.

Uraniferous pegmatites occur (Little, 1968) in a high grade metamorphic environment where they are associated with gneisses, migmatites, amphibolites, and some other metamorphic rocks, and with granites of the katazone. The pegmatitic granite dykes, which were exploited economically within the Bancroft area, occur in country rocks that are dominantly amphibolites (Robinson, 1960).

Lithologically favourable host rocks within uranium-bearing areas with vein and replacement types of deposits of Canadian Shield appear to be in general basic and argillaceous rather than acidic and sandy rocks. For example more favourable host rocks for pitchblende deposition within the Beaverlodge area are basalts, amphibolites, hornblende schists, and hematitic and graphitic rocks (Tremblay, 1968). Similarly in the Great Bear Lake area the occurrence of pitchblende is related to diabase, argillites, and andesitic hypabyssal rocks, but also to granites as host rocks (Campbell, 1955). These relationships depend mainly on local geochemical factors.

The lithological character of rocks enclosing the deposits and the chemical composition of source rocks as well as the geochemical character and kind of transport of uranium-bearing solutions are the factors influencing the localization of deposits. Most of the vein deposits in Canada occur in Precambrian rocks. Many such deposits are in the lower part of the mesothermal or in the leptothermal range and therefore were not formed at deep levels (Little, 1968). Generally the younger rocks of the Canadian Shield are higher in uranium (Fahrig and Eade, 1968), which is explained as a secondary result of vertical chemical zoning of the crust and as a result of metamorphism accompanied by anatectic melting. The further concentration of uranium can be caused, as with other ore elements, by metamorphic processes, granitization, and the action of deep-seated brines and groundwaters. The chemical determinations of uranium made by the Geological Survey of Canada in various types of rocks from the Beaverlodge area suggests that the granitized rocks can be regarded as the immediate source of uranium for most of the epigenetic deposits in the area. A similar source could be the argillaceous rocks or their metamorphic derivates (Tremblay, 1968). Therefore the lithological character of the original rocks and their uranium contents are important factors controlling the distribution of uranium deposits. The presence of such rocks as amphibolite and basic host rocks favourably influenced the distribution of uranium mineralization within individual deposits.

Regularities in the distribution of uraniferous conglomerates are specific. Such conglomerates occur within very coarse grained argillaceous, feldspathic quartzites. They lie unconformably on granitic and metamorphic rocks, and are interlayered with volcanic rocks (Roscoe, 1969).

Both the vein types and conglomeratic types of uranium deposits within the Canadian Shield occur mainly in Proterozoic (mainly Aphebian) complexes.

Wambeke (1967) recognized a similar relationship of uranium deposits to Proterozoic rocks of the shield areas within two periods. To the first period (2,000-1,000 m.y.) belong the uranium conglomerates of the Elliot Lake area, the majority of the veins of the Canadian Shield, the uranium deposits of the Rum Jungle and the Mount Isa-Cloncurry districts in Australia. To the second period, which is extended to the lower Paleozoic, belong the deposits of the Katanga-Zambia belt, the South Alligator, Broken Hill and Pandanus Creek areas, Australia, and the occurrences of Malagasy. The Proterozoic sediments were laid down in geosynclines or intracratonic basins.

It is also interesting that many of the European uranium deposits in Massif Central, France, and in the Bohemian Massif, Czechoslovakia and East Germany, are distributed within the Proterozoic or Eocambrian complexes which lie adjacent to Variscan granitic intrusions.

Wambeke (1967) also mentioned, among several basic criteria for distribution of uranium occurrences in Precambrian geosynclines, the presence of acid/intermediate volcanic and pyroclastic rocks in the sequence. He observed that the formation of vein and pyrometasomatic deposits in many geosynclines appears to be linked to the pre-existence of uraniferous beds, with later redistribution and often concentration of the uranium by granitic intrusions, alkali metasomatism or hydrothermal activity.

Proximity of uranium deposits to igneous rocks

A spatial relationship between igneous rocks and uranium deposits can be observed in many uranium-bearing regions in Canada.

Within the Canadian Cordillera the Rexspar deposit (see Fig. 24) is localized close to granodioritic and granitic intrusions (Campbell, 1964) which are strongly differentiated. Uranium orebodies occur in trachytic effusives. The general trend of the orebodies is northeast, and corresponds with that of the main fault system in the area.

Within the Canadian Shield biotite granite intrusions in the Great Bear Lake area were emplaced slightly before the pitchblende mineralization. The granitic and granodioritic intrusions invaded the Echo Bay Group rocks. Granodiorite and quartz monzonite intrusions also occur near the Rayrock deposit, which is localized within Snare Group rocks in the Great Slave Lake area. The Snare Group is believed to be equivalent to the Echo Bay Group at Great Bear Lake (Lang et al., 1962).

Within the Beaverlodge uranium-bearing area Tremblay (1968) distinguished two types of granite, a metasomatic granite and an intrusive one. Both types were probably formed at the same time and possibly by the same process, the intrusive granite being the molten and mobilized parts of the metasomatic granite. The granites occur in rocks of the Tazin Group, which are the host rocks of epigenetic uranium deposits in this area.

The proximity of granitic intrusions is also characteristic for the epigenetic pitchblende deposit at Rabbit Lake in the Wollaston Lake area (see 3e, Fig. 24). The granitic intrusions, which are accompanied by pegmatite

appear to be differentiated. The main host rock of pitchblende mineralization, the meta-argillite, is strongly affected by hydrothermal alteration processes.

Within the northeastern part of Makkovik-Seal Lake uranium-bearing area (see Fig. 24) the Archean and Early Proterozoic rocks are intruded mainly by granitic igneous rocks. Gandhi et al. (1969) distinguished premetamorphic intrusions represented by granite and granodioritic gneisses, and postmetamorphic intrusions represented by granite, diorite to syenite, and gabbro. As reported by Beavan (1958) the coastal end of this area is characterized by a profusion of dykes including amphibolite, pegmatite, lamprophyre, and diabase. Uranium mineralization is present mainly in metasediments and its age on one sample of pitchblende was determined by the Geological Survey of Canada as 600 ± 30 m.y. (Beavan, 1958).

It seems probable that the granitic intrusions functioned as a source of heat more than a source of uranium-bearing hydrothermal solutions. On the contrary the uranium-enriched granitic rocks could also be a favourable source for mobilization of soluble uranium components, and their deposition as epigenetic deposits.

Distribution of uranium deposits and assemblages with uranium mineralization

Canada's uranium reserves largely occur in sedimentary rocks, mostly conglomerates; the rest belong to vein and other types of deposits. As reported by International Atomic Energy Agency in December 1967, all production from quartz-pebble conglomerates has come from Elliot Lake district of Ontario, whereas radioactive quartz-pebble conglomerates in the Northwest Territories, Quebec, Labrador, and Nova Scotia were expected to be prospected in the future (ENEA and IAEA, 1967). All production from vein-type pitchblende deposits has come from the Port Radium-Marian River district of the Northwest Territories and from the Beaverlodge district of northern Saskatchewan. The Montreal River district in Ontario, and the Makkovik district on the Labrador coast were prime exploration targets for deposits of this type. Radioactive pegmatites and related deposits have provided production from the Bancroft area of the southern Ontario, and have been explored and partly outlined in many sections of the Canadian Shield, the Cordillera, and the Appalachians. The sedimentary sequences of the Tertiary and Mesozoic Basins of the Cordillera and radioactive lignites in southern Saskatchewan have been recognized as other sources.

The overwhelming number of known uranium deposits are within the Canadian Shield whereas other areas comprise uranium occurrences or small deposits only. However this does not mean that the possibilities of discovering new uranium deposits are limited. On the contrary such areas are a potential source of uranium raw material especially in places with favourable conditions for (a) primary enrichment of rocks with uranium, (b) secondary accumulation of uranium by ore-forming processes.

Wambeke (1967) studied the distribution of uranium mineralization within the Precambrian shields and explained the presence of uranium deposits on the basis of the geological and paleogeographical evolution of sedimentary basins. Uranium occurrences in conglomerates, arenaceous, and carbonaceous rocks show a paleogeographical environment favourable for

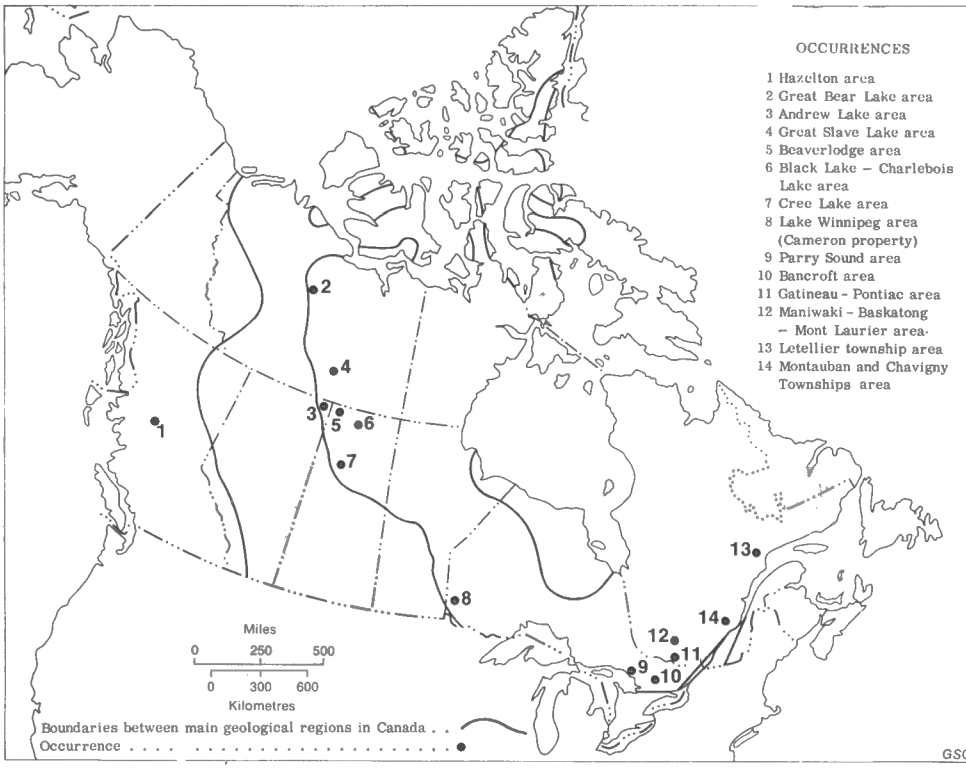

Figure 28. Distribution of the uranium-molybdenum association in Canada (compiled by V. Ruzicka from GSC Map 1045A, Vokes, 1963).

uranium mineralization in the marginal zones of basins, or at the boundaries of two geological units. In intracratonic basins uranium occurs preferably in sediments interbedded with acid or intermediate volcanics. The primary enrichment of Precambrian rocks during igneous and metamorphic processes was noted by Sterling et al. (1969). The average content of uranium increases regularly from 2.2 ppm U_3O_8 in granodiorites and diorites to 4.1 ppm U_3O_8 in quartz monzonites to 4.5 ppm U_3O_8 in granites. On the other hand the low grade metamorphic rocks contain 7.4 ppm U_3O_8 and the high grade metamorphic rocks 2.4 ppm U_3O_8. Significant correlations of radioactive elements between U and Th and Th and K have been found as results of both igneous and metamorphic processes.

The primary enrichment of Precambrian rocks in elements such as U, Th and K may be followed by enrichment due to weathering, transportation, sedimentation, diagenesis and metamorphism of such material in younger sedimentary basins. On the other hand the endogenous processes can multiply the accumulation of such elements and they can lead to formation of sources for uranium deposits.

Ore-forming processes

The Canadian Shield and many metallogenetic provinces in Canada are excellent examples of these ore deposit-forming processes. Typical ones will be discussed below.

Formation of uraniferous conglomerates

Roscoe (1969) made a comprehensive study of Huronian uraniferous conglomerates in the Canadian Shield and concluded that all features of radioactive conglomerates so far as he could determine, are consistent with the theory that they are essentially placer deposits. A significant feature of radioactive conglomerates is their iron content in sulphide rather than oxide form. The hematitic form is characteristic for various kinds of conglomerates of various ages. The pyritic form occurs in rocks which consist essentially of quartz and chert pebbles in a matrix of sericitic, feldspathic quartzite that contains grains of pyrite, titanium minerals, monazite and zircon. This form has been found only in rocks not younger than about 2×10^9 years.

The author's opinion is that the formation of uraniferous conglomerate in Elliot Lake area probably proceeded in the following cycles.

1. Primary concentration of metallic elements in pre-Huronian rocks. Evidence for this event can be seen in the characteristic features of these rocks. The granitic rocks from the vicinity of the source area for the clastics of the Matinenda Formation have similar properties to granitic rocks (e.g. in a U.S.S.R. deposit of similar type) which are supposed to be source rocks for this type of uranium deposit (Vol'fson, editor, 1968). They are differentiated, comprise higher quantity of potash and microcline and they contain higher contents of uranium and thorium. Pienaar (1963) mentioned several analyses of such rocks, which comprised: K_2O from 2.00 to 6.79 per cent, microcline from 13 to 33 volume per cent, and average uranium and thorium contents from 0.0011 to 0.0027 per cent. It is very interesting too that residual argillite beneath the Matinenda Formation comprises 1.7 to 4.3 per cent TiO_2, 9.4 to 11.0 per cent K_2O and 31 to 81 ppm ZrO_2 (two sample analyses mentioned by Roscoe, 1969).
2. The second cycle can be characterized by the release of metallic elements and minerals during weathering and erosion and their partial redistribution. The weathering conditions caused the separation of radioactive minerals (Roscoe, 1969), but also the leaching of uranium from rocks, which could be concentrated due to low temperature processes and under favourable conditions (writer's opinion).
3. The succeeding cycle was represented by syntectonic sedimentation, the evidence for which is indicated by the presence of volcanic rocks within the sequence, rapid facies changes and rapid thickening of units from the source area, soft-sediment deformation structures, and thickening, thinning, and erosion of sediments evidently related to warping and faulting in basement rocks during sedimentation (Roscoe, 1969). During this cycle the uranium ions and uranium-bearing minerals as well as uranium in colloidal form were transported and partly syngenetically deposited.
4. The diagenetic process caused further concentration of uranium components within the deposited clastic material. Both the third and the fourth cycles were accompanied by introduction of uranium contained in uranium-bearing solutions. These two stages occurred under nonoxidizing conditions. The presence of H_2S, FeS_2, TiO_2, hydrocarbon and others was favourable as geochemical environment for accumulation of uranium mineralization. Several authors (e.g. Kotlyar, 1961) supposed a metamorphic cycle, but Roscoe (1969) proved that processes attributed by these authors to the metamorphic phase belong to normal diagenetic processes. The mineral assemblage of the Elliot Lake deposits comprises uraninite, brannerite,

thucholite, uranothorite, uranothorianite, coffinite, allanite, xenotime and gummite as representatives of radioactive minerals. Pyrite is the most common nonradioactive metallic mineral. It is present in two generations (Roscoe, 1969); in one it is of detrital origin and in the other it is formed through diagenetic processes.

The position of the assumed source area for uranium mineralization can be an object of speculation. It is interesting that both the area of uranium deposits and the source area for clastic material contained within the deposits were affected by orogenic movements during the pre-Huronian periods. Syntectonic movements related to crustal movements accompanied the Huronian sedimentation. Finally the post-Huronian gabbroic intrusives, diabase dykes, and some faults follow the structural trends which are characteristic for the crustal structures. The whole area is affected by regional fracture systems some of which were occupied by diabase dyke swarms. If the repeatedly mobile character of such structures is assumed and the idea of analogous character with other structurally controlled uranium deposits within the Shield is accepted (e.g. Beaverlodge area), then it is possible to conclude that similar conditions might lead to primary enrichment of source rocks with uranium and thus to the first stage (cycle) of formation process mentioned previously in this chapter.

Formation of epigenetic vein-type deposits

Although this type of uranium deposits represents only a small part of Canadian sources of radioactive raw material, the regularities in distribution and the mineral assemblages of these deposits are most interesting. The hydrothermal veins and disseminations, a large class of deposits originated from hydrothermal solutions, can be classified from various points of view. Lang et al. (1962) distinguished two types: (a) those with simple mineral associations, and (b) those with complex mineral associations. In common classifications of this class of deposits the temperature of uranium-bearing solutions is considered. Kotlyar (1961) distinguished (a) davidite formation with iron and titanium minerals, (b) gold-molybdenite formation with allanite, monazite and uraninite, (c) iron-uranium formation which accompanies hematite-magnetite ores, (d) copper-uranium formation with Ni, Co and Se, (e) pitchblende-sulphides formation, (f) five-element formation (with detailed subdivision: uranium-nickel-cobalt-bismuth type, silver-nickel-uranium type, and silver-arsenic-uranium type), (g) pitchblende-fluorite formation, and (h) other types. Robinson (1958) used four groups for illustration uranium occurrences in Canadian hydrothermal deposits: (1) the hypothermal deposits of British Columbia, (2) the Eldorado mine on Great Bear Lake, (3) the Beaverlodge (Gold-fields) camp in northern Saskatchewan and (4) the Theano Point-Montreal River camp. From these examples Robinson recognized typical groups of minerals associated with pitchblende and other uranium minerals. He pointed also to the significance of principal gangue minerals. As characteristic minerals within the Canadian hydrothermal uranium deposits he listed pitchblende, thucholite, hematite, quartz, calcite, chlorite, chalcopyrite, galena, pyrite, arsenides, selenides and nolanite. As characteristic elements he reported U, C, Fe (Cu, Pb, S, V, Se, Co, Ni, As)[1]. The same kinds of minerals and elements were listed by Lang et al.

[1] Subdominant elements in brackets.

(1962) in the "Genetic classification of Canadian radioactive deposits". Within the hydrothermal class of deposits Au and Pt were added to the characteristic elements. Tananaeva (in Vol'fson, 1968) recognized the following as typical features for geochemical and mineralogical associations within uranium hydrothermal deposits. Pitchblende occurs as a rule with sulphidic compounds of Fe, Cu, Pb, Zn, Mo, Ag, Bi, As, Sb, in some types with arsenides of Co, Ni, and Fe, with the native metals Ag, Bi, Cu, As, Sb, with selenides of Cu, Pb, and Bi and with iron oxides. As noncharacteristic she recognized W, Sn, Be, Pt, rare earths, Li, Nb, Ta, Sc, Cs and Au. Characteristic minerals accompanying pitchblende are calcite, Mg, Fe, and Mn carbonates, quartz, sericite, chlorite, fluorite, barite, zeolites, anhydrite and some clay minerals.

As mentioned elsewhere in this paper a typical feature of this class of deposits is its development in several mineralization periods, whereby the rejuvenation of pitchblende or other uranium minerals occurred in most deposits.

Within the Port Radium deposit the uranium mineralization is mainly represented by pitchblende. Its deposition occurred during two stages, among which the earlier deposition took place predominantly in open space, whereas the later has predominantly a replacement character (Jory, 1964). The earlier deposition of pitchblende was accompanied by quartz and hematite deposition, the later by rhodochrosite, silver sulphides, native silver, native bismuth, hematite, and carbonates. (The sequential relations within the later stage are not fully certain.) The intermediate stages are represented by quartz and cobalt-nickel arsenides, chlorite and white mica, dolomite and sulphides of zinc, copper and lead.

The pitchblende mineralization within the Beaverlodge area was accompanied by hematite, calcite, chlorite, quartz, nolanite, arsenides, pyrite, chalcopyrite, galena, gold, bornite, selenides and copper (Robinson, 1955).

The pitchblende-bearing veins and breccia zones within the Rayrock deposit (see Fig. 24) contain pitchblende associated with hematite and minor amounts of pyrite and chalcopyrite (Byrne, 1957).

Pitchblende mineralization in the Rabbit Lake deposit within the Wollaston Lake area occurs as vein filling and encrustation on sulphide particles and quartz veins. Sulphides occur in trace amounts (see Fig. 24).

Pitchblende associated with hematite in calcite veins with small amounts of pyrite and lead and copper selenides occur in Theano Point-Montreal River deposits (Robinson, 1958 and Fig. 24). Two stages of mineralization were identified there, the first stage comprising pitchblende, and clausthalite in calcite and quartz gangue, and the second pyrite and galena with the same gangue material (Nuffield, 1956).

Pitchblende mineralization in carbonate veins within the Kitts deposit in Makkovik-Seal Lake area is accompanied by quartz and iron and copper sulphides.

Calcite-fluorite veins mentioned by Hewitt (1959) from Cardiff and Faraday Townships in the Bancroft uranium-bearing area contain uraninite, uranothorite, thorite, betafite and pyrochlore in assemblage with apatite, hornblende, pyroxene, scapolite, feldspar, magnetite, titanite and pyrite. Uranium mineralization appears to occupy its own separate stage within the vein-filling development.

The vein deposits in the Canadian Cordillera (Victoria, Little Gem, Index, Molly), which are near granitic and granodioritic intrusives, were formed during several periods of mineralization. The mineral assemblage in Little Gem deposit, which comprises the most developed mineral sequence among the above mentioned deposits, is represented by biotite, apatite, allanite, monazite, uraninite, orthoclase, cobaltite, loellingite, arsenopyrite, skutterudite, molybdenite, gold and gangue minerals quartz, chlorite, sericite and carbonates. Uraninite in association with apatite, allanite and monazite belong to the first stage of mineralization (Stevenson, 1951).

Other types of deposits and assemblages with uranium mineralization

A great group of granitic, syenitic, pegmatitic and migmatitic deposits is widespread in Canada particularly in Grenville Province, Superior Province, Churchill Province and in the Canadian Cordillera. But from the economic point of view the pegmatitic deposits in the Bancroft area are most interesting. There uranium mineralization is confined to pyroxene syenite pegmatite, porphyroblastic granite pegmatite, granite gneiss, pyroxene granite pegmatite and cataclastic quartz-rich pegmatite (Satterly, 1957). The principal ore minerals uraninite and uranothorite are commonly accompanied by other accessory minerals such as zircon, titanite, allanite, pyrite, molybdenite, fluorite, apatite, calcite, but rarely by pyrochlore, betafite, anatase, and umangite. The principal rock-forming minerals of radioactive dykes are soda plagioclase, microcline and quartz with minor pyroxene, amphibole and/or magnetite, rarely biotite.

Radioactive pegmatite from the Mount Laurier area[1] comprises locally an abundant quantity of allanite as the most common radioactive mineral (e.g. specimen taken from showing No. 2, Joliette Township).

Uranium mineralization in trachytic rocks from the Rexspar deposit in Canadian Cordillera is represented mainly by uraninite and/or uranothorite commonly intimately associated with rutile (Hughson, 1958, unpubl. rept.). The host rock is built up of a siliceous groundmass with feldspar and phlogopite. Sulphides (pyrite, chalcopyrite, covellite) and fluorite are in higher amounts, apatite, carbonates, and celestite in smaller amounts accompanying uraninite and uranothorite.

Pitchblende in a granulite host occurs in the Makkovik area. The granulite consists of plagioclase, clinopyroxene, hematite and apatite; pitchblende is transected by fractures which are healed with quartz and minor calcite. Also soddyite is present (specimen from near Michelin Camp, Labrador; mineragraphically analyzed by H. R. Steacy in 1969).

Among polymetallic type mineral assemblages the "five-element (i.e. Bi-Co-Ni-Ag-U) formation" is widespread in Canada. Its distribution is shown in Figure 29[2]. It occurs in Hazelton area in Canadian Cordillera (Rocher Déboulé occurrence), in Great Bear Lake and Beaverlodge uranium-bearing areas, in Port Arthur[3] area, in Michipicoten Island area, in Otter Township (Blind River) area. Numerous occurrences of this formation are present in Gowganda-Shiningtree, Auld-Cane-Elk Lake, Cobalt, Fabre

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[1] In another part of Grenville Province (see Fig. 24).

[2] The main elements in this formation are Ag, Ni and Co; uranium and bismuth are associated elements in some deposits only.

[3] Thunder Bay.

Township and Rabbit Lake-McDonald Lake areas (Geol. Surv. Can., Map 1233A). In addition it is interesting that the spatial distribution of the above mentioned formation roughly corresponds (within the Canadian Shield) with some of the hypothetically presumed structural trends, which might be interpreted as crustal lineaments partly healed by diabase dykes.

The uranium-molybdenum association is also widespread within Canadian deposits and occurrences. Its distribution is shown in Figure 28. In the Canadian Cordillera it is represented in the Hazelton area by a complex assemblage of molybdenite, arsenopyrite, cobaltite, cobalt-nickel sulph-arsenides, chalcopyrite, sphalerite, gold and uraninite (e.g. Victoria Group; Vokes, 1963) in hornblende, feldspar and quartz gangue. Within the Canadian Shield the uranium-molybdenum association is present in Great Bear Lake, Andrew Lake, Great Slave Lake, Beaverlodge, Black Lake-Charlebois Lake, Cree Lake, Lake Winnipeg and Parry Sound areas. Several deposits and occurrences within the Grenville Province of the Canadian Shield carry uranium accompanied by molybdenum mineralization, e.g. in Bancroft, Gatineau-Pontiac, Maniwaki-Baskatong, Mont Laurier and other areas (see Geol. Surv. Can., Map 1045A-M3). This assemblage occurs in vein, metamorphic and metasomatic, pegmatitic and combined or miscellaneous types of deposits.

Pitchblende is mostly accompanied by iron (especially hematite) and sulphide minerals. The common uranium-thorium association prevails in hypothermal types of deposits and usually has a paragenetical character. Uranium and vanadium mineral assemblages are characteristic for sedimentary types of deposits, but they are known in veins in Beaverlodge area too. A beryllium and uranium mineral assemblage occurs, for example, in Seal Lake area, and Nb-Ta-Mn-Zr-U-Th in Kapuskasing area. A uranium-titanium mineral assemblage occurs in the Rexspar deposit. Other assemblages are mentioned elsewhere in this paper.

Uranium-bearing areas or areas with uranium mineralization (as mentioned in the introduction) are as a rule a part of large metallogenetic regions, areas, zones or ore-districts. In some areas metallogenetic zoning appears to be present.

The northwestern part of Canadian Cordillera (1a)[1] is represented by gold, silver, copper, lead-zinc, tungsten, nickel, uranium and beryllium mineralization. Uranium mineralization is developed within the Atlin and Lincoln Creek areas. It is interesting that this area roughly coincides with the intersection of the hypothetical prolongation of northeasterly trending structural systems from the Great Bear Lake area of the Canadian Shield and northwesterly-trending systems of the Cordillera.

The central part of the Canadian Cordillera (1b) comprises several metallogenetic areas mentioned by Lang (1961): the Hazelton and Skeena Mountain areas (with silver, copper, lead, zinc, gold, molybdenum, cobalt, tungsten, barium, nickel, manganese, uranium and thorium mineralization irregularly developed in scattered localities), the Omineca Mountains and Interior Plateaux, with a significant belt of mercury occurrences structurally controlled by the Pinchi fault zone and other ones. Uranium mineralization is developed in scattered occurrences as well as mineralization of thorium, arsenic, antimony, beryllium, manganese, strontium, copper, lead, zinc, molybdenum, tungsten, platinum, iron and chromium.

The southeastern part of the Canadian Cordillera comprises mainly the Shuswap Terrane (in sense of Little and Smith, 1968, an area of granitic,

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[1] Numbers in brackets refer to Figure 24.

syenitic, pegmatitic and migmatitic deposits). It is characterized by many intrusions, among which the Nelson Batholith and the Coast Intrusions are the largest. Uraniferous occurrences are of vein, replacement and conglomeratic types. The latest type is represented by uraniferous conglomerate which consists of roundstones of pre-Tertiary rocks in a sandy matrix carrying secondary uranium minerals (mainly meta-autunite). In the vicinity of above mentioned uranium occurrence, occurrences of gold, silver, zinc, lead, antimony, chromium and copper are present. It is interesting that this area (1c) is localized at an intersection of the hypothetical prolongation of northeasterly uranium mineralization controlling structures in the Canadian Shield to the southwest and of the northwesterly-trending tectonic systems of the Canadian Cordillera.

A uranium-bearing area within the Plains is developed in southwestern Saskatchewan and is represented by Oligocene sediments of the Ravenscrag Formation. Uranium mineralization is confined mainly to the upper seam of lignitic beds. It appears to be of similar origin and analogous genesis as that within the lignitic uranium deposits in North and South Dakota. Within the same area radioactive spots were measured by author and by H.W. Little within the Frenchman Formation (Cameron et al., 1969).

The Great Bear Lake uranium-bearing area (3a) was recognized by Lang (1961), Lord (1951), and Jolliffe (1952) as a metallogenetic province or subprovince extending eastward from Great Bear Lake and southward to the north arm of Great Slave Lake. Konstantinov and Kulikova (1960) recognized the Great Bear Lake uranium subprovince which comprises (1) hypothermal deposits of native copper (in Coppermine River area) and (2) vein type deposits of four formations: (a) quartz-barite-chalcopyrite veins, (b) quartz-calcite-chalcocite veins, (c) quartz-hematite-pitchblende veins, and (d) manganese spar (rhodochrosite) deposits. Within the Great Bear Lake area in sensu stricto they distinguished three main metallogenetic zones: a north copper zone, a central uranium-pitchblende zone and a south uranium zone with uranium mineralization partly influenced by pegmatites.

The Great Slave Lake uranium-bearing area (3b) comprises parts of Yellowknife, East Arm, Taltson, and Nonacho areas in Lang's sense. Generally uranium mineralization can be classified in two groups in this area, pitchblende in veins and related deposits, and uranium-bearing pegmatites or related deposits. Within the pegmatites near Ross Lake Hutchinson (1955) observed regional zonation based on structural, physical and chemical factors. Lithium-bearing pegmatites were found farther from the batholithic hearth, whereas columbium-tantalum bearing bodies are closer. However, no regularity in distribution of radioactivity related to the regional zonation was verified.

The Beaverlodge uranium-bearing area (3c) comprises syngenetic and epigenetic types of deposits. The first group is characterized by uranium mineralization confined to faults or to subsidiary structures adjacent to faults. According to Robinson (1955) pitchblende in epigenetic deposits is associated with the following minerals: (1) hematite, chalcopyrite, pyrite and galena in gangue composed of calcite, chlorite, and quartz, (2) copper selenides with clausthalite and native copper, and, locally, copper, cobalt and nickel sulphides, (3) arsenides and sulpharsenides of nickel, cobalt and iron, and (4) gold, but rarely.

Another group of deposits contains nickel sulphide with pyrrhotite, pyrite, and chalcopyrite, but without uranium.

On the regional scale the uranium mineralization of both syngenetic and epigenetic types is accompanied by nonradioactive deposits, among which some form separate zones. Such nonradioactive deposits within the area between Tazin and Black Lakes are: copper in sedimentary gneisses near Tazin Lake; a northeast-trending zone of rare-earth pegmatites; and farther east a zone with gold-bearing quartz veins and lead-zinc mineralization in calcareous rocks. The eastern part of this area (i.e. that near Black Lake) comprises gold-bearing quartz veins, a northeasterly-trending zone with copper-nickel mineralization in noritic rocks and sedimentary iron-formation (Beck, 1964).

The Athabasca Basin uranium-bearing area (3d) does not include many explored uranium occurrences. Uranium mineralization was found in the sediments of the Athabasca Formation on Stewart Island forming pitchblende veinlets in altered Athabasca sandstone. Pitchblende veins that cut the Athabasca Formation are reported by Fahrig (1961). Favourable regional structures, especially fault zones, in the basement below the Athabasca Formation, as well as favourable lithological environments in the Athabasca sedimentary sequence are favourable loci for formation of uranium deposits of various types within this area. However, as reported by Lang (1961) the uranium occurrences known to have been found in this region were a few uranium occurrences only which at that time were classified as of supergene type. The author of this paper does not agree fully with Lang's opinion concerning the unfavourableness of the Athabasca Plain and thus in this report, the Athabasca Basin is ranged as a separate uranium-bearing area within the Canadian Shield.

The Wollaston Lake area (3e) coincides practically with the northeasterly-trending fault-system which is a structural belt controlling the distribution of uranium deposits analogous to the northeasterly-trending systems within the Great Bear Lake, Great Slave Lake, Beaverlodge and other areas of the Canadian Shield. However the stage of exploration of this area does not permit conclusions regarding the character of uranium mineralization.

The uranium-bearing area within the southern part of Churchill Province (3f) is a part of one of the leading metal-producing areas in Canada. Lang (1961) characterized the whole southern part of Churchill Province as a large segment containing northeasterly-trending belts of folded sedimentary and volcanic strata of early Precambrian types, separated by large areas of granitic and gneissic rocks. He recognized two belts of nickel occurrences, a large area of gold occurrence and smaller areas of zinc and copper occurrences. Uranium occurrences known at the present time are prevalently of the pegmatitic type but the presence of Proterozoic (especially Aphebian) complexes and the presence of regional fault systems, which are analogous with other ore-controlling systems within the Canadian Shield, are favourable geological features for occurrence of other types of uranium deposits within this area.

The group of occurrences within the western part of Superior Province (3g) is also prevalently pegmatitic. These occurrences are scattered mainly in the Red Lake and Lake of the Woods area. An area is characterized by several large easterly-trending belts of Archean complexes which contain mainly gold and iron deposits. The gold deposits are as a rule of mesothermal vein type (Whitmore et al., 1967).

The Port Arthur[1] uranium-bearing area (3h) comprises several uranium occurrences (Port Arthur, Greenwich Lake, Mountain Bay, Marathon)

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[1] Now Thunder Bay.

mainly of vein and pegmatitic types. The presence of Proterozoic complexes, ore-controlling fault-systems, and of the "five-element" mineralization makes the Port Arthur uranium-bearing area similar to the Great Bear Lake and some other areas in Canada.

The Elliot Lake uranium-bearing area (3i) in sensu lato comprises several types of uranium deposits; the conglomeratic and the vein types were mentioned previously. The pegmatitic and related types as well as undifferentiated ones are mentioned by Lang et al. (1962) as subdominant. The radioactive deposits and occurrences are accompanied by nonradioactive ones within this area. The latter occupy several mineral zones and form larger groups of nonradioactive mineral assemblages. (Compare Ontario Department of Mines Map 2108 and Preliminary Map P. 105 (second edition).) From the western to the eastern part of the area (i.e. from the Montreal River to Sudbury districts) the uranium mineralization is surrounded by copper, lead-zinc-silver, bismuth-cobalt-nickel, molybdenum, gold, iron, and especially in the eastern part, with nickel mineralization. The distribution of some of the nonradioactive mineral assemblages (e.g. Pb-Zn-Ag) appears to be structurally and lithologically controlled.

Lang et al. (1962) discussed the localization of the Elliot Lake conglomeratic type of uranium deposits. He mentioned two possibilities for their origin: (1) the ores may have resulted entirely from erosion of rocks relatively high in uranium and from localization of detrital sediments, (2) the ores may be partly a result of subsequent alteration or deposition, and their position may be related to the general belt of epigenetic gold and base-metal deposits extending from Lake Huron to the Chibougamau area. The author's opinion was mentioned elsewhere in this paper. It can be supported by analogous geological conditions participating in forming another conglomeratic type deposit in the Canadian Shield - in Padlei area in Northwest Territories, mentioned by Little and Smith (1968).

Within the southeastern part of Superior Province (3j) which lies adjacent to the Grenville Front, innumerable occurrences of gold, copper, zinc, silver, lead, molybdenum, lithium, iron, bismuth and tungsten and several occurrences of nickel, cobalt, chromium, beryllium, thorium, niobium, platinum and tin occur. Only minor uranium occurrences are known at the present time (Lang, 1961).

The Makkovik-Seal Lake area (3k) is predominantly built up of Proterozoic formations. Archean gneisses represent the basement and Phanerozoic formations are represented by lamprophyre dykes and Cenozoic till, gravel, sand and clay (Gandhi et al., 1969). Uranium mineralization is represented by pitchblende, uraninite and pyrochlore. Molybdenite mineralization was reported by Vokes (1963), and widespread copper occurrences, native silver, and silver-rich sulphide mineralization by Beavan (1958). In addition Gandhi et al. (1969) listed within the Makkovik Bay area fluorite and molybdenite, chalcopyrite, pyrite, galena and sphalerite as sulphidic mineralization representatives. The Seal Lake area comprises uranium mineralization in association with berylium and other elements (e.g. occurrence 65 on Geol. Surv. Can. Map 1218A). Pyrochlore is a common uranium-bearing mineral here. Beryl, eudidymite, sphalerite and a niobium mineral are characteristic minerals in the sodic paragneiss host rock.

The Grenville Province as a uranium-bearing area (3ℓ) comprises several localities such as Bancroft district with several uranium deposits and occurrences, Sharbot Lake-Palmerston Township area with uraniferous

pegmatitic dykes, the Pontiac-Gatineau area, Mont Laurier area, Charlevoix area, Seven Islands, and others. Within the Bancroft district according to Robinson (1958, 1960) the following types of uranium deposits of igneous types are distinguished: (1) granites and syenites, (2) pegmatites, (3) metasomatic deposits (a) general, and (b) fenites. Other localities comprise mostly pegmatitic type uranium occurrences. Analogously the gold, zinc, lead, titanium, molybdenum, beryllium and other mineral occurrences are prevalently of pegmatitic and metasomatic types.

The Appalachian uranium-bearing area (4) is a part of the Appalachian tectonic belt which was formed in the southeastern margin of Canadian Shield. Gabelman (1968) distinguished several mineralization cycles corresponding with different tectonic cycles in the North American Appalachian region. Each cycle had its own mineralization pattern controlled by tectonism rather than by igneous or hydrodynamic processes alone. Lang (1961) also recognized relations of mineral occurrences to different orogenies within the Canadian Appalachians. Most of the occurrences are related to the Devonian (Acadian) intrusions or orogeny. Copper in New Brunswick and copper, lead and zinc in Nova Scotia appear to be related to the Appalachian Orogeny. Uranium mineralization is widespread, but the radioactive anomalies and occurrences known at the present time, are scattered, and several of them not yet fully explored.

Some structural and lithological features as well as metallogenetic events related to orogenetic cycles were favourable for mineral deposition and for uranium mineralization respectively within the Innuitian region (5). However, no uranium deposit is known within this region at the present time. Incomplete radiometric measurement of Geological Survey paleontological collections in Calgary and Ottawa showed heightened reading of specimens taken from the Mesozoic beds in Svartfjeld Peninsula (Ellesmere Island)[1]. Fluorimetric analysis of a small part of a specimen (which is an ammonoid of Triassic age collected by R. Thorsteinsson from the Blaa Mountain Formation) indicated 40.0 ppm of uranium. Gamma-ray spectrometric analysis[2] of the whole two specimens indicated:

Table 10

No. of Specimen	RaD ppm	U ppm
1	95.4	68.7
2	64.3	67.1

A great number of radioactive anomalies and occurrences as well as favourable conditions in uranium-bearing and other metallogenetic areas mentioned by Little (1968), Roscoe (1965), Lang (1962), and Gabelman (1969) indicate huge possibilities in uranium exploration in Canada. However, the regularities in the distribution of uranium deposits, their types as well as their general geological features need further analytical and synthetical studies among which the present paper is a small contribution only.

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[1] However, the thickness of the ammonoid bed represents 1 foot only (E.T. Tozer, pers. comm., 1970).

[2] Done by L. Ostrihansky, G.S.C. laboratory, 1969/1970.

GEOLOGICAL FEATURES OF URANIUM MINERALIZATION IN SELECTED CANADIAN LOCALITIES

For the purposes of comparison between geological features of Canadian and East European deposits with uranium mineralization following localities were selected:

1. Cordilleran region: in the southeastern part of Canadian Cordillera (1c)[1], Rexspar property, Fuki and Donen prospect.
2. Plains: Cypress Hills near Eastend (2a).
3. Canadian Shield: in the Great Bear Lake area (3a), Eldorado Mine, Echo Bay Mines, Contact Lake Mine, Precambrian Exploration occurrence;
   in the Great Slave Lake area (3b), Rayrock deposit;
   in the Beaverlodge area (3c), Fay, Verna, Bolger and Hab properties, Gunnar Mine;
   in the Athabasca basin area (3d), Stewart Island and Carswell dome occurrences;
   in the Wollaston Lake area (3e), the Rabbit Lake deposit;
   in the Elliot Lake area (3i), Denison, Quirke and Agnew Lake deposits;
   in the Makkovik-Seal Lake area (3k), Kitt's deposit, Michelin and other occurrences;
   in the Grenville Province (3l), Faraday Mine and occurrences in the Bancroft area, Sharbot Lake zones, Mont Laurier occurrences.
4. Appalachian region: anomalies in New Brunswick and Nova Scotia.
5. Innuitian region: Ellesmere Island anomaly.

Most of these localities were visited by H. W. Little and by the author during 1969.

Rexspar property

The Rexspar uranium deposit (No. 13, Fig. 24) occurs in an area underlain by the metamorphic complexes. Greenstone, trachytic members (tuffs, breccia, flows), argillite (commonly black), and schists occur near the deposit (Campbell, 1964; Joubin and James, 1956). All metamorphic rocks are folded. Two systems of faults are characteristic in the vicinity of the Rexspar deposit: (1) shear zones which are parallel to the bedding of tuffs, and (2) block faults occurring at several places in the ore zones.

The orebodies occur in the trachytic member. They are present in northeasterly-trending radioactive zones (the "A" strikes 15 degrees and the "BD" zone 30 degrees). Recent prospecting showed a further extension of these zones and the presence of another in addition to those reported by Lang et al. (1962).

Mineragraphical investigations done on representative bulk samples from the "A" and "BD" zones pointed out that the uranium and thorium mineralization is mostly confined to uraninite and uranothorite which are commonly associated with rutile. Chemical analyses of these samples showed the following composition (Hughson, unpubl.):

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[1] Numbers in brackets refer to numbers on Figure 24.

Table 11

U_3O_8 (chem.)	0.093%
ThO_2 (chem.)	0.12%
U_3O_8 secondary	0.021%
Ti	0.12%
V_2O_5	less than 0.03%
S	11.75%

Nonradioactive minerals in the deposits are represented by mica, feldspar, sulphides, fluorite, carbonates, celestite, and rutile (Joubin and James, 1956). Hematite was identified in a hand specimen taken by the author in 1969.

The uranium mineralization is accompanied by thorium and is scattered within the ore. The distribution of radioactive minerals which are of replacement type is shown in autoradiograph (see Plate VI, VR-102).

Spectrographic analyses[1] made in the Geological Survey laboratory of a hand specimen showed following results (data in per cent):

Table 12

Ti	Mn	Sr	Ba	Cr	Zr
7.00	0.07	0.02	0.01	0.01	0.3
V	Ni	Ce	Cu	Y	Co
0.1	0.003	0.7	0.03	0.03	0.005
La	Th	Sc	Yb	U	
0.5	0.05-0.2	0.05-0.2	0.003	0.5	

The specimen was taken from the core of a diamond-drill hole that intersected a radioactive zone of the Rexspar deposit. Although the spectrographic analyses of a hand specimen taken from the core of a diamond-drill hole intersecting a radioactive zone of the Rexspar deposit are semiquantitative only, they show significant amounts of titanium, strontium, zirconium, cerium and lanthanum, a fact that might be used in geochemical prospection.

Fuki-Donen prospect

The Fuki-Donen prospect (see Fig. 24, No. 108) is on Dear Creek about 32 miles north of Rock Creek, British Columbia.

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[1] The analyses are expressed semiquantitatively. Wavelength interferences were caused by extensive complexity of specimens thus some data must be interpreted with reservations. This remark also refers to other analyses of hand specimens mentioned in this paper.

The uranium mineralization occurs in conglomeratic beds overlying the Marron Group (Daly's Midway Volcanic Group).

Uraniferous conglomerates are interbedded with thin clayey and silty thin beds which dip about 15 degrees and trend about 335 degrees. The conglomerate is polymictic with an arkosic matrix and is overlain by olivine basalt. The roundstones consist mainly of andesite and trachyte. The matrix contains limonitic and carbonaceous material (see Plate I).

The uranium mineralization is represented by secondary minerals and the main uranium mineral identified by X-ray diffraction method is meta-autunite, which is bound to the matrix and appears to have an epigenetic character.

A specimen, collected by the author, spectrographically analyzed in the Geological Survey laboratory, showed following results:

Table 13

Sr	Ba	Cr	Zr	V	Ni
0.015	0.3	0.003	0.03	0.007	NF
Ce	Cu	Y	Nb	Co	La
NF	0.01	<0.003	NF	NF	NF
Pb	Th	Sc	B	Yb	Be
NF	NF	<0.001	NF	<0.001	0.0005
U	Mo	Bi	Ag	Sn	
0.3	NF	NF	NF	NF	

The presence of some of the above mentioned elements completed by others on the basis of sufficient number of analyses might be a useful tool for interpretation of geochemical data in prospection for uranium.

Cypress Hills area

Uranium mineralization in the Cypress Hills area (near Eastend, Saskatchewan (see Fig. 24, No. 2a)) is mainly confined to carbonaceous trash layers and lignites of the Ravenscrag Formation which is here represented by thick, continental beds of finely bedded silts, fine sands and lignitic seams with interbedded shales that overlie the Frenchman Formation and are overlain by the Cypress Hills Formation (Furnival, 1950). The Ravenscrag Formation is of Paleogene age and is correlated with the Fort Union Formation in the Dakotas (Cameron and Birmingham, in press).

The uranium mineralization is irregularly distributed and the uranium contents are variable. The thickness of the uranium-bearing beds does not reach more than several feet. According to a personal communication of G. Jarry, the average content in seventy borehole intersections of uraniferous

orebodies is 0.42 lb U_3O_8/ton. The uranium mineralization appears to be of epigenetic origin, sorbed on carbonaceous material from the uranium-bearing solutions derived from leaching of tuffaceous material. As reported by Cameron and Birmingham (in press) volcanic ash has been observed interbedded with lignite at St. Victor and in association with the Cypress Hills beds near Duncairn (Fraser et al., 1935).

The extension of uranium mineralization in the Cypress Hills area is substantial, but the uranium content in the lignites is low and the uraniferous beds are thin.

A spectrographic analysis of selected hand specimen taken at 49°29'35"N and 108°51'25"W (see Plate II) showed following results:

Table 14

Sr	Ba	Cr	Zr	V	Ni
0.01	0.02	0.005	0.02	0.01	0.005
Ce	Cu	Y	Nb	Co	La
NF	0.003	0.005	NF	NF	NF
Pb	Th	Sc	B	Yb	Be
NF	NF	NF	NF	<0.001	0.0007
U	Mo	Bi	Ag	Sn	
0.5	NF	NF	NF	NF	

Although the analyses are semiquantitative only, the U/Th ratio as well as the association of present elements might testify to an epigenetic and low temperature origin of mineralization. Some of the elements were mentioned also in the section about uranium deposits in carbonaceous sediments in Czechoslovakia.

The Great Bear Lake uranium-bearing area

Within the Great Bear Lake uranium-bearing area (Fig. 24, No. 3a) in sensu lato the following complexes are developed. The oldest complexes can be divided into three fundamental groups: Echo Bay, Cameron Bay and Hornby Bay Groups. The oldest known rocks belong to the Echo Bay Group, which consists of the lower, predominantly sedimentary complexes, and of the upper, prevalently volcanic rocks. The Cameron Bay Group overlies the Echo Bay Group, and is built up of sedimentary rocks, predominantly of conglomerates. The Hornby Bay Group, which is composed mainly of sediments, overlies unconformably the Cameron Bay Group and is unconformably overlain by Phanerozoic complexes. Several intrusions were identified within the area; the oldest are plutonic and hypabyssal and the youngest are hypabyssal. Granitic and porphyritic rocks were emplaced between deposition of the

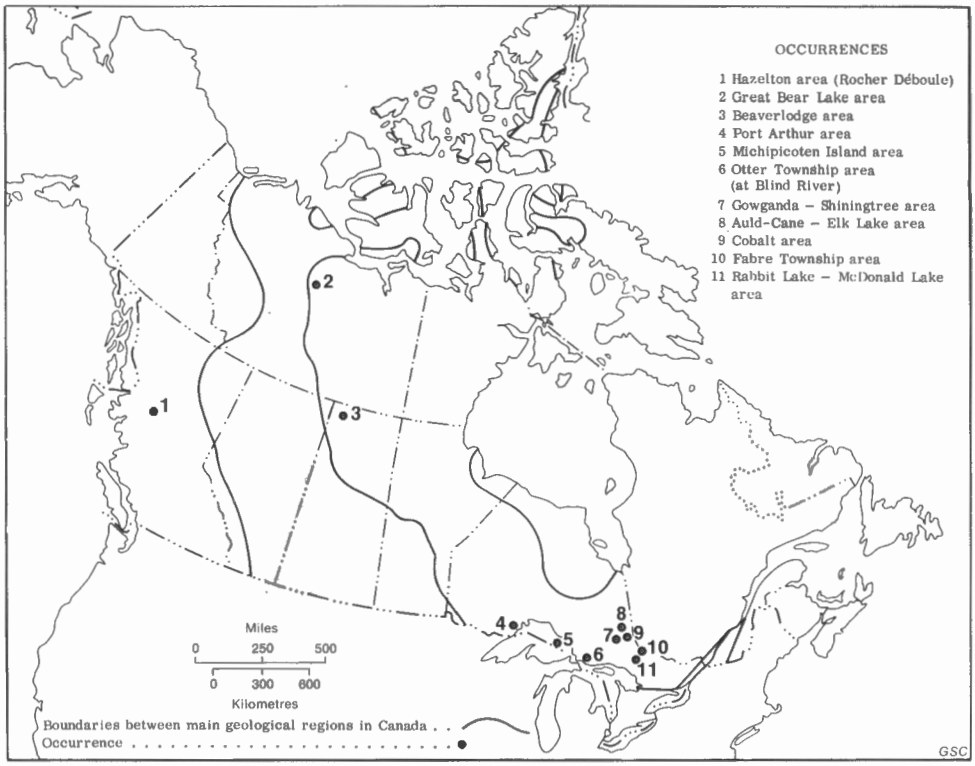

Figure 29. Distribution of the "five-element" (i.e. Bi-Co-Ni-Ag-U) mineral "formation" in Canada (based on GSC Map 1233A; compiled by V. Ruzicka).

Cameron Bay and Hornby Bay Groups and occurred repeatedly. Diabase dykes are the youngest igneous rocks and occupy all of the known major fracture systems and are of various ages.

The general features of the folding are represented by northeast trends within the Precambrian complexes. They are related to the earlier granitic intrusions and the subsequent uplift is affected by this trend. At least four fault systems are recognizable within the area: the northeast system (30-60 degrees), the east, northwest, and north systems. The northeast system belongs to the prominent and fundamental tectonic elements in the area. The northeasterly trending faults and fractures or faults and fractures related to that system were occupied by giant quartz veins, diabase dykes, and a succession of veins (Jory, 1964).

As mentioned previously the uranium mineralization in the Great Bear Lake area is confined to vein zones and accompanied by several metallic and nonmetallic mineral assemblages. The mineralization of veins occurred during several stages. The hydrothermal alteration accompanied several mineralization stages and affected host rocks as well as the previously deposited vein minerals. The vein mineral sequence and the sequence of the wall-rock alteration minerals are shown in Table 15.

Table 15

Mineral sequence and the mineralization stages in the Port Radium (Eldorado) deposits, Great Bear Lake, District of Mackenzie (after Jory, 1964)

Vein minerals	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6
Apatite	—					
Quartz	——	——	— - —			
Hematite	——	—	-		—	—
Pitchblende		——				—
Ni-Co arsenides			——			
Pyrite				—		
Chlorite				——		
White mica				——		
Barite					—	
Siderite					—	
Dolomite			—		——	
Sphalerite					—	
Tetrahedrite					—	
Bornite				——	——	
Chalcopyrite				—	——	
Galena					—	
Calcite						—
Rhodochrosite						—
Silver minerals						——
Native bismuth						—
Wall-rock alteration minerals						
Apatite	—					
Microcline	——					
Hematite	——					
Quartz	— —					
Chlorite				——		
White mica				——		
Pyrite				—		
Chalcopyrite				—	—	
Carbonates					—— -	—

The pitchblende mineralization stage followed the quartz-hematite stage. It was also accompanied by deposition of quartz, but Campbell (1955) reported the pitchblende deposition directly on the walls of the fissures. The deposition of quartz interstitially localized among pitchblende spherulites was also reported by him. Cyclic precipitation of pitchblende and quartz was common at the peak of the pitchblende deposition. This cycle was repeated at least three times. The siliceous uranium-bearing solutions were followed by carbonate containing solutions which probably redeposited pitchblende and deposited lead-zinc, copper, silver, bismuth and Ni-Co arsenides. The sulphidic minerals occupy mainly the fourth and the fifth stages of vein mineralization.

The alterations of host rocks as well as of the vein minerals of the preceding stages may be recognized by hematitization, argillization, chloritization, carbonatization, partly silicification, sericitization, sulphidization, and concentration of apatite (Campbell, 1955). The latest stages as well as the first stage of mineralization are characteristically accompanied by alternation processes. Hematitization ("red staining") was reported by Fortier (1948) from Glacier Lake (Port Radium, Great Bear Lake) area as widespread, but nowhere as marked as in the vicinity of LaBine Point and is most intense along fractures and faults. It belongs mainly to the first stage of vein mineralization. The argillization is later then hematitization and is also a common kind of wall-rock alteration. Chloritic alteration is also common. It is developed along fractures; the diabase and the ferromagnesian rocks are most intensely affected by that type of alteration. Carbonatization is widespread in all rock types, but it appears along certain parts of certain veins only (Campbell, 1955).

Regularities in distribution of uranium mineralization within the Great Bear Lake uranium deposits (or within the deposits with uranium mineralization) depend upon structural, lithological and geochemical conditions existing during the mineral deposition.

A schematical sketch of pitchblende-bearing vein system shows the interrelationships of veins in the Eldorado (Port Radium) (see Fig. 30).

Campbell (1955) suggested that the Bear Bay shear is the principal one in the northeasterly-trending regional fault system. The Bear Bay shear is a shear zone, 5 to 20 feet in width, filled with brecciated rock, clay, hematitic and/or chloritic material with a small quantity of gangue and vein mineralization. It is a first order dislocation, to which the other veins (No. 1 to 8) are spatially and genetically related. This relationship is analogous to that at Příbram in the Central Bohemian massif and the Bear Bay shear may be compared to the Děda or Dubenec-Druhlice faults.

Structural control of ore deposition is evident in places of greater tensional opening on the fracture zones. Such cases are developed in the vicinity of major bends or branches of the vein zones and in rocks favourable for fracturing and maintaining open spaces. Campbell (1955) observed a close correlation between different stages of mineralization and fracture openings in the Port Radium vein zones. The first (quartz-hematite) stage is represented extensively in Bear Bay shear, No. 1 vein and in the western parts of the No. 2 and 5 veins. The pitchblende-quartz and quartz-arsenides stage (i.e. the second and the third stage shown in Table 15) occupy practically all zones in various places, but not the Bear Bay shear. The chlorite stage (stage 4 in Table 15) is also represented in all zones in various places. The carbonate-sulphide-Ag-Bi stages (i.e. stages 5 and 6) are represented in the vertical members of the system, i.e. in the Silver Island (No. 8) vein, No. 2a vein, and locally in the No. 3, 5 and 7 veins. A schematical sketch showing distribution of different stages is shown on Figure 30. But a characteristic feature in the mineralization sequence and distribution is the superposition and telescoping of several mineral assemblages (stages) in one vein. Campbell reported that there is no regular correlation between uranium, silver and copper contents and this was verified in the Echo Bay deposit, which is adjacent to the Eldorado. Analyses of the bulk-samples, taken in different places, in Echo Bay Mine showed following:

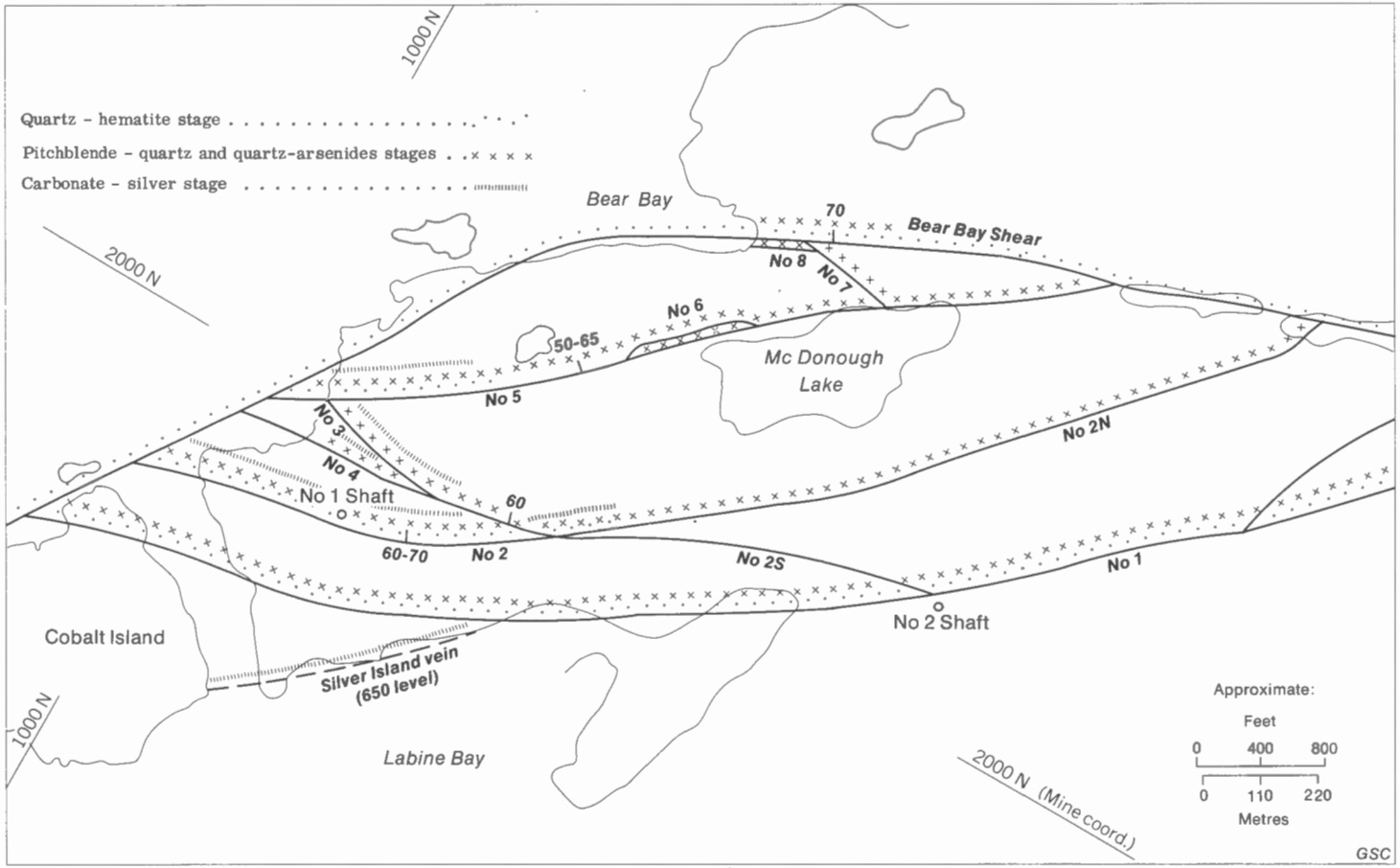

Figure 30. Sketch showing the distribution of different mineralization stages in veins - Port Radium deposits, Great Beat Lake (after Campbell, 1955).

Table 16

Location of the sample: (datum)/weight/ton	Ag content oz. /ton	Cu content %	U content %
No. 3 adit level (May 1969)	7.01	0.79	0.19
No. 206A drift (May 1969)	17.15	0.24	0.27
No. 206A W drift (July 1968) /501 ton/	38.6	1.16	0.35
No. 206A E drift (July 1968) /236 ton/	113.5	1.15	0.36
No. 206 E drift	241.0	0.6	1.26
No. 302-2 T.D.B. (March 1969) /123 ton/	199.8	0.91	1.04

Remarks: Results of analyses provided by Echo Bay Mine geologist, 1969.

The mineral succession indicates that the character of mineral-bearing solutions changed from lower values of pH to higher ones. The solutions, which came in several pulses, changed not only their acidity, but also their mineral content. According to Campbell (1955) the transport of uranium took place in an aqueous solution containing bicarbonate, carbonate and oxygen. Uranium was present in its hexavalent form. It is apparent that the transport of uranium in those solutions occurred under high pressure and high temperature. The decrepitation tests on the Port Radium pitchblende and on the accompanying quartz showed the possible crystallization of the quartz ranging up to 400°C. The release of CO_2 pressure in uranyl-carbonate solution was a significant factor in the precipitation of the uranium as pitchblende. The characteristic gangue mineral of the quartz-hematite-pitchblende stage (the second stage shown in Table 15) is quartz, whereas carbonate is the characteristic gangue mineral in the later generation of pitchblende. This fact may be explained by chemical equations mentioned by Barsukov et al. (in Vinogradov, 1963):

$$(1)\ \left[UO_2\,(CO_3)_3\right]^{4-} \rightleftarrows UO_2^{2+} + 3CO_3^{2-}$$

whereby Eh of uranyl complex is equal -0.32 to -0.39 volt (values by different authors). However, in the siliceous environment the hydrolysis of SiO_2 (in the presence of CO_2) will change equation (2) to equation (3)

$$(2)\ HCO_3^- \rightarrow OH^- + CO_2$$

$$(3)\ HCO_3^- + SiO_2 \rightarrow HSiO_3^- + CO_2 \nearrow .$$

If the equilibrium between uranyl carbonate solution and UO_2 in relation to CO_2, and pH is within certain limits illustrated in Figure 34, then carbonate remains in soluble form, and quartz is deposited simultaneously with pitchblende. These processes were characteristic for the earliest phase of pitchblende deposition. The latest phase occurred under conditions of higher values of pH and lower values of Eh.

Lithological control in the distribution of pitchblende mineralization in the Great Bear Lake area and especially within the Port Radium

pitchblende deposits was the subject of many studies and discussions. Campbell (1955) mentioned that the physical differences of the wall-rocks, but not the chemical differences, have produced favourable localities for pitchblende deposition. However, some exceptions could be observed where the wall-rocks consisted of calcareous or carbonaceous components. Also high contents of alumina in the host rocks could influence the deposition of pitchblende. Similar point of view was mentioned by Jory (1964). "The veins have different characteristics in different rock types. All appear to be severely restricted in width on entering the granite. For example the No. 1 vein and Bear Bay shear tend to have more or less uniform widths through all rock types except in the post-ore diabase sill. The other veins are restricted in the more competent rock bodies such as the porphyries than the sedimentary rocks."

The host rocks where the pitchblende mineralization occurs have varied lithological characteristics. Such rocks are tuffs, metamorphosed cherty sediments, andesites, granites, argillites, diabases, feldspar porphyries and other rocks of the Echo Bay Group. The hydrothermal alteration processes affected the host-rocks, which again reacted with the later hydrothermal solutions. The stratified rocks appear to be most favourable host rocks for the pitchblende deposition. As in other vein deposits, such as those in Erzgebirge, the lithologically favourable loci for ore deposition occur where there are rapid changes in the oxidizing-reducing nature of the mineralizing solutions due to the influence of the host rocks.

The problem of source for uranium-bearing solutions may be discussed by summarizing the geological events in the area and analyzing the geochemical relationship between the mineral composition of the deposit and the chemical-petrological composition of possible source-rocks. As mentioned previously and as quoted by several authors (Fortier, 1948; Jolliffe and Bateman, 1944; Campbell, 1955; Jory, 1964; Mursky, 1963), the geological events in the Great Bear Lake uranium-bearing area can be characterized as follows: (1) formation of Echo Bay and Cameron Bay Groups consisting of cherts, quartzites, bedded tuffs, fragmentals, conglomerates, shallow-water argillites and arkoses, and volcanics, (2) intrusion of acidic igneous rocks such as feldspar-hornblende porphyries, quartz-eye porphyries, quartz monzonites, latites, aplites, and biotite granites, (3) deposition of Hornby Bay Group, consisting of sandstone, quartzite, conglomerate, and limestone, (4) intrusions of diabase dykes and sills, (5) metallic mineralization introduced by thermal solutions (earlier stages), (6) intrusions of diabase dykes and sills, (7) metallic mineralization (the latest stage), (8) deposition of Phanerozoic strata.

Mursky (1963) studied petrological, mineralogical and geochemical relations in the Great Bear Lake area and concluded that the granitic rocks are consanguineous with the porphyries some of which exhibit the peculiarities of ignimbrites. The igneous rocks are about 1,800 million years old and the main stage of uranium mineralization in veins is about 1,400 million years old. This disproportion led to difficulties in accepting the conclusion that there is a connection between uranium mineralization and exposed granitic rocks. On the other hand the intrusions of diabase dykes took place at about the same time as uranium mineralization. Mursky concluded therefore that the crystallization of a subjacent uranium-bearing magma could release uranium-bearing fluids and, at the same time, could give rise to dykes which, depending on the stage during which the mineralizing solutions are expelled, would be represented by different metal assemblages characteristic of the

stage of differentiation in the magma. In such cases uranium was released very early. Mursky's investigations of trace elements in different kinds of rocks of Great Bear Lake area showed that they are enriched up to several times in comparison with similar rocks in the earth's crust. Therefore those enriched rocks could be also a source for mineralizing solutions.

The pitchblende mineralization is characteristic of all vein type deposits within the Great Bear Lake uranium-bearing area. Campbell (1955) listed several types of textures which have analogous features as pitchblende ore found elsewhere as for example in the Boulder Batholith deposits, Marysvale, and Joachimsthal (Jachymov).

To illustrate the textural features of the pitchblende mineralization from the Great Bear Lake uranium-bearing area some autoradiographs are shown on Plate VI.

Spectrographic analyses of specimens taken by the author from various localities in 1969 showed following results:

Table 17

	Si	Al	Fe	Ca	Mg	
(1)	1.00	0.7	5.00	10.00	3.00	
(2)	0.5	0.2	5.00	3.00	10.00	
(3)	10.00	1.00	7.00	3.00	0.07	
	Ti	**Mn**	**Sr**	**Ba**	**Cr**	**Zr**
(1)	0.02	2.00	0.01	0.05	<0.002	0.07
(2)	NF	1.5	NF	0.003	0.003	NF
(3)	0.05	0.15	NF	0.05	<0.002	0.01
	V	**Ni**	**Ce**	**Cu**	**Y**	**Nb**
(1)	0.03	0.015	0.1	0.5	0.07	NF
(2)	0.01	0.02	0.2	0.5	2.00	NF
(3)	0.03	NF	0.2	0.2	0.1	NF
	Co	**La**	**Pb**	**Th**	**Sc**	**B**
(1)	0.02	0.02	0.1	NF	0.007	<0.008
(2)	0.3	0.02	0.1	NF	0.007	NF
(3)	0.01-0.1	0.15	1.00	0.05-0.2	0.005	<0.008
	Yb	**Be**	**U**	**Mo**	**Bi**	**Ag**
(1)	0.005	NF	0.7	NF	NF	0.1
(2)	0.2	NF	1.00	NF	0.2	0.007
(3)	0.005	NF	1.00	NF	NF	0.015

(1) Echo Bay adit No. 2.
(2) Contact Lake mine.
(3) Trenches of Precambrian exploration.

Although the analyses are semiquantitative only, the presence of some metallic elements in specimens from three different localities point to similar metallization processes within a broader area.

Rayrock deposit

The geological features of this deposit (see Fig. 24) are similar to those of the Great Bear Lake area.

The host-rocks of uranium mineralization are represented by quartzite, dolomite, argillite, chert and mica schist of the Snare Group, of Proterozoic age, which is analogous to the Echo Bay Group at Great Bear Lake. The Snare Group is intruded by granites, granodiorites and quartz monzonites. The fault pattern is principally analogous to that within the Great Bear Lake area. The prominent Marian River Fault strikes northeast, the representatives of the northwest system are the younger faults.

The pitchblende mineralization is accompanied by specular hematite, pyrite and chalcopyrite. The alterations of host rocks are hematitization, epidotization, silicification and chloritization (Lang et al., 1962).

Beaverlodge uranium-bearing area

The area (see Fig. 24, No. 3c) is a part of the Churchill Province of the Canadian Shield. It is built up of two main Precambrian formations, the Tazin Group and the Martin Formation. The Tazin Group is characterized by metamorphosed rocks such as quartzites, amphibolites, granites, quartz-feldspar gneisses and garnet-bearing rocks. The Martin Formation is younger (probably Aphebian) and comprises basal conglomerate, arkose, siltstone, basaltic flows, and gabbroic sills. Gabbro dykes trend mainly west-northwesterly and are characteristic in the area north of the Black Bay Fault. They cut all rocks except the youngest which overlie the Martin volcanic flows (Tremblay, 1968).

The rocks of the Tazin Group were folded during the Hudsonian Orogeny. The characteristic structural trends follow the northeast directions. Intense deformation of the Tazin Group occurred before the more gentle folding of the Martin Formation. As mentioned previously in this paper two major periods of faulting may be recognized in this area: the earlier which is represented by wide zones of mylonitic and brecciated rocks and confined to the Tazin Group, and the later which is represented by clean-cut fractures and confined to all complexes of this area. A significant feature in this area is that the faulting was reactivated many times.

Uranium mineralization occurs in two main forms, as syngenetic, confined chiefly to the pegmatitic type of uranium deposits, and as epigenetic, confined chiefly to the pitchblende vein type.

Regularities in the distribution of uranium deposits and mineralization were mentioned previously in this paper. Further significant features in the localization of uranium deposits and mineralization can be recognized as follows:

1. The syngenetic mineralization is confined to areas with minor faulting and little or no mylonitization of the bedrock; such areas were designated as stable blocks by Beck (1967). The epigenetic mineralization is confined to areas with intense faulting, brecciation, mylonitization and characteristic folding; such areas Beck designated as linear belts.
2. Distribution of epigenetic deposits is structurally controlled; structural control is evident also in the localization and in morphological features of the pitchblende orebodies.

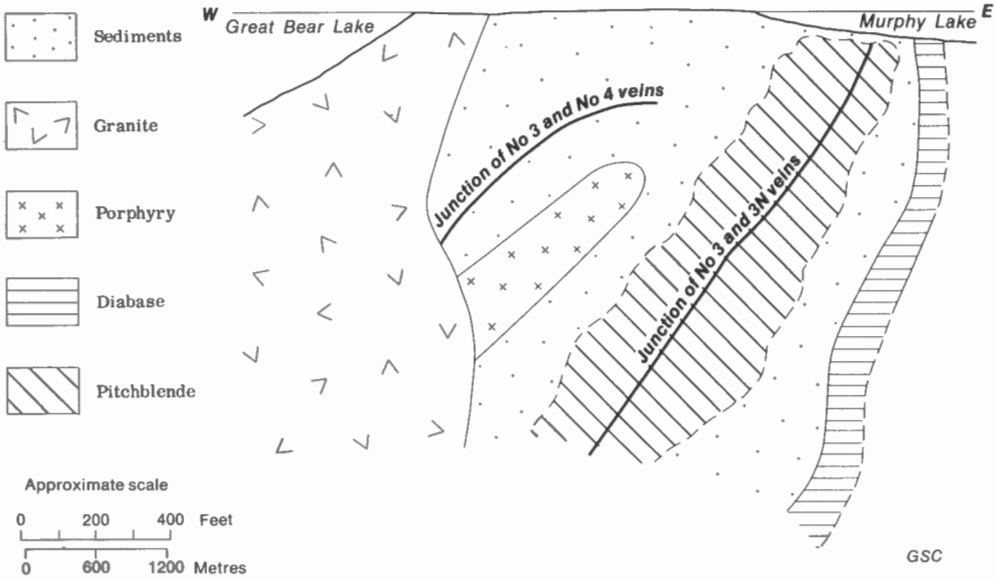

Figure 31. Schematical longitudinal section of No. 3 vein Eldorado Mine–Great Bear Lake–Northwest Territories (after geological mine documentation).

3. Uranium mineralization took place during at least six periods (Koeppel, 1968); the earliest two periods were syngenetic and the later ones epigenetic.
4. The mineralizing solutions forming the epigenetic deposits changed their physical and chemical character.
5. The solutions affected wall-rock alterations.

The general factors that control localization of ore deposits were mentioned in previous chapters. Regularities in localization of pitchblende mineralization will be demonstrated on some examples from selected uranium deposits. For comparative purposes and for the purpose of genetic classification the sequence of events in deposition of the epigenetic uranium deposits will be discussed.

Robinson (1955), on the basis of field and laboratory investigations, derived the following succession of minerogenetic events:

1. The initial stage characterized by brecciation and mylonitization, followed by feldspathization and hematitization.
2. Introduction of pitchblende and nolanite accompanied by calcite and chlorite as gangue minerals. Hematite was redeposited.
3. Deposition of pitchblende contemporaneously with hematite, chlorite and locally quartz and nolanite. Deposition of arsenides, sulphides and calcite.
4. Pitchblende with calcite, chalcopyrite, pyrite and galena.
5. Deposition of selenides, pitchblende and calcite.
6. The latest phase characterized by late hematite, late pitchblende, calcite, chlorite and native copper.

(See Table 18.) In addition to the minerals mentioned secondary uranium minerals as well as thucholite occur in smaller amounts.

Table 18

The minerogenetic sequence of more common ore-forming minerals from uranium deposits within the Beaverlodge uranium-bearing area (after Robinson, 1955)

Stage:	1	2	3	4	5	6
Oligoclase and Albite	—					
Hematite	—	—	—		—	—
Calcite		—	—	—	—	—
Chlorite		—	—	—		—
Quartz		—	—		—	
Nolanite	—	—	—			
Pitchblende		—	—	—		—
Arsenides			—	—		
Pyrite	—		—	—		
Chalcopyrite				—		
Galena				—		
Gold				—		
Bornite				—	—?—	
Selenides					—	
Copper						—

On the basis of Robinson's studies it may be concluded the physical and chemical character of mineralizing solutions suffered change. The pH gradually increased while Eh changed from positive to negative values. Similarly the temperature of mineralizing solutions decreased from about 500°C to about 150°C or lower.

Rock alteration phenomena are represented mainly by hematitization, chloritization and epidotization. Silicification, carbonatization, and albitization are less intensive developed within the uranium deposits. Edie (1953) investigated the relationship between pitchblende mineralization and rock alteration and concluded that in Goldfields (Beaverlodge) area the dominant types of alteration vary from place to place; the most intense alteration is restricted to the immediate vicinity of fault or breccia zones; hematitization (red alteration) is most widespread, but several stages of different types of alteration are often present. As reported by Tremblay (1968) the hematitization in the Beaverlodge area took place in several periods. The hydrothermally introduced hematite represented probably a minor part of red alteration here. Chloritization probably followed hematitization; as with hematitization, chloritization took place also in several periods. Epidotization occurs mainly as veinlets. As mentioned by Tremblay (1968) epidotization occurs in Tazin rocks only and is thought to be a product of the main hydrothermal metamorphism in the area, and closely related in time of formation to the regional metamorphism of Tazin rocks. The rest of rock alterations (silicification, carbonatization, albitization, introduction of carbon, and sericitization) occur as a rule in minor quantities; their occurrence depends upon rock character and varies also within the area.

As in Great Bear Lake uranium-bearing area the rocks of the Beaverlodge area have a high uranium content. For example argillite, chlorite schists, and impure quartzites contain (based upon 14 specimens, Tremblay

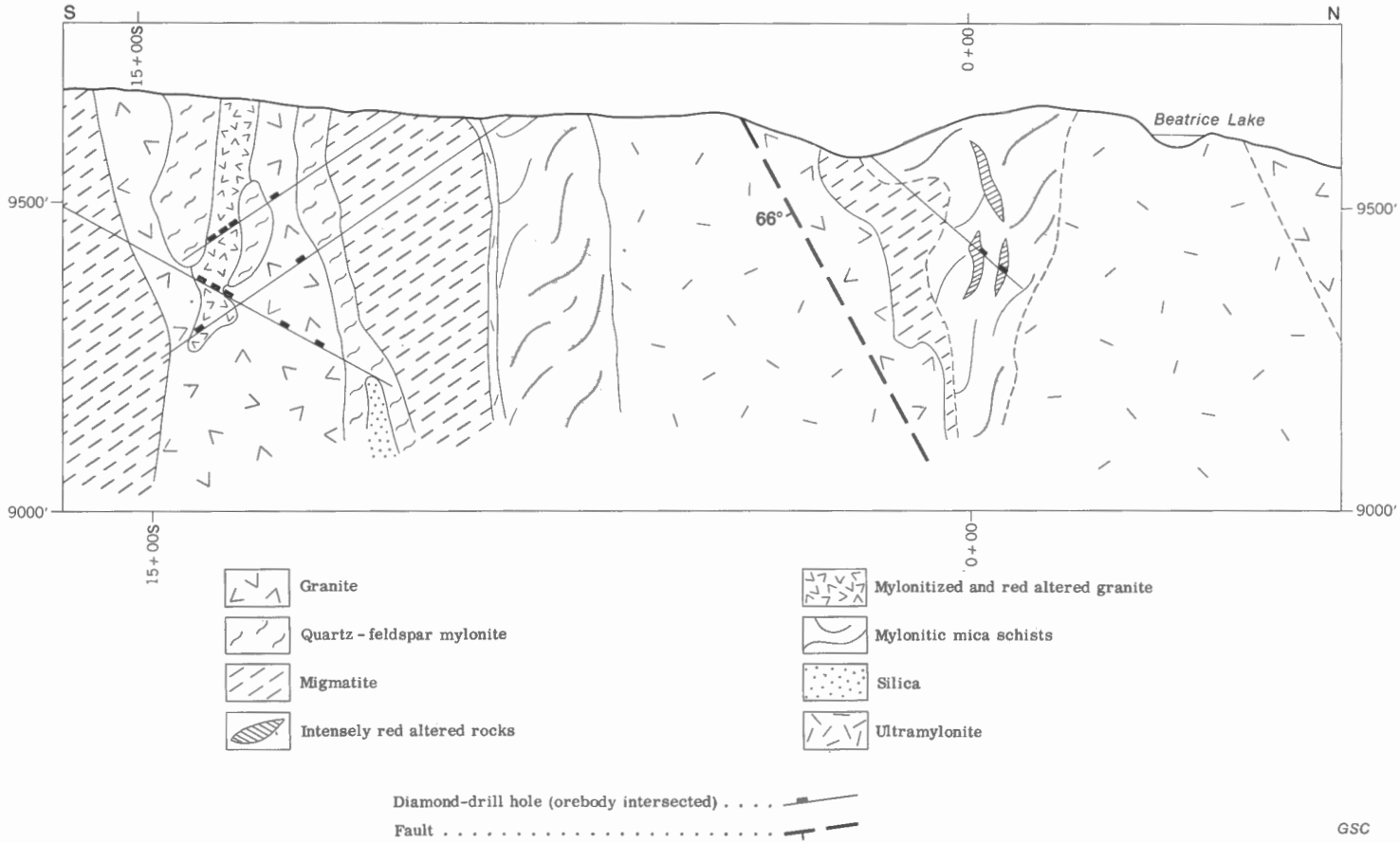

Figure 32. Hab deposit, Beaverlodge area, cross-section. (Compiled by V. Ruzicka on the basis of Eldorado Nuclear Ltd., Section 10 + OOE, 1969.)

1968) an average 4.5 ppm uranium. Granites (15 specimens analyzed) contain 5.4 ppm uranium. These facts and the presence of thucholite in few deposits as well as deep geological knowledge of the Beaverlodge area led Tremblay to the conclusion that the sediments were probably the source for uranium mineralization and uranium concentration could be the result of their granitization. As evidence for that hypothesis he mentioned the geological features of the environment of the deposits Fay-Ace-Verna, Lake Cinch, and Rix-Smitty Mines which are the largest known deposits in this area and where the chlorite-rich argillite-like rocks occur. Therefore he recognized the following events of uranium mineralization within the Beaverlodge area: (1) deposition of uranium-bearing sediments, (2) mobilization of uranium and its concentration during granitization, (3) remobilization of uranium and its concentration during mylonitization, and (4) remobilization and concentration during late fracturing, following the same zones of weakness as (3). The mineable accumulations of uranium were formed during the latest events, which conclusion seems probable. It also supports the theory of structural and lithological control in localization of orebodies.

Some regularities in localization of pitchblende mineralization may be demonstrated on Fay-Ace-Verna, Bolger, Hab and Gunnar deposits as the main representatives of uranium deposits within the Beaverlodge area.

The pitchblende mineralization in Fay-Ace-Verna deposits is confined to feldspar rocks and argillites and structurally controlled by St. Louis Fault and by junctions of St. Louis Fault with Larum, Radiore and ABC Faults. The favourable host rocks are enclosed by alaskite and alaskitic gneisses. Some orebodies occur in the breccia zone which follows the St. Louis Fault in its subjacent wall.

Uranium mineralization within the Hab deposit is confined to intensely mylonitized and red, altered granite and to intense red altered rocks surrounded by mylonitic mica schists (see Fig. 32). The pitchblende orebodies occur near northeasterly and easterly trending faults which dip north. The ore consists primarily of quartz, calcite, feldspar, chlorite, hematite and pyrite. Uranium mineralization is represented by pitchblende.

The Bolger deposit was mentioned by Lang et al. (1962) as an example of supergene mineralization, which was leached from the pitchblende in the outcrops by surface waters that moved a short distance laterally into the adjacent gravel before depositing their contained uranium. But further exploration and mining operations done by Eldorado Nuclear Ltd. showed that besides the secondary uranium mineralization the pitchblende mineralization also occurs in coarse crystalline calcite which accompanies siliceous rocks in epidotitic argillite beneath the supergene deposit. The uranium mineralization appears to be analogous to the mineralization of other pitchblende deposits within the Beaverlodge area.

Uranium mineralization in the Gunnar deposit is structurally controlled by two sets of faults, one striking northeast and dipping southeast and the other striking east and dipping south. The general plunge of the Gunnar orebody is roughly 45 degrees south. It is roughly parallel to the contact between paragneisses and Gunnar granite gneisses which are the host rocks of the orebody. The orebody is "pipe-like" in shape. It was formed in granite gneiss where quartz was replaced by carbonate. The ore consists of pitchblende, albite, chlorite and iron oxides. Uranophane is also present. Other minerals are pyrite, chalcopyrite, galena, calcite, dolomite, and quartz (Lang et al., 1962). Uranium mineralization is finely disseminated in the host rocks and its presence may be megascopically distinguished by red alteration of the host rocks, which is most abundant in the vicinity of fractures. The deposit is now mined out, but some radioactive spots remain in safety pillars (see Plates III, IV).

Spectrographic analyses of specimens taken from uranium mineralization in the Beaverlodge area showed following results:

Table 19

	Si	Al	Fe	Ca	Mg
(1)	10.00	3.00	5.00	5.00	0.5
(2)	10.00	3.00	5.00	7.00	2.00
(3)	0.5	0.15	1.00	20.00	0.1
(4)	10.00	5.00	3.00	0.2	0.7

	Ti	Mn	Sr	Ba	Cr	Zr
(1)	0.3	0.05	0.03	0.07	0.01	0.01
(2)	2.00	0.1	0.07	0.02	0.01	0.03
(3)	0.01	0.2	0.03	0.007	<0.002	NF
(4)	0.5	0.02	0.02	0.15	0.01	0.02

	V	Ni	Ce	Cu	Y	Nb
(1)	0.1	0.01	0.1	0.07	0.02	NF
(2)	1.00	0.003	0.3	0.005	0.01	NF
(3)	0.01	NF	NF	0.005	<0.003	NF
(4)	0.03	0.003	NF	0.007	<0.003	NF

	Co	La	Pb	Th	Sc	B
(1)	NF	0.15	0.3	0.05-0.2	0.007	<0.08
(2)	NF	0.015	0.5	0.05-0.2	0.003	NF
(3)	NF	NF	0.1	0.05-0.2	0.001	NF
(4)	NF	NF	0.07	NF	0.002	<0.008

	Yb	Be	U	Mo	Bi	Ag	Sn
(1)	0.003	NF	0.7	NF	NF	NF	n.d.
(2)	0.005	NF	5.00	NF	NF	0.002	NF
(3)	<0.001	NF	0.4	NF	NF	0.0005	NF
(4)	<0.001	0.0003	0.9	NF	NF	NF	NF

(1) Verna mine.
(2) Fay mine.
(3) Bolger pit.
(4) Hab mine.

Although the analyses are semiquantitative and made from selected hand specimens they show a distinctive difference from those from the Great Bear Lake area (compare Bi, Co, Ni, Ag etc.). This fact can be used for some considerations in classification of uranium deposits.

Athabasca Basin uranium-bearing area

As examples of uranium mineralization within this area (see Fig. 24, 3d) two localities will be mentioned: the Stewart Island area (120) and the occurrences in the Carswell dome area (109, 110).

In the Stewart Island area uranium mineralization was identified in sandstones of the Athabasca Formation. Disseminated pitchblende mineralization is accompanied by hematite and quartz. Semiquantitative spectrographic analysis of the a specimen taken from the radioactive zone intersected by diamond drilling showed following results (data are in per cent):

Table 20

Si	Al	Fe	Ca	Mg	Ti
10.00	1.5	7.00	0.2	0.2	0.02
Mn	Sr	Ba	Cr	Zr	V
0.015	0.007	0.003	<0.002	0.01	<0.003
Ni	Ce	Cu	Y	Nb	Co
0.01	NF	0.005	0.003	NF	0.003
La	Pb	Th	Sc	B	Yb
NF	NF	NF	NF	<0.008	<0.001
Be	U	Mo	Bi	Ag	
<0.0003	0.15	NF	NF	NF	

Radioactive anomalies in the Carswell dome area were found in the Athabasca Formation to be confined mainly to basal, coarse, hematitic, polymictic conglomerate and breccia. No uranium mineral was identified, but the radioactive spots are mineralized by quartz, feldspar, hematite and limonite. Radioactive anomalies also occur on the Numac property in the granite-gneisses, which represent the basement rocks of Archean age. Locations of these localities are: (1) latitude: 58°26'00", longitude: 109°39'00" (NTS 074K 05E) and (2) latitude: 58°21'45", longitude: 109°31'40" (NTS 074K 05E) (Little and Ruzicka, 1970).

During the flight from Uranium City to the Wollaston Lake area (made at about 400-800 feet above the surface) the measurement of the radioactivity of the Athabasca Formation was done by a Scintrex scintillometer (model GIS 3). The values of gamma radiation reached up to twice above the background values.

Wollaston Lake uranium-bearing area

As a representative of uranium deposits in this area (see Fig. 24, No. 3e) the Rabbit Lake deposit was selected. Uranium mineralization is here represented mainly by sooty pitchblende or uraninite. It is accompanied by a minor quantity os sulphides, such as pyrite, galena and sphalerite. The host rocks are mainly gneisses and meta-argillites. Near the mineralized zone they are altered due to argillization, carbonatization, silicification and to some extent due to hematitization. The localization of the uranium mineralization is structurally controlled mainly by northeasterly trending faults and

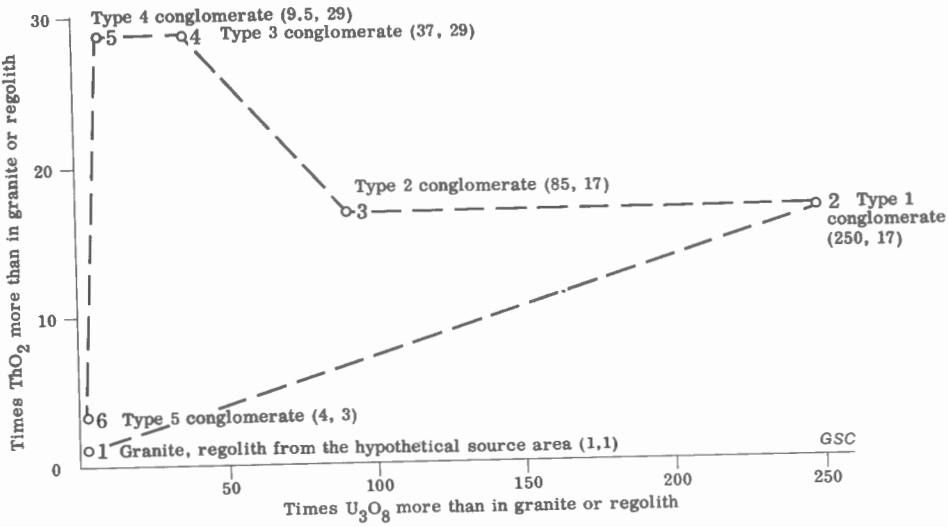

Figure 33. Diagrammatic illustration of U_3O_8 to ThO_2 ratio in the Elliot Lake deposits in comparison to the ratio in granite and granitic paleosol in the hypothetical source area (data from Roscoe, 1969).

other fractures possibly related to the previous ones. The general trend of the host rocks is also mainly northeastly. The mineral bodies appear to follow the general trends of the host rocks and the general trends of the fault and fracture junctions.

The deposit is underlain by ortho- and paragneisses of Archean age. The gneissosity, schistosity, foliation, and cleavage of these rocks trend northeasterly (Fahrig, 1957).

A significant feature within this area is the presence of several granitic intrusions which perhaps are related genetically to the formation of the Rabbit Lake deposit. The granites are strongly differentiated. Pegmatitic dykes occur near the uranium mineralization (Little and Ruzicka, 1970).

Elliot Lake uranium-bearing area

As mentioned previously this area (see Fig. 24, No. 3i) comprises several types of uranium deposits distributed within various geological environments. However, the most significant known uranium deposits are confined to conglomerates of the Matinenda Formation. Therefore the deposits that occur in the Elliot Lake area, in sensu stricto, and the Agnew Lake deposit will be briefly described.

The uranium mineralization within the Elliot Lake area, i.e. mineralization confined to conglomeratic sediments of the Elliot Lake Group, is mainly confined to the north and south limbs of the main syncline (Quirke Lake trough) in valleys that may represent channels in the early Huronian drainage system (Lang et al., 1962).

Roscoe (1969) distinguished two ore zones, the Nordic and the Quirke. It is interesting that the third significant ore zone, the Pronto, is localized along the prolongation of the line connecting the Nordic and Quirke zones.

The uranium mineralization within the Quirke zone occurs in the upper member of Matinenda Formation and is usually referred to as the Denison and Quirke reef zones, comprising several mineralized conglomeratic layers separated by quartzite beds.

The following general regularities in distribution of uranium mineralization can be observed: (1) the upper parts of the reef zones are richer in uranium than the lower ones, (2) the thickness of the reefs increases and the ore grade decreases from north to south, (3) the dislocations displacing the reefs did not influence the ore distribution, (4) mineralogical zoning appears to be present. For the Quirke zone, Roscoe (1969) mentioned the following zoning: (a) the uraninite-rich zone occurs mainly near the "upstream head" of the Denison reef, (b) the adjacent zone is represented by the brannerite-rich type of ore, (c) the further zone is mainly represented by monazite-brannerite mineralization, and (d) the "downstream part" comprises the monazite-zircon type, (6) on the basis of ratios of concentration of diagnostic elements (U, Th, Zr, Ti, and Fe) Roscoe also observed mineralogical zoning in a large geological environment and found that the concentration of U_3O_8 was enriched up to 250 times in the upstream part of the conglomeratic member of the deposit in comparison with the U_3O_8 concentration in the hypothetical source area (in granite and granitic paleosol), and only four times in the downstream part of deposit. The concentration of ThO_2 was enriched up to 17 times in the upstream part and up to 29 times in the lower part, but only three times in the lowermost part of conglomeratic uraniferous beds (see Fig. 33). The Zr, Ti, and Fe components also showed enrichment, but without evident correlations with the conglomerate types of deposit. However, further investigations based upon a statistically larger number of data may bring some corrections into these conclusions. (7) Another factor which also influenced the deposition of uranium mineralization (in both structural and geochemical directions) was represented by volcanic events during the Matinenda sedimentation. This question is being investigated at the present time (Bottrill, 1970).

The uranium mineralization in the Agnew Lake area (see Fig. 24, No. 118) is also confined to several conglomeratic beds interlayering the steeply-dipping sediments of Huronian age. The Agnew Lake uranium deposit occurs in the northern, steeply dipping limb of easterly striking syncline built up of quartzites, argillites, conglomerates, volcanic tuffs and flows, and gabbroic intrusions. The basement rocks belong to the Birch Lake batholith which is composed mainly of leucocratic granite. The contact zone between the granite and the Huronian sediments is as a rule represented by regolithic material.

The uraniferous conglomerate is composed of quartz pebbles and locally of microcline feldspar fragments in a matrix containing microcline, pyrite, rutile, pyrrhotite, uranothorite, monazite, brannerite (rarely), anatase, chalcopyrite, galena and zircon. The rare earths occur in relatively high quantities here. Another significant feature, which makes the mineralization within the Agnew Lake area different from the uranium mineralization in the Elliot Lake area, is the high ThO_2/U_3O_8 ratio. It varies in various ore types from 1.1 to 6.0; in average it represents 3.3 (weighted average of 11 samples)(Carrington and Wilton, 1969).

Spectrographic analyses of samples taken from above mentioned deposits (Agnew Lake mine, Denison mine, and Quirke I and II mines) showed following results (data in per cent):

Table 21

	Si	Al	Fe	Ca	Mg	Ti
(1)	10.00	1.00	5.00	0.1	0.07	0.05
(2)	10.00	2.00	10.00	0.1	0.05	0.2
(3)	10.00	2.00	7.00	0.2	0.05	0.3
(4)	10.00	2.00	3.00	0.05	0.1	0.3
(5)	10.00	2.00	10.00	0.07	0.05	0.07

	Mn	Sr	Ba	Cr	Zr	V
(1)	0.003	0.003	0.01	< 0.002	0.03	<0.003
(2)	0.005	NF	0.02	< 0.002	0.015	<0.003
(3)	0.005	< 0.002	0.03	0.003	0.02	<0.003
(4)	0.005	NF	0.03	< 0.002	0.02	0.003
(5)	0.003	NF	0.01	< 0.002	0.01	NF

	Ni	Ce	Cu	Y	Nb	Co
(1)	0.003	1.00	0.05	0.1	NF	0.03
(2)	0.007	0.07	0.01	0.15	NF	0.02
(3)	0.007	0.2	0.01	0.03	NF	0.01
(4)	0.003	0.1	0.007	0.02	NF	0.007
(5)	0.007	0.07	0.03	< 0.003	NF	0.015

	La	Pb	Th	Sc	B	Yb
(1)	1.00	0.3	0.05-0.2	0.003	NF	0.007
(2)	0.03	0.3	NF	< 0.001	NF	0.01
(3)	0.2	0.05	NF	0.001	NF	0.002
(4)	0.1	0.05	NF	< 0.001	<0.008	< 0.001
(5)	0.05	0.1	NF	NF	NF	0.002

	Be	U	Mo	Bi	Ag
(1)	< 0.0003	0.5	NF	0.003	NF
(2)	NF	2.0	NF	0.003	0.003
(3)	NF	0.3	NF	NF	NF
(4)	< 0.0003	0.3	NF	NF	NF
(5)	NF	0.5	NF	NF	<0.005

(1) Agnew Lake mine
(2) Denison mine east
(3) Denison mine south
(4) Quirke I mine
(5) Quirke II mine

Although the analysed specimens were selected at random and the analyses were semiquantitative, the similarity in the chemical composition (association of some elements) is very high.

Makkovik-Seal Lake uranium-bearing area

Within the Makkovik-Seal Lake area (Fig. 24, 3k) the coastal part is the best geologically explored uraniferous district.

This district is built up of (1) Archean basement rocks represented mainly by Hopedale (banded) gneisses, (2) the metamorphic sedimentary and volcanic formations of the Aillik Group, early Proterozoic in age, which are represented mainly by varied feldspathic quartzites, conglomerate, paragneiss and mafic lavas with associated tuffaceous beds, (3) Hudsonian intrusions (a) pre-metamorphic ones represented by biotite-hornblende-quartz-feldspar gneisses and varied felsic, mafic, and amphibolitic dykes, (b) synkinematic ones represented by granite gneisses and gneissic granites and (c) postkinematic ones represented by granites (strongly differentiated), granodiorites, diorites and gabbroic rocks, (4) diorite, diabase and lamprophyre dykes belong to the younger suites of intrusions (Gandhi et al., 1969). The Hudsonian folding affected the sedimentary, volcanogenic and earlier intrusive complexes and imparted a mainly anticlinorial character with prevalently north-northeast structural trends. The fault systems are represented by two sets, trending north-northwest and east-northeast.

Uranium mineralization occurs in syngenetic and epigenetic types of deposits. It is represented mainly by uraninite or pitchblende. Uranium mineralization occurs in various genetic types: (1) uraninite mineralization confined to granites and pegmatites, (2) a sedimentary-metamorphic type which is represented by disseminations mainly confined to metamorphosed quartzites, (3) pitchblende mineralization in veins and disseminations (usually associated with quartz-carbonate gangue material) confined to graphitic argillites, tuffs and tuffites locally interbedded with amphibolites, (4) uranium mineralization in shear and fault zones, (5) pitchblende mineralization confined to granulites in which pitchblende is as a rule botrytoidal and replaces hematite). (Selected forms of uranium mineralization from the Makkovik Bay area are shown by autoradiographs of specimens VR-302, VR-306, VR-308, see Plate VI, and by microphotographs of the specimen VR-304, see Plate VII.)

Uranium deposits and occurrences within the area have been explored by British Newfoundland Exploration Limited. Location and some characteristics are as follows:

1. Kitt's deposit (latitude: 54°59'53", longitude: 54°29'23", NTS 13J, 14W) occurs in argillitic and volcanic rocks of the Aillik Group in the vicinity of Long Island granodioritic gneisses and gabbroic postmetamorphic intrusions. Uranium mineralization is represented by pitchblende accompanied by quartz, carbonates, dispersed pyrite, pyrrhotite and chalcopyrite, and epidote. It is developed in three mineralized zones (A, B, C), where A and B zones appear to be displaced parts of one zone.
2. Michelin showing (latitude: 54°35'24", longitude: 59°53'40", NTS 13J, 12W) is situated in metamorphosed feldspathic quartzites of Aillik Group. The main components of uranium ore are quartz, feldspar, biotite, hornblende, pyrite, hematite and uranium minerals.
3. Nash showing (latitude: 54°54'30", longitude: 59°37'06", NTS 13J, 13E). Uranium mineralization is confined to tuffs.
4. Inda Lake showing (latitude: 54°55'40", longitude: 59°34'44", NTS 13J, 13E). Probable continuation of the Nash showing.
5. Henry Gear showing (latitude: 54°51'34", longitude: 59°32'43", NTS 13J, 13E). Pitchblende mineralization accompanied by magnetite, pyrite, chalcopyrite, graphite and hematite occurs in argillites.

6. John Michelin showing (latitude: 55°03'58", longitude: 59°11'50", NTS 13O, 03W). Radioactive mineralization occurs in feldspathic quartzite. Its character is similar as elsewhere in feldspathic quartzites within the area.

As reported by Gandhi et al. (1969) the feldspathic quartzite contains also molybdenum mineralization which occurs as molybdenite flakes and seams generally parallel to bedding and foliation. Other molybdenite-pyrite zones are frequently encountered in the feldspathic quartzite of the Round Pond anticline. However the semiquantitative spectrochemical analyses of specimens taken form various localities with uranium mineralization within the Makkovik area showed the presence of molybdenum in one case only, but lead, zirconium, stroncium, titanium and some other elements were found in all samples (see Table 22).

Table 22

Spectrographic analyses of samples from the Makkovik area

	Si	Al	Fe	Ca	Mg	Ti
(1)	3.00	2.00	3.00	20.00	0.5	0.2
(2)	10.00	5.00	5.00	1.00	0.7	0.7
(3)	10.00	5.00	3.00	1.00	0.15	0.5
(4)	10.00	3.00	10.00	7.00	3.00	0.2
(5)	10.00	3.00	10.00	10.00	3.00	0.3
(6)	10.00	9.00	3.00	0.5	0.05	0.3

	Mn	Sr	Ba	Cr	Zr	V	Ni	Ce
(1)	0.07	<0.002	0.03	<0.002	0.1	0.007	<0.002	NF
(2)	0.1	0.01	0.015	0.007	0.03	0.01	0.005	NF
(3)	0.05	0.002	0.03	<0.002	0.15	0.01	0.007	NF
(4)	0.5	0.1	0.007	0.007	0.015	0.3	0.007	NF
(5)	0.7	0.03	0.01	0.005	0.7	0.5	0.01	NF
(6)	0.07	0.02	0.2	<0.002	0.03	NF	0.005	NF

	Cu	Y	Nb	Co	La	Pb	Th	Sc
(1)	0.01	0.007	NF	NF	0.03	0.5	0.05-0.2	0.001
(2)	0.005	0.02	NF	0.003	<0.01	0.1	NF	0.0015
(3)	0.003	0.1	NF	NF	0.01	0.7	NF	0.007
(4)	0.0015	0.003	0.05	0.005	NF	0.1	NF	0.002
(5)	0.03	0.005	0.05	0.003	NF	0.1	0.05-0.2	0.001
(6)	0.003	0.02	NF	NF	NF	0.3	NF	0.001

	B	Yb	Be	U	Mo	Bi	Ag	Sn
(1)	NF	0.001	NF	1.00	0.2	NF	NF	n.d.
(2)	NF	0.0015	<0.0003	0.5	NF	NF	NF	NF
(3)	NF	0.005	0.001	1.00	NF	NF	NF	NF
(4)	<0.008	0.001	0.003	0.9	NF	NF	NF	NF
(5)	0.01	0.0015	0.003	2.00	NF	NF	NF	NF
(6)	NF	0.003	0.002	0.7	NF	NF	NF	NF

(1) Kitt's.
(2) Michelin.
(3) Michelin, till.
(4) Inda Lake.
(5) Henry Gear.
(6) John Michelin.

Grenville uranium-bearing area

This uranium-bearing area coincides roughly with the southeastern part of Canadian Shield-the Grenville Province (Fig. 24, 31).

It is composed of Proterozoic(?) and older complexes reworked during the Grenville Orogeny. Much of the Grenville Province is highly metamorphosed and is characterized by northeast-trending flow folds, redeformed easterly-trending Kenoran basement structures, and the northerly-trending structures of the Hudsonian Orogeny. Therefore the structural trends within the Grenville Province are very intricate.

Uranium mineralization in the Grenville uranium-bearing area is developed in varied forms and genetic types: (1) in granitic and syenitic bodies, mainly pegmatitic, (2) as metasomatic deposits in marbles and pyroxenites, and (3) as deposits formed from hydrothermal solutions.

Three areas were selected for a brief demonstration of uranium mineralization: the Bancroft, the Sharbot Lake and the Mont Laurier areas.

Bancroft area (see Fig. 24, No. 78)

This area is characterized by high-grade regionally metamorphosed rocks, granite batholiths, a syenite-granite plutonic complex, marginal zones of hybrid syenitic and granitic gneisses, and by concordant gabbro intrusives.

Uranium mineralization is here confined mainly to pegmatite bodies which are complex mixtures of syenitic, granitic and quartz-rich phases. According to Robinson (1958, 1960) the radioactive mineralization within the Bancroft area is confined to granites and syenites, pegmatites and metasomatic deposits. Lang et al. (1962) also mentioned a group of hydrothermal uranium deposits from the Bancroft area represented by calcite-fluorite-apatite, calcite-fluorite-apatite-biotite-pyroxene, and calcite-biotite-apatite veins.

The most favourable host rocks for uranium mineralization are pyroxene granite pegmatite, syenite pegmatite, leucogranite or leucogranite pegmatite with or without magnetite, and cataclastic quartz-rich granite-pegmatite (Satterly, 1957).

The largest and economically most important known uranium mineral accumulation in the Bancroft, and also in the Grenville uranium-bearing area, is developed within the Faraday mine deposit. The radioactive mineralization occurs in a swarm of leucogranite, leucogranite pegmatite, and pyroxene granite and syenite pegmatite dykes which cut the gabbro and amphibolite. All ore-bearing dykes occur within the boundaries of the Faraday metagabbro. The most common gangue mineral, quartz, occurs in two generations in the ore. The second most common gangue mineral is magnetite. Uraninite and especially uranothorite are the main uranium-bearing minerals. Uranothorite in its typical occurrence is as a rule associated with magnetite in quartz and with altered pyroxene and hornblende in feldspar and quartz (Cunningham-Dunlop, 1967). Radioactive mineralization is accumulated in several (up to more than twenty) orebodies usually lenticular in shape.

Sharbot Lake area (see Fig. 24, No. 119)

Several radioactive mineral occurrences have been developed and explored in Palmerston Township by Rexdale Mines Limited.

The radioactive mineralization is accompanied with quartz, feldspar, biotite, locally with molybdenite, garnet (almandine), sericite, and chlorite, and is confined to pegmatites, usually in the tan coloured dykes. The main megascopically visible uranium-bearing mineral is uraninite.

Mont Laurier area (see Fig. 24, No. 117)

Radioactive mineralization is confined to light coloured pegmatites that contain magnetite, biotite and sphene as accessory minerals. The most common radioactive minerals are allanite, uraninite, uranothorite and zircon. Weathered pegmatite is usually covered with thin stains of uranophane.

As examples two specimens from different localities within the Grenville area were spectrographically analyzed in the Geological Survey laboratories, one with uranium-thorium mineralization and the other with thorium content; the following results were obtained (in per cent):

Table 23

	Content			
Locality	>1.00	>1.00	>0.01-1.00	0.01-0.1
(1)	Si, Th	Al, U	La, Mg, Fe, Ba, Ca, Ti, Sr, Y, Ni, Co	B, Cu, Mn, Yb, Cr
(2)	Si	Al, Fe, Ca, Zr, Ce, La	Mg, Mn, Y, Th	Ti, Sr, Ba, Pb
	<0.01			
(1)	V			
(2)	Cr, V, Cu, Co, Sc, B, Yb, Be, Bi			

(1) Cheddar Township (weathered ore).
(2) Mont Laurier area (pegmatite).

Uranium mineralization in the Appalachian region

The Canadian part of the Appalachian region (see Fig. 24, No. 4a) does not contain any workable known uranium deposit but there are significantly favourable geological conditions for uranium mineralization.

Gabelman (1968, 1969) correlated the metallic mineralization within the Appalachian mobile belt with certain phases of the geotectonic cycles. He listed also the generalized sequence of elements and minerals characteristic for the Appalachian and the foreland region of eastern North America as follows (from oldest to youngest formations): (1) iron-titanium oxides (with vanadium), (2) thorium-uranium, (3) iron sulphides, (4) copper-nickel, (5) gold, (6) tungsten, (7) copper, (8) molybdenum, (9) copper-zinc,

(10) zinc, (11) base metals (Zn, Pb, Cu), (12) sulpho salts (As, Sb, Bi), (13) mercury, (14) manganese, (15) barite, (16) fluorite, (17) copper, (18) vanadium and (19) uranium (no. 17-19 low temperature deposits in clastic rocks). The most characteristic correlations between certain mineral assemblages and certain phases of geotectonic cycles were mentioned elsewhere in this paper.

The Appalachian mobile belt in the Canadian Maritime provinces contains the Ordovician Taconian belt developed in Gaspé and New Brunswick and the Devonian Acadian belt developed mainly in Nova Scotia. Between these two belts the Carboniferous basin is filled with Mississippian to Permian continental and marine sediments, slightly deformed by the Appalachian Orogeny.

Known uranium anomalies occur here in various environments: (1) in small amounts in granitic rocks, e.g. in granites near Mount Pleasant (at random taken specimen LF-59-2a contained 12 ppm of uranium, 70 ppm of thorium and 4.06% of potassium), (2) associated with rhyolites in shear zones, locally accompanied with fluorite, e.g. in the Harvey Formation of the Windsor Group in New Brunswick (Gross, 1957), (3) associated with hydrocarbon or albertite, e.g. at Upper Dorchester, New Brunswick (latitude: 45°56'08", longitude: 64°31'19", NTS 21H, 15E), (4) in sandstone, e.g. near Irishtown, New Brunswick, at Black Brook, Nova Scotia: latitude: 45° 40'37", longitude: 63° 12'09", NTS 11E/11E, and near Little Mininegash, Prince Edward Island: latitude 46°50'45", longitude: 64°15'30", NTS 21I, 10W (Prest et al., 1969).

The writer supposes that the geological environment similar to those with uranium mineralization in sandstones in the United States and elsewhere (Finch, 1967) is favourable for uranium mineralization in the Canadian Appalachian are too and thinks that it may be useful to seek and investigate such favourable conditions or places with similar conditions especially where (a) percolating waters contain higher uranium contents (5.10^{-5} g U/l or more), (b) pH and Eh values are favourable for the precipitation of uranium from waters, (c) physical, chemical and biological conditions are suitable for ore deposition.

Similar conditions, however, may be found elsewhere in Canadian sedimentary basins (e.g. in Plains, Innuitian region, Cordilleran region) too.

As examples some specimens from the Appalachians were spectrographically analyzed and the results shown on Table 24 (data in per cent).

Table 24

	Si	Al	Fe	Ca	Mg	Ti
(1)	10.00	3.00	3.00	10.00	0.5	0.5
(2)	3.00	2.00	1.00	20.00	0.5	0.2
(3)	5.00	2.00	1.00	20.00	0.5	0.3
(4)	10.00	3.00	2.00	0.1	0.3	0.3
(5)	10.00	3.00	1.00	5.00	0.3	0.3
	Mn	Sr	Ba	Cr	Zr	V
(1)	0.2	0.01	0.05	0.002	0.03	0.005
(2)	0.3	0.03	0.02	0.002	0.01	0.01
(3)	0.3	0.02	0.05	0.003	0.015	0.05
(4)	0.01	0.007	0.03	<0.002	0.03	0.003
(5)	0.2	0.007	0.02	<0.002	0.05	<0.003

	Ni	Ce	Cu	Y	Nb	Co
(1)	<0.002	NF	0.003	0.003	NF	NF
(2)	<0.002	NF	0.005	0.003	NF	NF
(3)	<0.002	NF	0.002	0.007	NF	NF
(4)	<0.002	NF	0.002	<0.003	NF	NF
(5)	<0.002	NF	10.00	0.003	NF	NF

	La	Pb	Th	Sc	B	Yb
(1)	NF	NF	NF	<0.001	<0.008	<0.001
(2)	NF	NF	NF	NF	NF	<0.001
(3)	NF	NF	NF	<0.001	NF	<0.001
(4)	NF	NF	NF	<0.001	0.008	<0.001
(5)	NF	NF	0.05-0.2	0.001	NF	<0.001

	Be	U	Mo	Bi	Ag	Sn
(1)	NF	0.15	NF	NF	NF	n.d.
(2)	NF	0.15	NF	NF	NF	n.d.
(3)	NF	0.3	NF	NF	NF	NF
(4)	<0.0003	0.3	NF	NF	NF	NF
(5)	NF	0.15	NF	NF	0.007	n.d.

(1) Little Mininegash (Prince Edward Island), red sandstone.
(2) Little Mininegash (Prince Edward Island), grey mudstone.
(3) Little Mininegash (Prince Edward Island), red and grey stained mudstone and sandstone.
(4) Port Hood (Nova Scotia), sandstone.
(5) Black Brook (Nova Scotia), sandstone.

Although the analyses are semiquantitative only, the higher uranium content (in association with vanadium) as well as the character of the geological environment of the above mentioned localities might testify to such processes, which were similar to those leading to the formation of infiltration type of uranium deposits (compare also Part IV of this report).

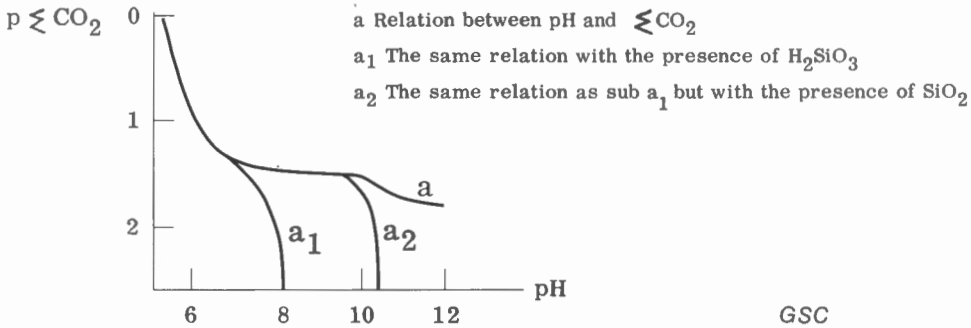

Figure 34. The equilibrium curves in uranyl-carbonate anions UO_2 (after Barsukov in Vinogradov, 1963) in relation to CO_2 contents and pH of solution.

PART IV

COMPARISON BETWEEN CANADIAN AND EAST EUROPEAN URANIUM DEPOSITS

A geological comparison between deposits of different metallogenetic provinces allows verification of the origin of ore deposits, construction of a genetic classification of the deposits present within these provinces and analysis of regularities in distribution of these deposits as well as in localization of mineralization within them.

The minerogenetic processes leading to accumulation of uranium in mineral deposits are in a tight relation to its geochemical features. Among these features Vinogradov, editor (1963) mentioned: (a) lithophile character of uranium; because of affinity of uranium to oxygen, uranium occurs in nature mostly in oxydic form and does not occur in sulphidic, arsenidic or native form; (b) it occurs in natural compounds as hexavalent or tetravalent form; (c) its redox potentials are: in the acidic environment $U \rightarrow U^{3+} + 3\bar{e} = -1.80$ V, $U^{3+} \rightarrow U^{4+} + \bar{e} = 0.61$ V, $U^{4+} \rightarrow UO_2^{2+} + 2\bar{e} = +0.334$ V (in HCl solutions), $U^{4+} \rightarrow UO_2^{2+} + 2\bar{e} = +0.407$ V (in H_2SO_4 solutions); in the basic environment $U \rightarrow U(OH)_3 + 3\bar{e} = 2.17$ V, $U(OH)_3 \rightarrow U(OH)_4 + \bar{e} = -2.14$ V, and $U(OH)_4 \rightarrow UO_2(OH)_2 + H_2O + 2\bar{e} = -0.62$ V; (d) U^{4+} ions in acidic environment react in relation to Fe^{3+}, Mn^{4+}, V^{5+}, Mo^{6+}, and Cr^{6+} as reducers, U^{6+} ions in an acidic environment react in relation to Cu^{1+}, Sn^{2+}, Ti^{3+}, V^{2+} and Cr^{2+} as oxidizers, and U^{6+} ions in basic environment react in relation to Fe^{2+} as oxidizers; (e) hydrolysis of uranium compounds in relation to pH occurs: $U^{4+} + 4OH \rightarrow U(OH)_4 = 1.69 - 1.72$ pH, and $UO_2^{2+} + 2OH \rightarrow UO_2(OH)_2 = 4.24 - 4.26$ pH; (f) in endogenic processes uranium forms uranium carbonate complexes, but in exogenic processes uranium forms uranium carbonate, uranium hydoxide, uranium sulphate and uranium humate complexes; (g) sorption processes have a significant role in the accumulation of uranium. For example the sorption ability for uranium increases within the sediments as follows: (1) sandstones → (2) limestones → (3) clays → (4) ortsteins (i.e. hardpan) → (5) phosphorites → (6) carbon-rich sediments and coals.

Different uranium contents are characteristic for different types of rocks, for various natural aqueous solutions and for various inorganic and organic environments.

The mobile character of uranium results in the differentiation of uranium compounds occurring in igneous, sedimentary and metamorphic cycles. According to the geochemical and mineralogical features of uranium and uranium-bearing minerals, these are present in certain mineral forms, in certain mineral assemblages and are accompanied by characteristic elements.

The evidence of regularities of properties was demonstrated on examples from Canadian, East European and North Asian uranium-bearing areas and deposits in previous chapters.

THE GENETIC CLASSIFICATION OF MINERAL DEPOSITS

The genetic classification of mineral deposits is a tool for demonstration of their characteristic geological features.

For radioactive deposits such classifications were done by several authors, some of whom were mentioned in previous chapters.

The genetic classifications of Canadian uranium deposits were published by Griffith et al. (1958), Robinson (1958) and Lang et al. (1962). A compilation of these classifications is shown in Table 26.

Analyzing his genetic classification of Canadian uranium deposits Robinson (1958) mentioned that some deposits are genetically hybrid and might be listed under more than one type. Also the elements listed did not include rock-forming elements which are the constituents of the ore. On the basis of his studies Robinson concluded that many similarities in mineralization occur in granites, metasomatic deposits and pegmatites. The differences in those types were governed also by the reactions with wall-rocks. Within the group of hydrothermal deposits he observed the influence of host rocks in the Beaverlodge area, whereas in other cases he supposed a limited effect of host rocks only. Within the sedimentary group of deposits the conglomeratic type of the Elliot Lake area comprises those elements associated with uranium that belong to no single geochemical environment and are more likely to be the result of clastic deposition than of igneous origin.

As examples of individual types of deposits the following localities were listed (Griffith et al., 1958; Robinson, 1958; see also Table 26):

Table 25

Type 1 (1)[1]: Dykes and lenses in deposits in Bancroft uranium-bearing area, Lac La Ronge, Parry Sound.

Type 1 (2): Foster Lake, Viking Lake, migmatites of Charlebois Lake, Pontiac area, Richardson deposit (Bancroft area).

Type 1 (3), general: Cardiff deposits, Normingo[2], migmatites of Beaverlodge and Charlebois Lake areas, Pontiac area.

Type 1 (3), fenites: Oka deposit, Beaucage, basin properties.

Type 1 (4), with simple mineral associations: Marian River, Beaverlodge uranium-bearing area (most deposits), Makkovik area, Camray.

Type 1 (4), with complex mineral associations: Great Bear Lake area, Nicholson deposit, Rocher De Boule.

Type 2 (1): Cordilleran region.

Type 2 (2): Elliot Lake uranium-bearing area.

Type 2 (3): Middle Lake, Saskatchewan.

Type 2 (4): McLean Bay.

Type 2 (5): Fernie region in Rocky Mountains.

Type 2 (6): Marine shales, lignite in Saskatchewan.

Type 3 (1): On most deposits.

Type 3 (2): Parts of Gunnar and Fish Hook Bay deposits.

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[1] Numbers in brackets refer to Table 26.
[2] Dungannon Township, Ontario (Satterly, 1957).

The above mentioned genetic classification may be applied also to uranium deposits in some other uraniferous provinces.

Table 26

Genetic classification of Canadian uranium deposits
(compiled from Griffith et al., 1958, Robinson, 1958 and Lang et al., 1962)

1. Igneous (magmatic) and related types:
(1) Granite, syenite (including pegmatitic facies): (a)[1] characteristic elements: Th, U, Zr, Si (Ce, Fe, P, F)[2]; (b)[1] characteristic minerals: uraninite, uranothorite, thorite, zircon, monazite, magnetite, sphene, allanite, fluorite.
(2) Pegmatite: (a) U, Th, Nb, Ta (Zr, Si, Ce, P, Fe, F, Ti, Mo, C); (b) uraninite, pyrochlore, betafite, euxenite, samarskite, thucholite, brannerite, molybdenite, biotite, magnetite, allanite.
(3) Metasomatic: (general): (a) U, Th, Ce, P, Si (F, Mo, Fe, S); (b) uraninite, thorianite, thorite, monazite, rare-earth, silicates, biotite, apatite, pyrite, fluorite, molybdenite, magnetite; (fenites): (a) U, Th, Nb (Ta, Ce, P, F, Ti, Fe, S); (b) pyrochlore, betafite, perovskite, calcite, soda pyroxene and amphibole, apatite, biotite, magnetite.
(4) Hydrothermal: (with simple mineral associations): U, C, Fe; (b) pitchblende, thucholite, hematite, quartz, calcite; (with complex mineral associations): (a) U, C, Fe (Cu, Co, Pb, Se, V, Ni, As, Au, Pt); (b) pitchblende, thucholite, hematite, quartz, calcite, chlorite, chalcopyrite, galena, pyrite, arsenides, selenides, nolanite.

2. Sedimentary types:
(1) Placer: (a) Th, U, Ce, P, Zr, Fe (Nb, Ta, Ti, W, Sn); (b) monazite, uraninite, pyrochlore, zircon, magnetite, garnet, ilmenite, pyrite.
(2) Conglomerate: (a) U, Th, Ti, Ce, P, Fe (Cr, Zr, C); (b) brannerite, uraninite, monazite, uranothorite, zircon, pyrite, anatase, chromite, traces of common sulphides, hydrocarbon.
(3) Sandstone: (a) U, Ca, P; (b) autunite, phosphuranylite, hematite.
(4) Dolomite: (a) Th, U, Fe; (b) monazite, hematite, zircon.
(5) Phosphorites: (a) U, Ca, P, C; (b)[3] collophanite, bitumen.
(6) Carbonaceous shales: (a) U, C, H; (b)[3] bitumen, lignite.

3. Supergene types:
(1) Cappings: (a) Fe, U, Si, Se, V, Al, Mn (Pb, Cu, Co, Ni); (b) uranophane, liebigite, zippeite, gummite, limonite, erythrite, malachite.
(2) Deposits formed by percolating water: (a) U, Si, S; (b) uranophane, pitchblende, thucholite.

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[1] Letters in brackets are (a) = characteristic elements, (b) = characteristic minerals.
[2] Elements in brackets are less characteristic.
[3] Uraniferous minerals in these types are not identified.

Klepper and Wyant (1957) based their genetic classification of uranium deposits on the analysis of the ore-forming processes. Their classification of principal types of uranium deposits is shown in a brief form in Table 27. As characteristic criteria, the character of mineralization, size and grade of deposits, their tectonic setting as well as their assumed or

proved origin have been used. The sandstone type deposits as well as the uraniferous conglomerates were classified as deposits of uncertain origin. They also concluded that certain areas are richer in uranium deposits than others. Some of the areas seemingly poor in uranium deposits are geologically similar to areas relatively rich in uranium deposits. They also deduced that uranium provinces may reflect differences in composition of the primordial earth or that they may have originated and been maintained solely by geochemical processes activated by cyclic tectonic forces.

Table 27

Classification of principal types of uranium deposits
(after Kepper and Wyant, 1957)

1. Deposits formed by igneous or metamorphic processes:
   (1) Syngenetic deposits: (a) acidic and alkalic rocks; (b) pegmatite; (c) carbonatites.
   (2) Epigenetic deposits: (a) fissure veins; (b) replacement lodes, disseminations and impregnations.

2. Deposits formed by sedimentary and weathering processes:
   (1) Syngenetic deposits: (a) marine carbonaceous shale; (b) marine phosphorite; (c) placers.
   (2) Epigenetic deposits: (a) uraniferous lignite and coal and associated carbonaceous shale; (b) others.

3. Deposits of uncertain origin:
   (a) Sandstone type deposits (including uraniferous asphaltite). (b) Uraniferous conglomerate.

On the basis of East European (including the Asian part of U.S.S.R.) as well as other world deposits Surazhskiy published a genetic classification of mineable uranium deposits (1956, see Table 28[1]), a list of morphological types of economic uranium deposits (1959, see Table 29[1]), and a classification of types of industrial uranium deposits (1960, see Table 30[1]). He distinguished two classes, six groups and fourteen types of uranium deposits: (a) the first class (endogenetic deposits) comprised two groups: (I) pegmatites and pegmatoids, and (II) hydrothermal deposits; (b) the second class (exogenetic deposits) comprises four groups: (III) syngenetic deposits in marine sediments, (IV) epigenetic (infiltration) deposits in continental sediments, (v) metamorphogenetic deposits, and (VI) ancient metamorphosed placers. The (I) group comprised the (1) to (3) types, the (II) the (4) to (6) ones, the (III) group the (7) to (10) types, the (IV) group the (11) and (12) types, the (V) group the (13) type, and the (VI) group the (14) type (see Table 30).

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[1] The tables contain the classifications in an abreviated form.

Table 28

Genetic classification of mineable uranium deposits
(after Surazhskiy, 1956)

1. Magmatic deposits:
   (1) Pegmatites and pegmatoid veins.
   (2) Hydrothermal deposits.

2. Sedimentary (syngenetic) deposits:
   (1) Marine shales.
   (2) Marine phosphorites.

3. Sedimentary-metamorphogenetic deposits:
   (1) Beds in limestones.
   (2) Beds in carbonaceous-silicic shales.

4. Weathering deposits:
   (1) Beds in sandstones and conglomerates.
   (2) Beds in subbituminous coals and lignites.

Table 29

Morphological types of economic uranium deposits
(after Surazhskiy, 1959)

1. Mineralized beds.
2. Large stratifrom deposits.
3. Vein-like deposits.
4. Lenticular and pocket-like deposits.
5. Thin veins.

Table 30

Types of industrial uranium deposits
(after Surazhskiy, 1960)

1. Granite pegmatites.
2. Pegmatoid veins with iron and uranium titanates.
3. Zones of migmatitized rocks with uraninite in quartz-feldspar veinlets.
4. Uranium, uranium-nickel-cobalt-bismuth-silver, uranium-polymetallic and other veins and stockworks formed as open space filling.
5. Uranium, iron-uranium, copper-uranium and other stratiform deposits formed by metasomatism of host-rocks.
6. Uranium, uranium-molybdenum and other vein and columnar deposits formed as open space filling and as a result of host-rock metasomatism.
7. Uranium-bearing marine shales.
8. Uranium-bearing marine phosphorites.
9. Clays with uranium-remnants, remnants of fish bones.
10. Uranium-bearing marine sandstones.
11. Uranium, copper-uranium, uranium-vanadium and other stratiform and lenticular deposits in fluvial sediments.
12. Uranium stratiform deposits in coals and lignites.
13. Uranium stratiform deposits in organogenic limestones, carbonaceous-clayey and clayey-quartzose shales.
14. Gold-uranium and uranium-thorium stratiform deposits in ancient conglomerates.

The genetic classifications of uranium deposits published by Kotlyar (1961) and by Gotman and Zubrev (1963) were based upon analyses of known uranium deposits. Some of the subtypes and types or subgroups and groups were illustrated by examples of deposits. Both of these classifications were modifications of the basic classification done by A. G. Betechtin. The abbreviated compilations of the above mentioned classifications are shown in Tables 31 and 32.

Table 31

Classification of uranium deposits
(Kotlyar, 1961)

Class I. Endogenetic uranium deposits:
Group I. Magmatic deposits.
Group II. Pegmatitic deposits:
Subgroup 1. Deposits in granite-pegmatites.
Subgroup 2. Deposits in nepheline syenite pegmatites.
Group III. Contact-metasomatic deposits (skarn).
Group IV. Hydrothermal deposits:
Subgroup 1. Hypothermal deposits.
Subgroup 2. Meso- and epithermal deposits.

Class II. Exogenetic uranium deposits:
Group I. Deposits formed by weathering:
Subgroup 1. Oxidation zones deposits.
Subgroup 2. Infiltration deposits.
Group II. Sedimentary deposits:
Subgroup 1. Deposits in river, lake and paludal sediments.
Subgroup 2. Placer deposits in sandstone: marine-coastal, deltaic and dune placers.
Subgroup 3. Deposits in marine sediments.

Class III. Metamorphogenic uranium deposits:
Group I. Deposits in carbonaceous and quartz-bearing shales.
Group II. Deposits in ancient conglomerates.

Table 32

A genetic classification of uranium deposits
(Gotman and Zubrev, 1963)

Magmatogenetic deposits:
1. Pegmatitic type:
(a) granite pegmatite vein formation,
(b) granite pegmatite in migmatites,
(c) calcite-fluorite pegmatites.

Magmatogenetic deposits: (cont'd.)

2. Hydrothermal type:
   A. Metasomatic subtype:
      (a) Cu-Ni-Co-U formation,
      (b) Fe-U formation,
      (c) uranium formation.
   B. Vein subtype:
      - Hypothermal deposits:
        (a) davidite formation.
      - Meso- and epithermal deposits:
        (a) uranium formation,
        (b) five-element formation (U-Ni-Co-Bi-Ag)
        (c) U-Mo formation,
        (d) U-sulphidic formation,
        (e) uranium-fluorite-barite formation,
        (f) uranium-thalium formation,
        (g) uranium-hydroalumosilicate formation.

Exogenetic deposits:

1. Syngenetic type:
   A. Marine subtype:
      (a) dark clay and clay shale with organic matter formation,
      (b) phosphorus-bearing sandstone and phosphorite formation,
      (c) organogenetic limestones formation,
      (d) clay with fish bone detritus formation.
   B. Lake-paludal subtype:
      (a) brown coal, sandstone and clay formation.
2. Epigenetic type:
   A. Fluviatile sediments subtype:
      (a) sandstone formation; mineralization controlled by zones of oxidation,
      (b) sandstone, conglomerate, and limestone formation with plant remnants and asphaltites.

Sedimentary metamorphogenetic deposits:

1. Metamorphosed uranium-bearing dark shales type:
   (a) uranium-bearing carbon-quartz shales formation.
2. Metamorphosed uranium-bearing conglomerates type:
   (a) uranium-bearing conglomerate formation,
   (b) gold-uranium-bearing conglomerate formation.

Deposits of disputable origin:

1. Uranium-phosphorus-formation.

Sullivan's classification of metalliferous provinces and deposits (Sullivan, 1957) also comprised a classification of uranium deposits. Sullivan criticized the generally accepted classification based, largely, on assumed temperatures of deposition and based his own classification on "field associations". He suggested that many metalliferous provinces are coextensive with particular groups of sedimentary, volcanic, or basic plutonic rocks. Deposits may be truly syngenetic, reconcentrated by circulating waters or

reconcentrated thermally during metamorphism and granitization. Unlike many authors he put the source rocks as the main criterion of his classification and the ore-forming processes as a tool for further specification. In respect to uranium his classification in abbreviated form is shown in Table 33.

Chenoweth and Malan (1969) published their classification of uranium deposits of United States and Canada; it was based on the mode of occurrence (see Table 34). Wambeke (1967) classified the uranium deposits in the Precambrian shields (see Table 35). According to the occurrence of uranium a classification of resources is used by the International Atomic Energy Agency (see Table 36).

Table 33

Classification of metalliferous provinces and deposits
(uranium deposits only mentioned as examples; after Sullivan, 1957)

1. Ores derived from sediments:
   (1) Syngenetic sedimentary ores: (a) beach pebble conglomerate (Witwatersrand, Elliot Lake); (b) deltaic and closed basin sediments, shoreline beds, reef facies.
   (2) Sedimentary ores reconcentrated by circulating meteoric waters: (a) continental and lacustrine beds (alternating oxidizing and reducing conditions of sedimentation; Colorado Plateau); (b) banded iron-formation.
   (3) Metal accumulations reconcentrated thermally from sediments: (a) dolomitized limestone; (b) limestone intruded by granite or converted to paragneiss (Rum Jungle); (c) euxenic shales intruded by granite; (d) carbon-rich shales and allied sediments granitized (Lake Athabasca metalliferous province).

2. Ores derived from tuffs:
   (1) Tuffs and tuffaceous sediments converted in places to porphyry, granite, or paragneiss.

3. Ores derived from basalts:
   (1) Ores concentrated during cooling of basalt.
   (2) Ores derived during metamorphism of basalt.
   (3) Ores concentrated during granitization of basalt.

4. Ores due to granitization of chloritized carbonated lavas.

5. Ores derived from gabbro-diabase.

6. Ores derived from ultrabasic igneous rocks.

Table 34

Significant geologic types of uranium deposits United States and Canada (classification is done mostly on the mode of occurrence; after Chenoweth and Malan, 1969)

1. Stratiform deposits:
   (a) Sandstone and conglomerate.
   (b) Limestone.
   (c) Lignite.

2. Vein deposits:
   (a) Fault-controlled deposits.
   (b) Deposits in breccia pipes.
   (c) Intrusive contact deposits.

Table 35

Classification of uranium deposits in the Precambrian shields (after Wambeke, 1967)

Uranium deposits in the Precambrian shields may be divided into four main types (in order of decreasing importance):

(1) Uranium disseminations in sedimentary rocks or volcanics.
(2) Vein deposits.
(3) Pyrometasomatic deposits.
(4) Uraniferous pegmatites.

Table 36

Classification of uranium resources according to their occurrence (after 'Uranium resources revised estimates' edited by European Nuclear Energy Agency and the International Atomic Energy Agency, 1967)

1. Vein type.
2. Sandstones.
3. Shales.
4. Quartz-pebble conglomerates.
5. Phosphates.
6. Others: (a) pegmatite; (b) schists; (c) uranothorianite; (d) copper leach byproducts; (e) hyper-alkaline silicates; (f) lignites; (g) monazites; (h) volcanics.

Most classifications of endogenetic and especially hydrothermal uranium deposits published by East European authors are based on the mineral associations or on characteristic elements accompanying uranium in ores. Some authors tried also to correlate these mineral associations and

genetic types of hydrothermal uranium deposits with their structural position. Tishkin (in Vol'fson, editor, 1966) distinguished within the upper structural level the pitchblende-hydromica, the pitchblende-sulphidic, and the pitchblende-quartz types. Within the middle structural level he distinguished the pitchblende-arsenide and the pitchblende-apatite-zircon types. Within the lower structural level the pitchblende-carbonate, apatite-zircon-brannerite, brannerite, and davidite types were recognized (see Table 38). The same author and his colleages published (1958) a list of mineral associations in Soviet hydrothermal uranium deposits (see Table 37). An analogous classification of main types of pitchblende mineral associations in hydrothermal uranium deposits from the territory of U.S.S.R. was done by Tananaeva (1968, see Table 39). As did Robinson (1958) for the Canadian deposits, she also emphasized the characteristic elements in association with uranium, the hydrothermal uranium deposits of U.S.S.R. She detailed further those elements and distinguished between main elements introduced, subsidiary elements introduced, and elements leached from the host rocks. In addition to the list of ore and gangue mineral associations she also used as a classification tool the alteration effects and mineral sequence within the hydrothermal uranium deposits (see Tables 39 and 40; in abbreviated form).

A genetic classification, based on a statistical analysis and on the values of correlation coefficient between uranium and other associated elements of the uranium ores of the U.S.S.R. deposits, was published by Fomin (1968). His criteria were: (1) associations of main elements in the ores, (2) correlation coefficients between these elements, (3) mineral associations (primary deposited, superposed and redeposited), (4) character of metasomatism, and (5) host rocks and processes of alteration (see Table 41; presented in abbreviated form).

Table 37

Mineral associations in Soviet hydrothermal uranium deposits
(after Tishkin et al., 1958)

1. Mineral associations with uranium oxides (pitchblende and uraninite):
   (1) Pitchblende-sulphide association: (a) pitchblende-molybdenite; (b) pitchblende-galena; (c) pitchblende-sphalerite; (d) pitchblende with copper sulphide; (e) pitchblende-quartz-pyrite; (f) pitchblende-stibnite-marcasite.
   (2) Pitchblende-diarsenide association.
   (3) Pitchblende-uraninite with carbonates: (a) pitchblende-calcite; (b) uraninite-pitchblende-dolomite; (c) pitchblende-calcite-iron hydroxides.
   (4) Pitchblende-halogenide (fluorite) association.

2. Mineral association with uranium silicate (nenadkevite).

Remark: The most common associations are: pitchblende-sulphide and pitchblende-carbonates.

Table 38

Types of hydrothermal uranium deposits in relation to their tectonic structural position (after Tishkin in Vol'fson, editor, 1966)

1. Upper structural level:
(1) Pitchblende-hydromica type: (a)[1] kaolinite-quartz; (b) kaolinite-quartz; (d) conglomerates, sandstones, trachytes-andesites.
(2) Pitchblende-hydromica type: (a) pitchblende-carbonate-hydromica; (b) pitchblende, sooty pitchblende, siderite, ankerite, hydromicas, native arsenic; (c) coffinite, pyrite, galena, sphalerite, montmorillonite; (d) as at (1, d).
(3) Pitchblende-sulphidic type: (a) pitchblende-molybdenite; (b) pitchblende, molybdenite, sericite; (c) quartz, pyrite, uraninite, chlorite; (d) quartz-porphyries, felsites, granite-porphyries, syenite-porphyries, andesite-dacite-porphyrites[2].
(4) Pitchblende-sulphidic type: (a) pitchblende-galena; (b) pitchblende, galena, quartz, sericite; (c) calcite, pyrite, chlorite, sphalerite, chalcopyrite; (d) as at (3, d).
(5) Pitchblende-sulphidic type: (a) pitchblende-sphalerite; (b) pitchblende, sphalerite, quartz, sericite; (c) galena, fluorite, chalcopyrite, chlorite, albite, kaolinite, bitumen; (d) as at (3, d).
(6) Pitchblende-sulphidic type: (a) pitchblende-sulphides-carbonates; (b) pitchblende, galena, bournonite, pyrargyrite, miargyrite, calcite; (d) as at (3, d).
(7) Pitchblende-sulphidic type: (a) pitchblende-stibnite-pyrite; (b) pitchblende; (c) pyrite, quartz, carbonates, stibnite, cinnabarite, realgar, auripigment; (d) shales, limestones.
(8) Pitchblende-carbonate type: (a) pitchblende-calcite; (b) pitchblende, calcite; (c) uraninite, pyrite, chalcopyrite, sphalerite, galena, marcasite, quartz, goethite; (d) quartz-porphyries, felsites, carbonaceous-carbonate shales.
(9) Pitchblende-carbonate type: (a) pitchblende-calcite-sulphides; (b) pitchblende, calcite, chalcopyrite, bornite, chalcocite, chlorite, goethite; (c) quartz, marcasite, pyrite, native copper, silver, bismuth; (d) granodiorites, granite porphyries, quartz porphyries, felsites.
(10) Pitchblende-carbonate type: (a) pitchblende-dolomite (ankerite); (b) dolomite (ankerite), pitchblende; (c) chalcopyrite, pyrite, galena, sphalerite, quartz, loellingite, fluorite, goethite; (d) schists, diabases, amphibolites, limestones.
(11) Pitchblende-fluorite type: (a) pitchblende-fluorite; (b) fluorite, pitchblende; (c) pyrite, marcasite, chalcopyrite, galena, sphalerite, argentite; (d) quartz porphyries, alaskite granites.
(12) Pitchblende-fluorite type: (a) pitchblende-fluorite-sulphides; (b) fluorite, pyrite, (marcasite), pitchblende; (c) chalcopyrite, galena, sphalerite, argentite; (d) quartz porphyries, alaskite granites.

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[1] Letters in brackets: (a) mineral association, (b) main minerals, (c) other minerals, (d) host rocks.
[2] The term "porphyrites" is here and elsewhere used in sense as explained in the first chapter.

1. Upper structural level: (cont'd.)
(13) Pitchblende-fluorite type: (a) pitchblende-quartz-fluorite; (b) quartz, pitchblende; (c) fluorite, chalcopyrite, galena, sphalerite, argentite; (d) quartz porphyries, alaskite granites.
(14) Pitchblende-quartz type: (a) pitchblende-quartz-molybdenite; (b) pitchblende, molybdenite, sericite, quartz; (c) pyrite, marcasite, chalcedony; (d) granites, quartz diorites, felsites, quartz porphyries.
(15) Pitchblende-quartz type: (a) pitchblende-quartz-galena; (b) pitchblende, quartz; (c) galena, marcasite, pyrite, sphalerite, chalcopyrite, arsenopyrite, sericite, chlorite, calcite.

2. Middle structural level:
(1) Pitchblende-arsenide type: (a) pitchblende-quartz-arsenides; (b) pitchblende, quartz, skutterudite, loellingite; (c) safflorite-rammelsbergite, niccolite, native arsenic, silver, bismuth; (d) gabbro-diorites, diabases, amphibolites, adamelites, quartz porphyries.
(2) Pitchblende-arsenide type: (a) pitchblende-carbonates (dolomite, calcite)-arsenides; (b) pitchblende, ankerite, skutterudite, loellingite, (c) coffinite, native mercury, realgar, uraninite; (d) gabbro-diorites, diabases, amphibolites, adamelites, quartz porphyries.
(3) Pitchblende-apatite-zircon type: (a) apatite-zircon-pitchblende; (b) apatite, carbonates; (c) pitchblende, albite, quartz, chlorite, uraninite, fluorite, hematite, hydromicas, rutile, pyrite, galena, chalcopyrite, molybdenite; (d) clayey schists, limestones, diorites.

3. Lower structural level:
(1) Pitchblende-carbonate type: (a) pitchblende-dolomite; (b) dolomite, pitchblende; (c) chalcopyrite, pyrite, galena, sphalerite, quartz, (boulangerite), (jamesonite), loellingite, fluorite, goethite, hard bitumens; (d) schists, diabases, amphibolites, limestones.
(2) Apatite-zircon-brannerite type: (a) apatite-zircon-brannerite; (b) apatite, malacon, albite; (c) brannerite, ilmenite, chlorite, rhodusite, magnetite, chalcopyrite, galena, sphalerite, molybdenite, pyrrhotite; (d) quartzites, Fe-quartzites, albitites.
(3) Brannerite type: (a) brannerite-carbonates; (b) brannerite, dolomite; (c) pyrite, ilmenite; (d) gneisses, amphibolites, granites.
(4) Davidite type: (a) davidite-scapolite-calcite; (b) davidite, calcite, scapolite; (c) ilmenite, rutile, pyrite, pyrrhotite, chalcopyrite, apatite, tourmaline, molybdenite; (d) gabbro.
(5) Davidite type: (a) davidite-diopside; (b) davidite, diopside, scapolite, chert; (c) quartz, calcite, tourmaline, biotite, apatite; (d) granites.
(6) Davidite type: (a) davidite-plagioclase-carbonates; (d) amphibolites.

Table 39

Main types of pitchblende mineral associations in hydrothermal deposits (after Tananaeva, 1968)

Explanation: (a) Ore-minerals.
(b) Gangue-minerals.
(c) Alteration.
(d) Mineral succession.

1. Pitchblende-carbonates associations:
(1) Pitchblende with calcite and Fe-oxides: (a) coffinite, hematite, goethite, rarely Cu, Fe, Bi sulphides; (b) calcite, sericite, chlorite, quartz, barite; (c) sericitization, adularia alteration, albitization, chloritization, carbonatization, enrichment of host rocks by K or Na, hematitization; (d) first stage: calcite + hematite, second stage: native copper and Bi + pitchblende, third stage: sulphides + calcite.
(2) Pitchblende with carbonates and sulphides: (a) Fe, Cu, Pb, Zn, Bi, Ag, As, Mo sulphides; (b) calcite, (sericite)[1], chlorite, (quartz); (c) the same as at (1, c); (d) first stage: (calcite), (pitchblende), (hematite), (sulphides Pb and Zn), (molybdenite), (sericite), second stage: pitchblende, (native Cu, Bi), (molybdenite), (galena), (pyrite), (quartz), third stage: (sulphides), (calcite), (quartz), (goethite), fourth stage: (calcite), (goethite).
(3) Pitchblende with Ni, Co, Fe arsenides: (a) niccolite, rammelsbergite, skutterudite, smaltite-chloanthite, native Bi, Ag, As; (b) calcite, ankerite, dolomite, barite; (c) as at (1, c); (d) first stage: dolomite and oxides, second stage: native Bi and Ag + pitchblende, third stage: niccolite, rammelsbergite, pitchblende, fourth stage: sulphides.

2. Pitchblende-fluorite association:
(1) Pitchblende with fluorite and Fe-oxides: (a) hematite, goethite, sphalerite, pyrite, marcasite, argentite; (b) fluorite, kaolinite, barite, calcite; (c) argillization and fluoritization, no hematitization; (d) first stage: disulphides, second stage: pitchblende, fluorite, hematite, third stage: fluorite, goethite, kaolinite, fourth stage: calcite.
(2) Pitchblende with fluorite, hydroalumosilicates and Fe sulphides: (a) coffinite, pyrite, marcasite, wurtzite; (b) fluorite, halloisite, kaolinite, calcite, dolomite; (c) as at (1, c); (d) first stage: halloisite, fluorite, second stage: pitchblende, wurtzite, Fe disulphides, third stage: calcite, laumontite.

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[1] Brackets mean mineral may not be present.

Table 40

Chemical composition of pitchblende mineral associations in hydrothermal uranium deposits (after Tananaeva, 1968)

1. Pitchblende-carbonates associations:
(a) With calcite and oxides:
Main introduced elements: U, Fe, Ca, C, K.
Subsidiary introduced elements: Pb, Cu, Bi, S, Mg, Mn, Si.
Elements leached from host rocks: S, Fe, Cu, Bi, Si, Al.
(b) With calcite and sulphides:
Main introduced elements: U, Pb, Zn, Fe, Cu, As, Mo, Mg, Ca, C, S, K, Si, Al, Na.
Subsidiary introduced elements: Ag, Bi, Mn.
Elements leached from host rocks: Fe, As, Si, Al, S.

1. Pitchblende-carbonates associations: (cont'd.)
   (c) With arsenides Co and Ni:
   Main introduced elements: U, Fe, As.
   Subsidiary introduced elements: Pb, Zn, Cu, Ca, C, Mg, Mn.
   Elements leached from host rocks: Ni, Co, Fe.

2. Pitchblende-fluorite associations:
   (a) With fluorite and Fe oxides:
   Main introduced elements: U, Fe, Ca, F.
   Subsidiary introduced elements: Zn, Ag, Mo, Pb.
   Elements leached from host rocks: Si, Al.
   (b) With fluorite, hydroalumosilicates and Fe disulphides:
   Main introduced elements: U, Fe, Ca, F, S.
   Subsidiary introduced elements: Zn, C, Mg.
   Elements leached from host rocks: Si, Al.

Table 41

Classification (of a group of uranium deposits) based on correlation coefficients between uranium and various ore-components (after V. P. Fomin, 1968)

Explanation: (1) Main element associations.
(2) Correlation coefficient (see text).
(3) Mineral association: (a) primary,
(b) superposed,
(c) redeposited.
(4) Character of metasomatism.
(5) Rocks and processes of alteration.

1. (1) U-Fe, Ti-(P).
   (2) n. d.[1]
   (3) (a) Ilmenite-biotite-apatite; (b) uraninite-quartz; (c) uraninite-brannerite-rutile-hematite-uranium-bearing apatite.
   (4) Syn-uranic[2].
   (5) Porphyrites. Chloritization, silicification, carbonatization.

2. (1) U-Fe, Ti-(P).
   (2) n. d.
   (3) (a) Brannerite-uraninite; (b) carbonate; (c) pitchblende-carbonate.
   (4) Post-uranic[3].
   (5) As in 1, (5).

3. (1) U-Fe, Ti-(P).
   (2) +0. 802.
   (3) (a) Magnetite-pyrite-quartz; (b) uraninite-molybdenite-chlorite-quartz; (c) magnetite-uraninite-molybdenite-chlorite-quartz-pyrite.
   (4) Syn-uranic.
   (5) Granites, granodiorites. Silicification, chloritization, carbonatization.

4. (1) U-Fe, Ti-(P).
(2) +0.334.
(3) (a) Magnetite-uraninite-molybdenite-chlorite-quartz-pyrite; (b) chalcopyrite-calcite; (c) magnetite-uraninite-molybdenite-chalcopyrite-chlorite-quartz-calcite-pyrite.
(4) Post-uranic.
(5) As in 3, (5).

5. (1) U-Fe, Ti-(P).
(2) +0.991.
(3) (a) Pyrite-sericite; (b) pitchblende-molybdenite, (jordizite); (c) pitchblende-molybdenite-pyrite-sericite.
(4) Syn-uranic.
(5) Felsite-porphyries. Sericitization, carbonatization, chloritization, silicification.

6. (1) U-Fe, Ti-(P).
(2) +0.457.
(3) (a) Pitchblende-molybdenite-pyrite-sericite; (b) quartz; (c) pitchblende-quartz, molybdenite-quartz.
(4) Post-uranic.
(5) As in 5, (5).

7. (1) U-Mo.
(2) +0.712.
(3) (a) Pyrite-arsenopyrite-chalcopyrite-sphalerite-galena; (b) pitchblende-molybdenite; (c) pitchblende-sulphides.
(4) Syn-uranic.
(5) Granosyenite-porphyries, diabase-porphyrites. Silicification, sericitization, albitization, carbonatization.

8. (1) U-Mo.
(2) +0.440.
(3) (a) Pitchblende-sulphides; (b) calcite-barite-fluorite-quartz; (c) pitchblende-quartz-sulphides-carbonates.
(4) Post-uranic.
(5) As in 7, (5).

9. (1) U-Mo.
(2) +0.720.
(3) (a) Arsenopyrite-sericite; (b) pitchblende-molybdenite-sphalerite-galena; (c) pitchblende-sulphides.
(4) Syn-uranic.
(5) Felsites. Sericitization, silicification, carbonatization.

10. (1) U-Mo.
(2) +0.476.
(3) (a) Pitchblende-sulphides; (b) quartz-calcite; (c) pitchblende-quartz, calcite-sulphides.
(4) Post-uranic.
(5) As in 9, (5).

11. (1) U-Mo.
(2) +0.653.
(3) (a) Pyrite-sphalerite-quartz-ankerite; (b) pitchblende-molybdenite-galena; (c) pitchblende-sulphides.
(4) Syn-uranic.
(5) Quartz-porphyries. Sericitization, albitization, silicification, carbonatization.

12. (1) U-Mo.
(2) +0.221.
(3) (a) Pitchblende-sulphides; (b) quartz-calcite-fluorite; (c) pitchblende-quartz, sulphides-carbonates.
(4) Post-uranic.
(5) As in 11, (5).

13. (1) U-Mo.
(2) +0.543.
(3) (a) Pyrite-sphalerite-quartz-calcite; (b) pitchblende-molybdenite-galena; (c) pitchblende-sulphides.
(4) Syn-uranic.
(5) Quartzose syenite-porphyries. Basic metasomatism, carbonatization.

14. (1) U-Mo.
(2) n. d.
(3) (a) Pitchblende-molybdenite; (b) calcite-ankerite-dolomite; (c) pitchblende-fluorite.
(4) Post-uranic.
(5) As in 13, (5).

15. (1) U-Mo.
(2) +0.406, +0.152.
(3) (a) Pitchblende-molybdenite; (b) calcite-ankerite-dolomite; (c) pitchblende-carbonates, molybdenite-carbonates.
(4) Post-uranic.
(5) Tuffs, porphyrites. Chloritization, carbonatization.

16. (1) U-Mo.
(2) +0.400, +0.095.
(3) (a) Pitchblende-molybdenite-galena; (b) dolomite-ankerite-calcite; (c) as at 15, (3) (c).
(4) As at 15, (4).
(5) Tuffs, porphyrites. Chloritization, albitization, silicification, carbonatization.

17. (1) U-Mo, U-Pb-Zn-Cu.
(2) +0.430, +0.503.
(3) (a) Pyrite-sphalerite; (b) pitchblende-molybdenite-galena-chalcopyrite; (c) pitchblende-sulphides.
(4) Syn-uranic.
(5) Granite-porphyries. Sericitization, chloritization, silicification, carbonatization.

18. (1) U-Pb-Zn-Cu.
(2) +0.824, +0.620, +0.275.
(3) (a) Pyrite-quartz-calcite; (b) pitchblende-galena-molybdenite-sphalerite-chalcopyrite; (c) pitchblende-sulphides.
(4) Syn-uranic.
(5) Tuffs, quartz porphyries. Argillization, basic metasomatism, carbonatization, chloritization.

19. (1) U-Pb-Zn-Cu, U-Co-Ni-As-Ag.
(2) +0.260.
(3) (a) Pyrite-sericite; (b) pitchblende-galena-sphalerite-molybdenite; (c) pitchblende-sulphides.
(4) Syn-uranic.
(5) Felsite-porphyries. Sericitization, silicification, carbonatization.

20. (1) U-Pb-Zn-Cu, U-Co-Ni-As-Ag.
(2) -0.060.
(3) (a) Pitchblende-sulphides; (b) quartz-ankerite-calcite; (c) pitchblende-quartz, sulphides-carbonates.
(4) Post-uranic.
(5) As in 19, (5).

21. (1) U-Co-Ni-As-Ag.
(2) +0.702.
(3) (a) Pyrite-quartz; (b) pitchblende-galena-chalcopyrite; (c) pitchblende-sulphides.
(4) Syn-uranic.
(5) Gabbro-diorites. Sericitization, chloritization, carbonatization, silicification.

22. (1) U-Co-Ni-As-Ag.
(2) +0.818.
(3) (a) Pitchblende-sulphides; (b) pitchblende-smaltite-remmelsbergite-loellingite; (c) pitchblende-sulphides, pitchblende-arsenides.
(4) Syn-uranic.
(5) As in 21, (5).

23. (1) U-Co-Ni-As-Ag.
(2) +0.036.
(3) (a) Pitchblende-sulphides, pitchblende-arsenides; (b) quartz; (c) pitchblende-quartz.
(4) Post-uranic.
(5) As in 21, (5).

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[1] n.d. = no data.
[2] Caused by uranium-bearing solutions.
[3] Caused by solutions without uranium following uranium-bearing solutions.

Within the group of deposits with the metasomatic uranium mineral associations the so-called "Precambrian iron-ore-uranium formation" (Petrov, 1969) occupies a significant place. Its occurrence within the Krivoy

Rog iron-ore deposit was mentioned elsewhere in this paper. Petrov et al. (1969) classified the uranium mineral associations as follows: (1) the apatite-malacon type, (2) the uraninite-uranium silicate (nenadkevite)[1] type, (3) the uraninite type, (4) the pitchblende-sparse sulphides and (5) sulphides-pitchblende types (see Table 42).

Danchev (1961) suggested two basic criteria for the classification of exogenetic uranium deposits: the genetical character of host rocks, and the ore-forming processes (see Table 43 comprising these two points of view in abbreviated review). The exogenetic processes participate in the formation of the uranium deposits with various intensity and during various stages. The interrelationship among these processes is shown in the B part of Table 43.

The distribution of uranium in sediments in relation to the hydrologic cycle was emphasized by Rosholt Jr. (1963). He mentioned its influence on the distribution of abnormal uranium occurrences in the following manner: (a) by means of its energy in the removal of uranium from the ultimate source in igneous rocks and deposits produced from affiliated magmatic activity, (b) through aggradation of sediments with small concentrations of uranium for later enrichment by cyclical deposition following rapid erosion, (c) as a medium for the transport of organic matter and sulphate-reducing bacteria, (d) as a dynamic hydrology system in underground aquifers supporting the migration and accretion of uranium deposits, (e) through river water supplying uranium to shallow basins of marine mud accumulation, (f) as oceanic upwelling of deep phosphate-rich water supplying source material for phosphorite deposition, (g) through evaporation to produce the minor occurrences of uranium in evaporite deposits, and (h) through evaporation and precipitation to produce glaciers and ice sheets which contributed to the accelerated erosion and concentration of sandstone-type uranium deposits. He recognized the following main occurrences of abnormal amounts of uranium in the sedimentary environment: (1) marine black shales and modern marine mud, (2) phosphorite deposits, (3) ancient conglomerates, (4) terrestrial sandstones.

This review demonstrates the great variety of the genetic types of uranium deposits in selected uranium provinces and also as an introduction to an attempt to classify the known uranium deposits as demonstrated in the following statement.

A comparative classification system of uranium deposits is considered in this paper. The basic idea of this classification is that a solution of the problem of genetic classification will solve the problems of understanding the metallogenetic processes leading to the formation of uranium deposits.

As a rule these processes last a long time and may be cyclical. On the other hand they may be interferred with or replaced by processes leading to destruction or to dispersion of accumulations formed. The ore-forming cycles occur under various geochemical conditions, during various geological periods and on various scales.

Klepper and Wyant (1956) suggested that it is convenient to think of the geochemical cycle as consisting of three phases that grade into one another: one in which igneous processes prevail, one in which weathering and sedimentary processes prevail and one in which metamorphic processes prevail. In relation to the rock-forming processes the ore-forming processes may have either syngenetic or epigenetic characteristics.

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[1] See remark below Table 42.

Table 42

Metasomatic uranium mineral associations within the Precambrian iron formations (after Petrov et al., 1969)

Type of association	Localization	Mineral composition
Apatite-malacon.	Disseminations in albitites and aegirinites.	Apatite, malacon, sphene, minor(?) uranium silicates, albite, aegirine, alkali amphiboles, micas, hematite, magnetite.
	Veinlets and cavity-fillings in dolomite marbles.	Apatite, malacon, sphene, partly uranium silicates, calcite, dolomite, talc, serpentine, chlorite.
Uraninite-uranium silicate.	Disseminations in albitites and other alkaline metasomatites.	Brannerite, uraninite, uranium silicate, sphene, apatite, malacon, albite, aegirine, alkali amphiboles, micas and hydromicas, epidote, chlorite, hematite, magnetite.
Uraninite.	Disseminations in iron-carbonate ore and surrounding rocks.	Uraninite, carbonates Fe-Mg, dolomite, calcite, andradite, talc, hematite, magnetite, acmite, crocidolite, hydromicas, quartz, apatite, sphene.
Pitchblende-sparse sulphides.	Veinlets in rocks and in metasomatites.	Pitchblende, coffinite, anthraxolite, carbonates, quartz, chlorite, epidote.
Sulphide-pitchblende.	Veinlets in rocks and in metasomatites.	Pitchblende, coffinite, carbonates, quartz, chlorite, sulphides and arsenides, barite.

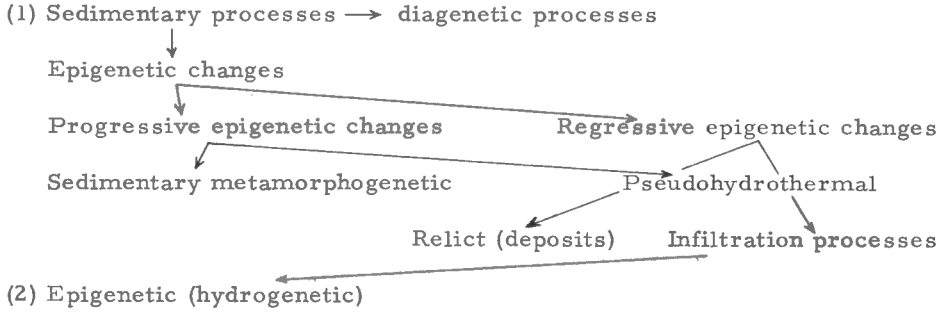
Remarks: Uranium silicate refers to a mineral named nenadkevite in East Europe: $(U^{4+}, RE, Th)U^{6+}(Ca, Mg, Pb).(SiO_4).(OH_2).nH_2O$.

Table 43

Classification of exogenetic uranium deposits
(after Danchev, 1961)

A. According to the types of host-rocks:
(1) Clastogenetic: (a) uraniferous conglomerates containing uraninite, pitchblende, sooty pitchblende (uranium blacks), and other uranium minerals; (b) placers with uranium-thorium minerals (monazite, allanite and others).
(2) Chemogenetic: (a) uranium-bearing phosphorites, siderites, dolomites, limestones and corresponding cement within clastic and pyroclastic and pyroclastic rocks.
(3) Biogenetic: (a) uranium concentrations related to the accumulations and transformation products of the organic matter in sedimentary rocks; (b) uranium-bearing peats, coals, combustible schists, asphaltites; (c) uranium concentrations in the skeletal remains of organisms.

B. According to the ore-forming processes:
(1) Sedimentary processes ⟶ diagenetic processes



(2) Epigenetic (hydrogenetic)

Thus as results of these factors or as results of combinations of these factors many possible types of uranium deposits may be logically derived.

For our purposes this logical operation will be simplified using empirical evidence and geological features of deposits that might represent their genetical character.

The proposed classification generalizes the ore-forming processes into two commonly accepted classes: (1) syngenetic and metamorphic, and (2) epigenetic without regard to facts that the combination of both can take part especially during the formation of complicated deposits.

Within the syngenetic and metamorphic class the deposits are classified into six groups, which correspond to three monomial and three binomial combinations of the syngenetic ore-forming processes. The eventual participation of the third factor may be used as a subsidiary criterion for the classification of a deposit in a certain type. It may also be diagrammatically expressed using the triangular diagram.

The following groups are distinguished: (1.1) deposits formed prevalently by magmatic differentiation, (1.2) deposits formed by igneous and sedimentary processes, (1.3) sedimentary deposits, (1.4) slightly metamorphosed sedimentary deposits, (1.5) deposits formed prevalently during

the metamorphic stage and (1.6) deposits highly metamorphosed or formed by participation of igneous processes. The boundaries among these groups are not sharp especially in complicated deposits (see Fig. 35). To avoid the subjective point of view on the "prevalent" character of deposit as well as to express possible variations within the group, arrows are used in the triangular diagram.

Syngenetic and metamorphogenetic types

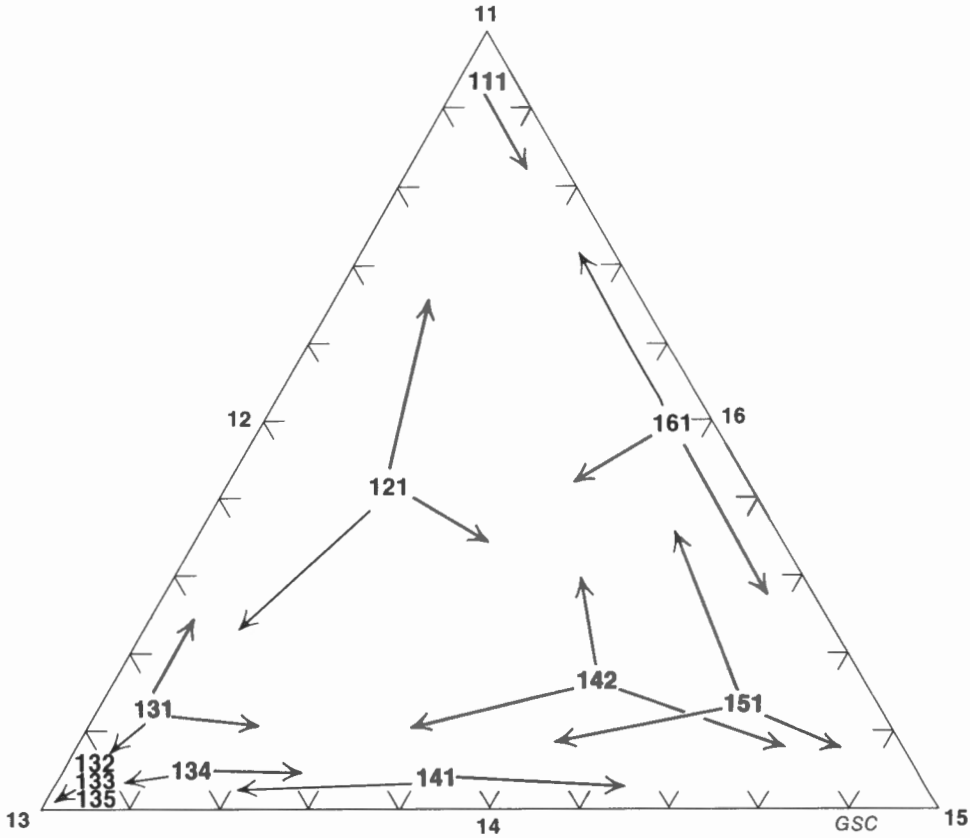
The differentiation of uranium through magmatic processes may increase in igneous rocks with their increasing acidity and alkalinity (Gabelman, 1969a) as well as towards their extrusive phase (Coats, 1956; Butler et al., 1956) and/or chronologically later (Vinogradov, editor, 1963) phases which may be genetically unrelated. The concentration of uranium occurs also in connection with the differentiation of the basic magma (Gotman and Zubrev, 1963). In this group the (1.1.1.) deposits in pegmatitic alkalic granites and syenites (Grenville type) may be mentioned. Although this group of deposits contains low grade mineralization, the primary enrichment of rocks with uranium as well as the separation of soluble uranium compounds in the "out of lattice" space during the differentiation processes represent an important source of uranium for the epigenetic processes.

Due to both igneous and sedimentary processes the (1.2.1.) effusive-sedimentary deposits (Huta type) were formed. The representative of this type is characterized in Table 47. As shown on the triangular diagram (see Fig. 35), metamorphic processes participated only in part in the formation of the Novoveská Huta deposit.

The group of sedimentary deposits is represented by many types; according to various genetic classifications of sedimentary rocks, various types of deposits within this group may be distinguished. The (1.3.1.) ancient conglomerates (Elliot Lake type) are the most important representative of this group. The syngenetic origin of mineralization with the petrogenetic processes of quartz-pebble conglomerates was mentioned elsewhere in this paper. According to Roscoe (1969) diagenetic processes were the final processes in the formation of the greater part of the ore. In Witwatersrand metamorphic processes influenced the distribution of uranium mineralization more than at Elliot Lake. In the uraniferous conglomerates of U.S.S.R. igneous processes also participated as well in the formation of uranium mineralization, but these facts do not change the placing of this type in the above mentioned genetic group. The uranium-bearing placers (1.3.2.) in sensu stricto are, however, known from only a few uranium-bearing areas. Different points of view may be taken for the classification of uranium-bearing marine sediments. In the proposed classification the phosphatic sediments (1.3.3.), the caustobioliths and carbonaceous shales (1.3.4.), as well as syngenetic deposits in limestones, clays and sandstones (1.3.5.) are distinguished.

The group of sedimentary-metamorphic deposits comprises the uranium-bearing graphitic shales and graphitic schists (1.4.1.) (Iron Ranges type) and the sedimentary-metamorphic deposits in metamorphosed argillaceous, micaceous and black shales (1.4.2.), which often contain pyritic and/or carbonaceous material.

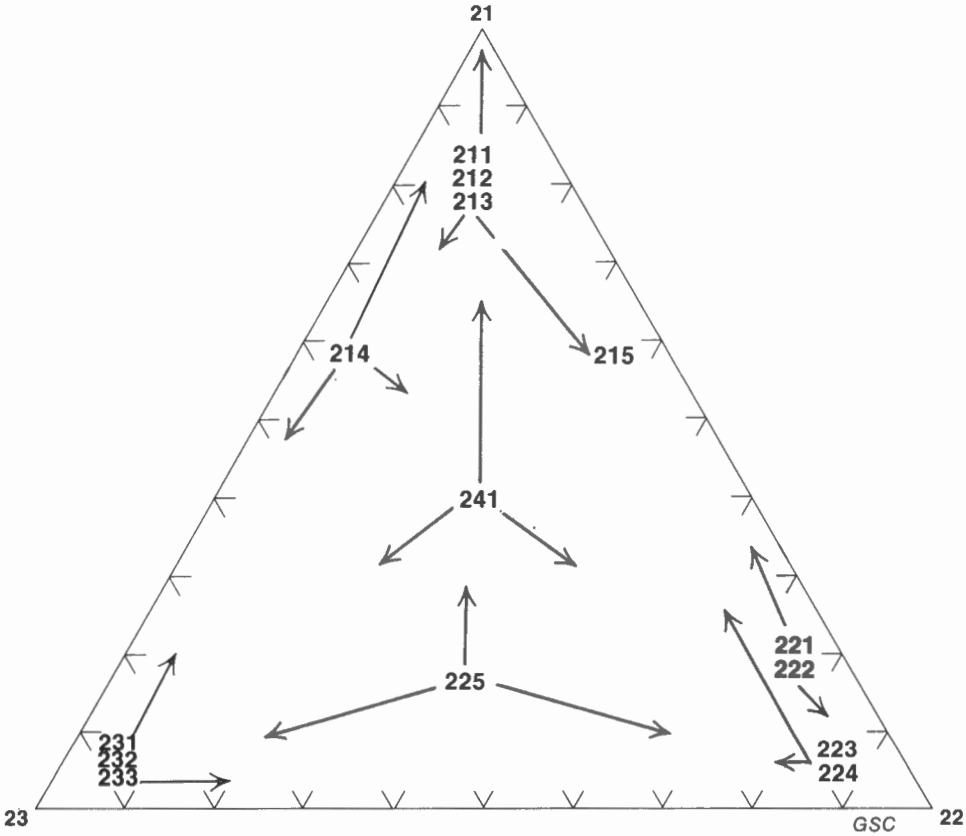
The (1.5.1.) metamorphogenetic disseminations (Aillik type) are characterized by arrangements of uranium minerals that follow the metamorphic



EXPLANATION

11 Igneous processes prevail
12 Igneous and sedimentary
13 Sedimentary
14 Sedimentary and metamorphic
15 Metamorphic
16 Metamorphic and igneous
111 Deposits in pegmatitic granites and syenites
121 Effusive sedimentary
131 Ancient conglomerates
132 Placers
133 Phosphatic sediments
134 Caustobioliths organic shales and related rocks
135 Syngenetic deposits in sandstones
141 Graphitic rocks
142 Sedimentary-metamorphic deposits in argillaceous, micaceous and black shales
151 Metamorphogenic disseminations
161 Granulites or analogous metamorphic rocks; (further explanation see text)

Figure 35. Schematic illustration of the principle of classification of uranium deposits formed by syngenetic magmatic and sedimentary, and metamorphic processes (by Ruzicka).



EXPLANATION

21 Impregnation and metasomatic types
22 Vein and related
23 Infiltration
211 Migmatites and general metasomatic
212 Alkalic metasomatites
213 Pyrochlore-bearing fenites
214 Skarns
215 Pyrometasomatic deposits in intrusives and extrusives
221 Davidite type
222 Brannerite type
223 Pitchblende with simple mineral assemblages
224 Pitchblende - polymetallic type
225 Sooty pitchblende with hydrous aluminum silicates in shear zones
231 Blanket type
232 Roll type
233 Epigenetic mineralization in lignites, coals, etc.
241 Pipe type with collapse structures; (further explanation see text)

Figure 36. Schematic illustration of the principle of classification of uranium deposits formed by epigenetic processes (by Ruzicka).

structural and textural features of the host rocks. Examples of this type of mineralization were mentioned from the Makkovik-Seal Lake uranium-bearing area. The mineralization of deposits from this group is commonly affected by epigenetic processes.

As an example of mineralization of the 1.6 group, the (1.6.1.) uraniferous granulites may be mentioned. The geological features of such type of mineralization were mentioned elsewhere in this paper.

Epigenetic types

The proposed classification of epigenetic uranium deposits is based on the generalization of processes which led to deposition of uranium compounds from uranium-bearing fluids within the diagenetically consolidated rocks. The epigenetic mineralization could impregnate[1] and replace the original rock mass, be emplaced in fractures in hard rocks (usually through precipitation of ore components from hydrothermal solutions) or be precipitated or sorbed in porous rocks (mainly from low temperature fluids) by infiltration[1]. The boundaries between the processes may not be sharp and one process may predominate or may only participate in the ore-formation. For the demonstration of the classification scheme the triangular diagram was used (see Fig. 36).

The groups of deposits are mnemonically characterized as (2.1.) impregnations and/or replacements, (2.2.) veins and related bodies formed from hydrothermal solutions, (2.3.) infiltrations, and (2.4.) epigenetic hybrid deposits.

The classification of deposits and types within individual groups may be based on various criteria too. For example the replacement uranium deposits (belonging here in the (2.1.) group) were classified by Tugarinov (in Vinogradov, editor, 1963) as follows: (a) deposits in iron-bearing rocks (amphibole schists and ferriferous quartzites), (b) in aluminum silicate rocks (quartzose micaceous schists, granitoids, skarns), (c) in carbonate rocks (dolomites, dolomitized schists, marbles), (d) in sediments containing organic matter (carbonaceous and graphitic schists), and (e) in sulphide-rich rocks.

Robinson's (1958) classification of the replacement types comprised the (a) general metasomatic uranium deposits, and (b) fenites.

The author's classification comprises types of deposits that were formed by impregnation in various geological environments, which deposits are: (2.1.1.) uranium-bearing migmatites and metasomatic deposits in general, (2.1.2.) deposits formed through alkalic metasomatism in ferriferous rocks (Krivoy Rog type), (2.1.3.) the pyrochlore-bearing fenites (Oka type), (2.1.4.) contact-metasomatic deposits in carbonate rocks (skarn type), (2.1.5.) pyrometasomatic deposits in intrusive and extrusive rocks (e.g. Rexspar deposit).

The localization of uranium mineralization within the deposits of the (2.1.) group is often structurally controlled.

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[1] The term "impregnation" is used here for designation of such processes that resulted from introduction of high temperature ore-bearing solutions, whereas the term "infiltration" for designation of low-temperature ore-bearing processes.

The deposits of the (2.2.) group were formed from uranium-bearing hydrothermal solutions, as a rule during decreasing gas pressure, the precipitation depended on the values of pH factor and Eh potential and was affected by the chemical reactions between the solutions and host rocks. All these factors influenced the character of mineralization, which as a rule developed in several stages. The main uranium stage was commonly represented by pitchblende in a simple mineral association. Davidite and brannerite as well as other radioactive minerals as a rule indicate specific ore-forming conditions. The nonradioactive mineral assemblages, which are usually developed within separate stages, are represented by iron oxides (hematite, goethite), sulphides of Fe, Cu, Pb, Zn, Bi, Ag, Mo, arsenides of Ni, Co, Fe, selenides of Pb, Cu, and native metals, or various associations of above mentioned assemblages. As gangue minerals quartz and/or carbonates, fluorite, barite, and hydrous aluminum silicates are mainly present. The main wall-rock alterations are developed as hematitization, sericitization, chloritization, silicification, argillization, albitization and carbonatization.

On the basis of the character of mineralization the following types of deposits are distinguished within the group of veins and related deposits: (2.2.1.) the davidite type (Radium Hill type), (2.2.2.) the brannerite type (deposit mentioned by Tishkin in Vol'fson, editor, 1966), (2.2.3.) the pitchblende type with simple mineral associations (Příbram or Beaverlodge types), the pitchblende-polymetallic type (2.2.4.) (Jachymov or Great Bear Lake types), and the pitchblende (commonly sooty)-hydrous aluminum silicates type in shear zones, often accompanied with graphite and/or fluorite (Rožná type).

The infiltration or low-temperature epigenetic uranium deposits represents a great part of economic uranium resources.

Gabelman (1969) listed some characteristic environments and geochemical features of this group of deposits. In order of decreasing favourability for occurrence of uranium deposits of the epigenetic (low temperature) origin he mentioned following environments: (1) alluvial, (2) lacustrine, (3) eluvial, (4) littoral, (5) lagoonal, and (6) shallow marine. The favourability of those environments was determined by the various degrees of permeability and the presence of different precipitating agents. Uranium was precipitated from solutions by rocks rich in constituents that cause precipitation by reduction, adsorption, ion exchange, ionic substitution or formation of insoluble uranyl complexes. The most influential materials are: carbonaceous matter, bacteriogenic H_2S, vegetal hydrocarbons, clay, and vanadium or phosphorus minerals.

Some characteristic features of the epigenetic deposits in porous sediments were also mentioned in previous chapters.

Saum and Link (1969) summarized the genetical features of sedimentary uranium deposits from the western United States and classified them into two types according to the possible modes of accretion of sedimentary uranium ores. The first type are deposits formed by prevalently downward migrating uraniferous solutions which they name the "blanket" type. The second type are deposits formed by laterally migrating solutions (i.e. peneconcordantly with the permeable beds) at the geochemical front, which may be partially defined by the parameters of pH, Eh, and ionic concentration of sulphate, carbonate, bicarbonate and uranyl ions, complicated by the activity of anaerobic bacteria, and are named the "roll" type. Similar processes caused the accumulation of uranium in some lignites and coals. The authors

Table 44

Geological classification of uranium deposits
(by V. Ruzicka)

Part 1

Classification			Characteristic			Example (reference)
Class	Group	Type	Geological environment	Mineralization	Other distinct features	
a	b	c	d	e	f	g
(1) Syngenetic magmatogenetic and sedimentary, and metamorphogenetic.	(1.1) Deposits formed mainly by igneous processes.	(1.1.1.) Deposits in pegmatitic granites and syenites (Grenville type).	Mainly pegmatite bodies which are complex mixtures of syenitic, granitic and quartz rich phases.	Uraninite, uranothorite, allanite, betafite, zircon, fergusonite, microcline-microperthite, antiperthite, sodic plagioclase, quartz, pyroxene, hornblende, minor biotite and muscovite; magnetite; fluorite, calcite.	Ore mineralization is mainly concentrated along dyke margins, adjacent to inclusions and in zones near internal fractures. Metamorphic (sedimentary) or epigenetic features may be present in varied degrees.	Deposits in the Grenville Province of Canadian Shield as mentioned in this paper, radioactive mineralization in granites and syenites mainly of Precambrian age. Lang et al. (1962), competent references in this paper.
	(1.2) Deposits formed by igneous and sedimentary processes.	(1.2.1.) Effusive-sedimentary deposits (Huta type).	Uranium mineralization is related to quartz-porphyry volcanic events. Uranium mineralization is confined mainly to tuffites and related rocks originated through volcanic and sedimentary processes.	Sooty pitchblende, pitchblende, secondary uranium minerals, molybdenite, chalcopyrite, tenantite-tetrahedrite, galena, sphalerite, arsenopyrite, ilmenite, magnetite, hematite, covellite.	The uranium mineralization is syngenetic due to differentiation through volcanic processes, accumulation during sedimentation with participation of hydrogen sulphide exhalations. Metamorphism may affect the distribution of mineralization.	Novoveska Huta and Muran deposits in the Czechoslovakian West Carpathians. Rojkovic (1968), Zhukov (1963), Drnzik (1965), Adamek (1967).
	(1.3) Deposits formed mainly by sedimentary processes.	(1.3.1.) Ancient conglomerates (Elliot Lake type).	Uranium mineralization mainly confined to quartz-pebble conglomerates comprised in basal sedimentary complexes unconformably overlying Precambrian complexes, in which with uranium enriched rocks were weathered. The igneous processes and metamorphism could influence the formation of deposits.	Uraninite, uranothorite, brannerite, allanite, xenotime, pyrite, hematite, magnetite, titanium minerals, gold and other minerals characteristic for placers.		Elliot Lake, anonymous deposit in the U.S.S.R., Witwatersrand, Jacobina. Roscoe (1969), Shcherbin (in Vol'fson, editor, 1968).
		(1.3.2.) Uranium-bearing placers.	Unconsolidated placers of Recent age.	The main radioactive minerals are pyrochlore, allanite, monazite, uraninite, zircon; nonradioactive: magnetite, garnet, ilmenite, pyrite.		Bugaboo Creek, British Columbia; Haggart Creek, Yukon Territory. Lang et al. (1962), Robinson (1958).

Table 44

Geological classification of uranium deposits
(by V. Ruzicka)

Part 2

Classification			Characteristic			Example (reference)
Class	Group	Type	Geological environment	Mineralization	Other distinct features	
a	b	c	d	e	f	g
(1) Syngenetic magmatogenetic and sedimentary, and metamorphogenetic.	(1.3) Deposits formed mainly by sedimentary processes.	(1.3.3.) Uranium-bearing phosphatic sediments.	Marine sediments with uranium content proportionally related to phosphate content (roughly) and inversely proportional to CO_2 content.	Uranium is as a rule a part of phosphate minerals, other compounds: collophanite, bitumen or organic matter, eventually iron, cobalt, molybdenum, rare earths and gold.	A specific example of deposit with uranium and rare earths sorbed by phosphate compounds of fish-bone detritus is known from U.S.S.R.	Fernie group, Rocky Mountains (Canada), very low grade mineralization; anonymous deposit from U.S.S.R.; some deposits in U.S.A. Robinson (1958), Lang et al. (1962), Gotman and Zubrev (1963).
		(1.3.4.) Caustobioliths, organic shales and related rocks with syngenetic uranium mineralization (Chatanooga type).	Pre-orogenic deposits in marginal part of platform adjacent to geosyncline mostly of Paleozoic age.	Uranium is finely distributed and mainly proportionally related to carbonaceous matter; clay minerals, pyrite, quartz, feldspar etc.		Marine shales in Saskatchewan, mineralization in graptolitic shales in Barrandien (Czechoslovakia): from other countries: Chattanooga shale and Kvarntorp and Ranstad (Sweden). Klepper-Wyant (1957), Peterson (1967), Robinson (1958).
		(1.3.5.) Syngenetic deposits in (limestones), (clays) and sandstones.	Mainly marine sediments.	Uranium as a rule does not appear in mineral forms.	According to Surazhskiy (1960) the syngenetic deposits in marine sandstones are similar to the deposits in black shales, but they do not contain phosphatic material. They are rich on quartzose siltic material.	Deposits mentioned by Surazhskiy (1960) as representants of the tenth type in his classification.
	(1.4) Deposits formed mainly by sedimentary and metamorphic processes.	(1.4.1.) Uranium-bearing graphitic shales and graphitic schists (Iron Ranges type).	Syngenetically deposited uranium in marine sediments was further locally concentrated by moderate metamorphic processes.	Uraninite, secondary uranium minerals; uraniferous turquoise, kolovratite, volborthite, vanadium minerals.		Mineralization from Middle Asia (U.S.S.R.), Iron Ranges (U.S.A.). Klepper and Wyant (1956).
		(1.4.2.) Sedimentary - metamorphic deposits in argillaceous, micaceous and black shales.	Argillaceous, micaceous and black shales and dolomitized limestones; graptolithic and other material of organic origin; pyrite containing rocks.	Pitchblende, sooty pitchblende; quartz, sericite, clay minerals, calcite, dolomite, pyrite, chalcopyrite, sphalerite, galena, bravoite, graphite, pyrophyllite, marcasite, chloanthite, niccolite, chlorite, pyrobitumen, anthraxolite.	Uranium mineralization occurred syngenetically with sedimentation and was concentrated during the metamorphic processes.	Anonymous deposit mentioned by Getseva (1958) and by Surazhskiy (1960).

Table 44

Geological classification of uranium deposits
(by V. Ruzicka)

Part 3

Classification			Characteristic			Example (reference)
Class	Group	Type	Geological environment	Mineralization	Other distinct features	
a	b	c	d	e	f	g
(1) Syngenetic magmatogenetic and sedimentary, and metamorphogenetic.	(1.5) Deposits formed mainly by metamorphic processes.	(1.5.1.) Metamorphogenic disseminations (Aillik type).	Uranium contained in original sedimentary or igneous rocks was further concentrated by metamorphic processes.	Pitchblende, quartz, feldspar, biotite, hornblende, pyrite, hematite.	The arrangement of uranium minerals follows usually the metamorphic structural and textural features of the host rocks.	Several localities within the Makkovik-Seal Lake uranium-bearing area. Beavan (1958), Gandhi et al. (1969), Little and Ruzicka (1970).
	(1.6) Deposits formed mainly by igneous and metamorphic processes.	(1.6.1.) Granulites and/or lithologically analogous uraniferous metamorphic rocks (Makkovik type).	Metamorphic rocks.	Pitchblende, hematite, plagioclase, clinopyroxene, apatite, quartz, calcite, (soddyite).	Ore-mineralization may be affected by epigenetic processes.	Occurrence in the Makkovik-Seal Lake uranium-bearing area. Steacy (1969), written communication).

Table 44

Geological classification of uranium deposits
(by V. Ruzicka)

Part 4

Classification			Characteristic			Example (reference)
Class	Group	Type	Geological environment	Mineralization	Other distinct features	
a	b	c	d	e	f	g
(2) Epigenetic uranium deposits.	(2.1) Impregnation and metasomatic types of deposits.	(2.1.1.) Uranium-bearing migmatites and general metasomatic deposits.	Migmatites in gneisses.	Uraninite, thorianite, thorite, monazite, rare earth silicates, biotite, apatite, pyrite, fluorite, molybdenite, magnetite.		Charlebois Lake, Beaverlodge migmatites, Cardiff Mine, Normingo. Robinson (1953).
		(2.1.2.) Deposits formed by alkalic metasomatism in ferriferous rocks (Krivoy Rog type).	Quartzites and related rocks of Precambrian age with iron-ore mineralization, migmatitized and altered (by aegirinization, rhodusitization, albitization and carbonatization).	Uraninite, magnetite, hematite, aegirine, rhodusite, malacon, pitchblende, uranium silicate (nenadkevite), aragonite, graphite, pyrite, galena, marcasite, quartz, carbonates.	Uranium mineralization is related to the alkaline-silicate and carbonate metasomatism.	Uranium deposit at the edge of the Krivoy Rog iron ore-deposit. Reference of such type: Kotlyar (1961), Petrov et al. (1969).
		(2.1.3.) Pyrochlore-bearing fenites (Oka type).	Carbonate and alkaline rocks intruded into gneisses or other rocks.	Calcite, pyrochlore, betafite, niocalite, niobian perovskite. Uranium occurs as a minor constituent of niobium minerals.	Replacement of original minerals in rocks by calcite, soda pyroxene, soda amphibole or chlorite.	Quebec Columbium property near Oka, Quebec. Lang et al. (1962).
		(2.1.4.) Contact-metasomatic deposits in carbonate rocks (skarn type).	Deposits formed in carbonate rocks at the contact with intrusives.	Uraninite, allanite; sulphides, garnet, diopside, scapolite, microcline, albite.		Kotlyar (1961).
		(2.1.5.) Pyrometasomatic deposits in intrusive or extrusive rocks.	Granite-porphyries, lava flows and tuffs with epigenetic impregnations of uranium mineralization mainly of metasomatic character.	Uraninite, uranothorite, pitchblende, rutile, phlogopite, feldspar, sulphides, carbonates, fluorite, etc. or some of them.	"Porphyry-uranium", "liparite formation", uranium mineralization in trachytic rocks etc.	Anonymously described deposits in U.S.S.R., Rexspar in British Columbia (Canada). Vol'fson (1968), Lang et al. (1962), Wambeke (1967).
	(2.2) Veins and related types of uranium deposits.	(2.2.1.) Davidite type.	Amphibolites, granites, gabbro. Lower structural level.	Davidite, diopside, scapolite, chert, carbonates, plagioclase, tourmaline, ilmenite, rutile, pyrite, chalcopyrite, pyrrhotite, molybdenite, apatite, etc.		Radium Hill, Australia. Nininger (1954), Tishkin (1966).
		(2.2.2.) Brannerite type.	Gneisses, amphibolites, granites, quartzites, albitites. Lower structural level.	Brannerite, zircon, apatite, ilmenite, pyrite, chlorite, rhodizite, magnetite, etc.		Deposits mentioned by Tishkin (in Vol'fson, 1966), Zavarzin (1961).

Table 44

Geological classification of uranium deposits
(by V. Ruzicka)

Part 5

Classification			Characteristic			Example (reference)
Class	Group	Type	Geological environment	Mineralization	Other distinct features	
a	b	c	d	e	f	g
(2) Epigenetic uranium deposits.	(2.2) Veins and related types of uranium deposits	(2.2.3.) Pitchblende (with simple mineral associations) type (Pribram-Beaverlodge type).	Veins and related bodies in igneous, metamorphic and rarely unmetamorphosed sedimentary rocks.	Pitchblende, quartz, carbonates, iron oxides, sulphides, uranoan anthraxolite or some of these minerals.	Mainly pitchblende mineralization in carbonate, quartz-carbonate or quartz gangue. Alterations of wall-rocks. The boundaries between this and the next type are not sharp.	Most deposits in the Beaverlodge uranium-bearing area, Pribram uranium deposit etc. Robinson (1955), Klepper and Wyant (1957), Hruby-Sorf (1968), Harlass and Schuetzel (1965), Vol'fson, editor (1966, 1968).
		(2.2.4.) Pitchblende-polymetallic type (Jachymov-Great Bear Lake type).	Veins and related bodies in igneous, metamorphic and rarely unmetamorphosed sedimentary complexes.	Pitchblende, quartz, carbonates, iron oxides, sulphides, arsenides Co, Ni, sulpharsenides, selenides, native silver, bismuth, arsenic, copper.	Mineralization is developed in several stages; wall-rock alterations.	Uranium deposits in the Great Bear Lake uranium-bearing area, in the Krusne hory (Erzgebirge) Mountains, and many others. Robinson (1958), Dymkov (1960), Mrna (1961, 1963, 1967), Sattran (1966), Vol'fson (1968), Campbell (1955), Jory (1964).
		(2.2.5.) Pitchblende (often in the sooty form) with hydrous aluminum silicates in shear zones (Rozna type).	Shear zones (often of regional character) in metamorphic rocks.	Sooty pitchblende, pitchblende, uranoan anthraxolite, hydrous aluminum silicates, graphite, fluorite, sulphides or some of these components.	Irregular orebodies, often structurally controlled. Wall-rock alterations developed as argillization, fluoritization, graphitization. Hematitization as a rule absent. (Various grades of alterations.)	Rozna, Zadni Chodov, Hermanicky and some other deposits in Czechoslovakia, deposits mentioned by Tananaeva (in Vol'fson, 1968), probably Rabbit Lake deposit at Wollaston Lake in Canada. Little, Ruzicka (1970), Vol'fson, editor (1968).

Table 44

Geological classification of uranium deposits
(by V. Ruzicka)

Part 6

Classification			Characteristic			Example (reference)
Class	Group	Type	Geological environment	Mineralization	Other distinct features	
a	b	c	d	e	f	g
(2) Epigenetic uranium deposits.	(2.3.) The group of infiltration types of deposits.	(2.3.1.) Blanket type.	Deposits formed in porous sedimentary rocks from prevalently downward migrating uranium containing solutions.	Uranium oxides, silicates, uranyl-hydroxide, uranium vanadates, carbonates, sulphates, phosphates, sulphides, or various assemblages of those and other components with carbon, iron, vanadium, selenium, etc.		Mecsek deposit in Hungary. Barabas and Virag (1966), Saum and Link (1969).
		(2.3.2.) Roll type.	Deposits formed in porous sedimentary rocks from the solutions migrating peneconcordantly with the permeable beds.	Sooty pitchblende, coffinite, fluorapatite; vanadium, copper, silver, lead, zinc minerals; sulphides, carbonates, vanadates, sulphates; carbon-rich matter.	Uranium is precipitated at the oxidation/reduction front.	Hamr deposit in Czechoslovakia, many epigenetic uranium deposits in sandstone in the U.S.A. Finch (1967), Vinogradov, editor (1963).
		(2.3.3.) Infiltration deposits in lignites or coals (Dakota type).	Deposits formed in lignites or coal similarly as the two (2.3.1.) and (2.3.2.) types or one of both.	Autunite, carnotite, torbernite, zeunerite, lignite or coal; material with small amounts of molybdenum, vanadium, copper. phosphorus, arsenic, germanium, beryllium, etc.	Uranium was introduced in the coal after coalification by waters. The participation of syngenetic processes may be not excluded.	Cypress Hills in Saskatchewan (Canada), uranium mineralization in Tertiary lignites and Permocarboniferous coals within Bohemian massif. Denson et al. (1959), Cameron and Birmingham (1969), Skocek (1967), Lepka (1967).
	(2.4.) Transitional group.	(2.4.1.) Pipe type (Orphan pipe type) of collapse origin.	Ore solutions sought to be hydrothermal which used the permeability and porosity of rocks and possibly reacted with them.	Minerals containing uranium, copper, lead, zinc, molybdenum, cobalt, silver and nickel.	This type of deposit can be classified within a transitional group of epigenetic uranium deposits.	Orphan pipe at Grand Canyon (U.S.A.), perhaps an anonymous deposit mentioned by Velichkin (in Vol'fson, editor, 1968), Saum and Link (1969).

also mentioned another type of epigenetic deposits, which represents a transitional type between all three groups of epigenetic deposits according to the classification proposed in this paper. The ore-bearing solutions forming this type of deposit, believed to be hydrothermal, used the permeability and porosity of rocks in a volcanic pipe, and possibly reacted with them ("pipe" type).

Using previously mentioned genetic features and generalizing the epigenetic processes the deposits within the (2.3.) group were classified as (2.3.1.) the blanket type, (2.3.2.) the roll type and (2.3.3.) the infiltration deposits in lignites or coals.

As an example of the deposits which belong to the (2.4.) hybrid group of deposits the pipe type with collapse structures (2.4.1.) (Orphan pipe type) can be selected. A deposit that can, with some reservations, be placed in the same group was described by Velichkin (in Vol'fson, editor, 1968) from U.S.S.R.

For summarized review of selected geological features of the genetic types of uranium deposits as well as selected examples from Canada and East Europe (inclusive the Asian part of U.S.S.R.) and elsewhere, see Table 44.

THE COMPARISON BETWEEN CANADIAN AND EAST EUROPEAN URANIUM DEPOSITS

The following regularities in the development of uranium mineralization and other interesting features are shown by a comparison between Canadian and East European uranium deposits.

Although the uranium-bearing pegmatitic granites and syenites occur as a common member of the Precambrian intrusives or granitized complexes, only few deposits of this type are exploited for uranium. A classical area with uranium deposits of such type is the Grenville Province in Canada. The geological features of the Faraday Mine deposit as well as a generalized characteristic of the pegmatitic uranium occurrences in the Bancroft area are presented on the Tables 45 and 46. The radioactive pegmatites from East Europe were studied by Nováček (1936), Fersman (e.g. 1931), Kuzmenko et al., editor (1965), Černý (1967) and by others, but as may be concluded from Gotman's and Zubrev's (1963) reference they are not significant there as a uranium source.

The effusive-sedimentary type of deposits occurs in the Czechoslovakian West Carpathians and its representatives, the Novoveska Huta and Muran deposits, are reviewed in the Table 47. The uranium mineralization is accompanied by molybdenum and copper mineralization within these deposits. Their exact analogue is not yet known from Canada.

Within the group of syngenetic sedimentary deposits the uraniferous quartz-pebble conglomerates are comparable from both Canada and the U.S.S.R. The geological features of the representative deposits are mentioned in an abbreviated form in Table 48. Their common features are: the radioactive mineralization is confined to the quartz-pebble conglomeratic facies of sedimentary complexes unconformably overlying the Precambrian basement rocks. Near the deposits the granites primary enriched by radioactive elements underwent an intensive weathering which also caused the separation of uranium compounds from the solid rocks. The chemical and

Table 45

Geological features of Canadian and East European uranium deposits

	Canadian	East European
1. Host rocks		
(a) Lithology	(a) Mainly pegmatite bodies which are complex mixtures of syenitic, granitic and quartz-rich phases.	
(b) Age	(b) Radioactive minerals from pegmatitic rocks range from 1,100 to 800 million years (mid-Proterozoic). Grenville Group.	
2. Mineralization		
(a) Mineral assemblage	(a) Uraninite, uranothorite, allanite, betafite, zircon, fergusonite, microcline-microperthite, antiperthite, sodic plagioclase, quartz, pyroxene, hornblende, minor biotite and muscovite; magnetite; fluorite, calcite. Close association of ore and accessory minerals with iron-bearing minerals.	
(b) Mineral sequence		
3. Other features	Ore mineralization is concentrated along dyke margins, adjacent to inclusions, in zones near internal fractures. Mineralization may have been derived from sedimentary rocks of littoral or protopelitic origin situated in or below the Grenville Group.	
4. Example	Bancroft area (general) (Lang et al., 1962). Remark: For further references see the competent parts in the text.	

Table 46

Geological features of Canadian and East European uranium deposits

	Canadian	East European
1. Host rocks		
(a) Lithology	(a) Leucogranite, leucogranite pegmatite, pyroxene granite, syenite pegmatite dykes, which cut the gabbro and amphibolite.	
(b) Age	(b) Radioactive minerals from pegmatitic rocks range from 1,100 to 800 million years (mid-Proterozoic).	
2. Mineralization		
(a) Mineral assemblage	(a) Uraninite, uranothorite in associations with magnetite, quartz, altered pyroxene, hornblende, feldspar. The most common gangue mineral, quartz occurs in two generations in the ore. The common mineral is magnetite.	
(b) Mineral sequence		
3. Other features		
4. Example	Faraday mine deposit, Bancroft area (Lang *et al.*, 1962).	

Table 47

Geological features of Canadian and East European uranium deposits

	Canadian	East European
1. Host rocks		
(a) Lithology		(a) Quartz-porphyries, tuffites, arkose shales, porphyroids and tuffs.
(b) Age		(b) Permian.
2. Mineralization		
(a) Mineral assemblage		(a) In quartz-porphyries: pitchblende, sooty pitchblende (uranium blacks), chalcopyrite, tenantite-tetrahedrite, pyrite, sphalerite, molybdenite. In tuffites: pitchblende, sooty pitchblende (uranium blacks), molybdenite, chalcopyrite, tenantite-tetrahedrite, galena, sphalerite, arsenopyrite, ilmenite, magnetite, hematite, covellite, autunite, torbernite, tyuyamunite. In arcose shales, porphyroids and tuffs: sooty pitchblende (uranium blacks).
3. Other features		The uranium mineralization is syngenetic. The source of ore elements were quartz-porphyries. The quartz-porphyry volcanism occurred during the sedimentation of tuffaceous rocks. The hydrogen sulphide exhalations caused precipitation of ore elements; the subsequent metamorphic processes caused local mobilization, migration and accumulation of ore elements.
4. Example		Novoveská Huta and Muráň deposits, Czechoslovakia, West Carpathians.

Table 48

Geological features of Canadian and East European uranium deposits

	Canadian	East European
1. Host rocks (a) Lithology	(a) Uraniferous conglomerates of the Matinenda Formation. Pyritic conglomerates of quartz and chert pebbles in a matrix of sericitic, feldspathic quartzite.	(a) Uraniferous conglomerates composed mainly of vein quartz pebbles; oligomict conglomerates composed of quartz and granite pebbles; polymict conglomerates composed of quartz, quartzite, granite and schist pebbles.
(b) Age	(b) Proterozoic (Aphebian).	(b) Uraniferous conglomerates are a member of Cambrian complexes unconformably overlying the Precambrian granite, schists and gneisses.
2. Mineralization (a) Mineral assemblage	(a) Uraninite, brannerite, thucolite, uranothorite, uranothorianite, coffinite, allanite, xenotime, gummite, pyrite, garnet, spinel, chromite, cassiterite, tourmaline, rutile, magnetite, hematite, ilmenite, sphene, apatite, fluorite, barite, muscovite, phlogopite, grunerite, epidote, zoisite.	(a) Microcline, malacon, thorite, uranothorite, allanite, ilmenite, rutile, brannerite(?), hematite, magnetite, secondary autunite, in smaller amounts titanium-tantalum-niobates priorite, monazite, xenotime, pyrite and chalcopyrite. Mineralization in veinlets is represented by quartz, ilmenite, hematite, thorite, uranothorite, zircon. Disseminations are represented by allanite.
(b) Mineral sequence		
3. Other features	Uranium mineralization is developed within several zones in gently to steeply dipping beds. The most productive uranium-bearing zones are represented by quartz-pebble conglomerate.	The most productive uranium-bearing zone is represented by monomict quartz-pebble conglomerate.
4. Example	The Elliot Lake area (Roscoe, 1969).	Uranium deposit in U.S.S.R. (Shcherbin, 1968).

mineral composition of the source rocks (hypothetical) and the ore-bearing zones show in many cases correlation. On the other hand the uranium-bearing conglomerates mentioned from the U.S.S.R. were also affected by the activity of hydrothermal solutions, but the intensity of that phase seems to be not substantial among the ore-forming processes. Another different feature between those deposits is the age of uraniferous conglomerates. The Canadian deposit belong to the Proterozoic (Aphebian), whereas the U.S.S.R. belongs to the Cambrian.

The other types of deposits within the syngenetic sedimentary group, i.e. placers, phosphatic sediments, syngenetic mineralization in caustobioliths, sandstones, limestones and clays are either present in only one of the compared territories, or less published than other types. A similar situation is the case of other types of deposits within the sedimentary-metamorphic, metamorphic or igneous-metamorphic groups.

Because of the great potential source of radioactive raw material from the sedimentary-metamorphic types of uranium deposits, which may be also found within many extensive favourable areas, the metamorphic black shale type has to be mentioned. Some geological features of deposits belonging to this type are summarized in the Table 49. According to Getseva (1958) the black shales of the Rum Jungle region, the Iron ranges, and the uranium ores confined to lower Paleozoic rocks, which show no association with exposures of Variscan granites, may be classified as sedimentary-metamorphic type of uranium mineralization, coincides in with the author's classification comprised in this paper.

Within the epigenetic class of uranium deposits three types of deposits were selected from the metasomatic group for the comparison purposes: the type of the "iron formation" (Krivoy Rog type), the pyrochlore-bearing fenites (Oka type) and the pyrometasomatic deposit in trachytes (Rexspar type).

The metasomatic mineralization confined to the border facies of a hematite-magnetite iron ore deposit in the Precambrian complexes is related to alkaline-silicate and carbonate metasomatism. The host-rocks are strongly fractured and intruded by granites. The intrusion of granites was accompanied by migmatitization of the host rocks. (A review of some characteristic geological features is comprised in the Table 50.) In Canada similar conditions were not found within analogous Precambrian iron deposits. On the other hand such possibility cannot be excluded.

Uranium-bearing niobium mineralization related to intrusions of carbonate and alkaline rocks was reported by Lang et al. (1962) from Quebec Columbium property near Oka, Quebec (see Table 51). Analogous mineralization was not reported from the East European deposits.

Mineralization of the Rexspar type is shown by Table 52.

Within the group of vein and related epigenetic deposits many similarities exist between the Canadian and East European uranium deposits. For example the deposits from the Great Bear Lake area and the deposits from the Krušné hory (Erzgebirge) in Europe, e.g. from the Jáchymov area show many parallel features.

In abbreviated form the description of some selected geological features of deposits from those areas are comprised in Table 53.

Some such analogous features are:

1. The uranium deposits occur in areas with broadly developed and complicated tectonic activity. The uranium-bearing areas are parts of larger

Table 49

Geological features of Canadian and East European uranium deposits

	Canadian	East European
1. Host rocks		
(a) Lithology		(a) Argillaceous, micaceous and black shales and dolomitized limestones. Presence of the graptolithic member within the Paleozoic complexes, other organic material and considerable quantity of pyrite.
(b) Age		(b) Lower Paleozoic.
2. Mineralization		
(a) Mineral assemblage		(a) Quartz, sericite, clay minerals, calcite, dolomite, disseminated organic material, pyrite, chalcopyrite, sphalerite, galena, bravoite, graphite, pyrophyllite, (sooty) pitchblende, marcasite, chloanthite, niccolite, chlorite, pyrobitumen types of anthraxolite.
(b) Mineral sequence		(b) Three stages of mineralization[1]: (1) recrystalization, dehydration, carbonization; (2) ore metasomatism; (3) formation of veins and cement of breccia.
3. Other features		This type of uranium deposit is classified as sedimentary metamorphogenic in this paper.
4. Example		Anonymous uranium deposit in East Europe (Getseva, 1958; further references in text).

[1] During the metamorphic phase.

Table 50

Geological features of Canadian and East European uranium deposits

	Canadian	East European
1. Host rocks		
(a) Lithology		(a) Quartzites and accompanied rocks. The host-rocks are migmatitized, altered by aegirinization, rhodusitization, albitization and carbonatization and carry also hematite-magnetite mineralization.
(b) Age		(b) The host-rocks are Proterozoic in age.
2. Mineralization		
(a) Mineral assemblage		(a) Uraninite, magnetite, hematite, aegirine, rhodusite, malacon, pitchblende, uranium silicate (nenadkievite), aragonite, graphite, pyrite, galena, marcasite, quartz, carbonates.
(b) Mineral sequence		
3. Other features		The occurrence of uranium deposits together with iron deposits is caused mainly by structural conditions. Uranium mineralization is related to the alkaline-silicate and carbonate metasomatism. The uranium mineralization can be parallelized with other metasomatic types of uranium mineralization.
4. Example		Uranium deposits at the edge of Krivoy Rog iron deposit (U.S.S.R.).

Table 51

Geological features of Canadian and East European uranium deposits

	Canadian	East European
1. Host rocks		
(a) Lithology	(a) Carbonate and alkaline rocks intruded into gneisses and other rocks of the Grenville Province of the Canadian Shield.	
(b) Age	(b) Carbonate and alkaline rocks are probably post-Precambrian.	
2. Mineralization		
(a) Mineral assemblage	(a) Calcite, pyrochlore, betafite, niocalite, niobian perovskite. Uranium apparently occurs as a minor constituent of niobium minerals.	
(b) Mineral sequence		
3. Other features	Alteration of gneiss, granulite, anorthosite and gabbro is caused chiefly by replacement of original minerals by calcite, soda pyroxene, soda amphibole or chlorite.	
4. Example	Quebec Columbium property near Oka, Quebec (Lang *et al.*, 1962).	

Table 52

Geological features of Canadian and East European uranium deposits

	Canadian	East European
1. Host rocks		
(a) Lithology	(a) Trachytic member of Permian or earlier complexes at the contact with rocks of the Shuswap metamorphic complex. The orebodies occur in trachytic tuff and breccia.	
(b) Age	(b) Permian or earlier.	
2. Mineralization		
(a) Mineral assemblage	(a) Uraninite, uranothorite, rutile, phlogopite, feldspar, sulphides, fluorite, apatite, carbonates, celestite. Uraninite and uranothorite are commonly associated with rutile.	
(b) Mineral sequence	(b) Ore mineralization has replacement character.	
3. Other features	Both the orebodies and the trachytic members are elongated in the northeast direction.	
4. Example	Rexspar deposit, British Columbia, Cordilleran region.	

Table 53

Geological features of Canadian and East European uranium deposits

	Canadian	East European
1. Host rocks		
(a) Lithology	(a) Sedimentary-volcanic rocks of Echo Bay Group intruded by granites, porphyries and diabases.	(a) Metasediments cut by intrusive and effusive rocks.
(b) Age	(b) Precambrian.	(b) Metasediments are of Proterozoic to early Paleozoic age. Granites probably Upper Carboniferous. Volcanics are Tertiary.
2. Mineralization		
(a) Mineral assemblage	(a) Apatite, quartz, hematite, pitchblende, Ni-Co arsenides, pyrite, chlorite, white mica, barite, siderite, dolomite, sphalerite, tetrahedrite, bornite, chalcopyrite, galena, calcite, rhodochrosite, silver minerals, native bismuth.	(a) Quartz, arsenopyrite, pyrite, galena, sphalerite, chalcopyrite, bornite, ankerite, hematite, dolomite, pitchblende, fluorite, native silver, native bismuth, skutterudite, rammelsbergite, niccolite, safflorite, loellingite, gersdorfite, bismuthite, native arsenic, proustite, pyrargyrite, argentite, sternbergite, stephanite, stibnite, realgar, tennantite, calcite.
(b) Mineral sequence	(b) Six stages of mineralization: (1) quartz-hematite, (2) pitchblende-quartz-hematite, (3) quartz-arsenides, (4) iron and copper sulphides-chlorite, (5) sulphides-carbonate, (6) Bi-Ag.	(b) Six stages of mineralization: (1) early sulphides, (2) quartz-hematite, (3) pitchblende, (4) arsenides, (5) sulpharsenides, (6) later sulphides.
3. Other features	Alterations: hematitization, argillitization, chloritization, carbonatization, partly silicification, sericitization, sulphidization, concentration of apatite. Structural and lithological control of uranium mineralization; mineralization is confined to quartz-carbonate veins.	Alterations: formation of skarns, biotitization, scapolitization, pyritization, chloritization, graphitization, silicification, carbonatization, hematitization, sericitization, kaolinization, greisenization. Structural and lithological control of uranium mineralization; mineralization is confined to quartz-carbonate veins.
4. Example	Deposits within the Great Bear Lake area.	Deposits within the Jáchymov (Erzgebirge) area.

metallogenetic provinces, where other deposits with metallic mineralization are developed.

2. The metamorphosed complexes are spatially related with granitic and granite-related rocks.
3. Distribution of uranium deposits and the localization of uranium mineralization within them are structurally and lithologically controlled. Uranium deposits are developed at intersections of regional deep fault and fracture systems, along which the tectonic movements were several times repeated.
4. The mineralization is confined to quartz-carbonate or carbonate veins and is developed in several stages. In both cases the hematite, pitchblende, arsenide and sulphide minerals stages are (with some nuances) developed. Beside uranium, metallic elements such as silver, bismuth, nickel, cobalt, but also copper, lead, zinc and iron are commonly present. Pitchblende mineralization, which in both cases represents the overwhelming quantity of uranium mineralization, is present either in a separate stage or redeposited within mineral assemblages of later stages.
5. The alteration of wall-rocks is in both areas represented by hematitization, chloritization, silicification, carbonatization, sericitization and pyritization (sulphidization). The general widespread argillization in the Great Bear Lake area has its quasi analogy in kaolinization in the Jáchymov area.

On the other hand the deposits from those areas differ each from other:

1. In the relation of the main uranium mineralization period to the geotectonic events: the absolute age of the main uranium mineralization from the Great Bear Lake area coincides roughly with the period of Elsonian Orogeny (or occupies the period between Hudsonian and Grenville Orogenies), whereas the mineralization in the Erzgebirge area is related to the Variscan Orogeny. Thus the difference in the absolute age of uranium mineralization from both areas represents roughly 1,000 million years or more.
2. The metamorphosed sedimentary-volcanic complexes of the Echo Bay Group are Proterozoic (Aphebian), whereas the Klínovec, Jáchymov, Barbara and Potůčky Series occupy the time period from Proterozoic to early Paleozoic.
3. A significant mineral which often occurs in the mineral assemblage with pitchblende in the Erzgebirge deposits, the dark purple fluorite, is not listed as a member of the mineral assemblage from the Great Bear Lake area.

A deposit with an assemblage which comprises pyrite-quartz, quartz-barite, pitchblende-arsenides, quartz-carbonate-sulphide and prehnite-calcite and zeolites-calcite veins, was mentioned by Strelcov (in Vol'fson, editor, 1968) from the U.S.S.R. Its characteristic features are described in the second part of this paper.

Some similarities may be found between the deposits in the Beaverlodge and Příbram areas. A prominent analogous geological feature is the structural control in the distribution of uranium deposits and in the localization of uranium mineralization within them. From the Beaverlodge area Tremblay (1968) classified the epigenetic deposits as breccia, stockwork, network and dissemination, dissemination, and vein, among which the vein type belongs to the most common types of deposits, but the breccia, the stockwork, and the network and dissemination deposits are the most important. He

Table 54

Geological features of Canadian and East European uranium deposits

	Canadian	East European
1. Host rocks		
(a) Lithology	(a) Metamorphosed rocks of Tazin Group: quartzites, amphibolites, granites, quartz-feldspathic gneisses and garnet-bearing rocks. Martin Formation: basal conglomerate, arkose, siltstone, basaltic flows and gabbroic sills.	(a) Slightly metamorphosed pelitic and coarser sediments intruded by dykes of the Central Bohemian pluton dyke suite. These complexes overlay black shales and volcanics.
(b) Age	(b) Precambrian.	(b) Late Proterozoic (Algonkian) spilitic and post-spilitic series.
2. Mineralization		
(a) Mineral assemblage	(a) Oligoclase, albite, hematite, calcite, chlorite, quartz, nolanite, pitchblende, arsenides, pyrite, chalcopyrite, galena, gold, bornite, selenides, copper; thucolite. Veins are most common type of deposit.	(a) Carbonates, pitchblende, uranoan-anthraxolite, galena, sphalerite, pyrite, other metallic minerals are present in small amounts only.
(b) Mineral sequence	(b) Six stages of mineralization: (1) feldspar-hematite, (2) pitchblende-carbonate-chlorite, (3) pitchblende-hematite-chlorite, (4) pitchblende-calcite-sulphides, (5) selenides, (6) calcite-pitchblende-copper.	(b) Five generations of carbonates; uranium mineralization is chiefly in the third and fourth generations of carbonates.
3. Other features	Alteration: hematitization, chloritization, epidotization, silicification, carbonatization, albitization. Uranium (pitchblende) mineralization is developed in veins and irregular orebodies. Localization of uranium mineralization is structurally controlled.	Alteration: chloritization, sericitization, hematitization developed in limited extension from the carbonate veins. Localization of uranium mineralization is mainly structurally controlled.
4. Example	Epigenetic uranium deposits in the Beaverlodge area.	Uranium deposits in the Příbram uranium-bearing area.

Remarks: For references see text.

Table 55

Geological features of Canadian and East European uranium deposits

	Canadian	East European
1. Host rocks		
(a) Lithology		(a) Sandstones and accompanied sedimentary rocks.
(b) Age		(b) Cretaceous.
2. Mineralization		
(a) Mineral assemblage		(a) The main representative of uranium mineralization is probably sooty pitchblende
(b) Mineral sequence		
3. Other features		Uranium deposits in sandstones were formed by precipitation or adsorption of uranium from low temperature waters. Adjacent igneous rocks are believed to be the primary source of uranium.
4. Example		Epigenetic low temperature uranium deposits in sandstones of the North Bohemian Cretaceous basin.

Table 56

Geological features of Canadian and East European uranium deposits

	Canadian	East European
1. Host rocks		
(a) Lithology		(a) Arkosic sandstones, siltstones with clayey-carbonate matrix, argillites; "red" and "grey beds". Terrigenous sediments.
(b) Age		(b) Upper Permian.
2. Mineralization		
(a) Mineral assemblage		(a) Uranium oxides, silicates, uranyl-hydroxide and in smaller amounts carbonates, sulphates, phosphates, galena, chalcopyrite and traces of other sulphides.
(b) Mineral sequence		
3. Other features		Uranium was leached from "red beds" under oxidizing conditions, transported by low temperature waters and precipitated under reducing conditions. The age of mineralization is supposed Upper Jurassic and Lower Cretaceous, but also recent mineralization appears to be present.
4. Example		Mecsek deposit in Hungary.

Remarks: References see text.

mentioned that the vein type belongs apparently as in the Ace mine, to the latest pitchblende-bearing types of deposits. The most common gangue minerals are calcite, chlorite, and quartz. In some deposits (e.g. Bolger) the pitchblende mineralization is confined to masses of calcite. Within the Příbram uranium-bearing area the pitchblende mineralization is mainly confined to carbonate veins, which according Píša (1966) belong probably to the latest hydrothermal phases of mineralization within the Proterozoic complexes in the Příbram area and possibly also in the whole Barrandien.

Some features with the two areas differ substantially, e.g. the absolute age of pitchblende mineralization, the lithological character of the host rocks, the grade of metamorphism of the host rocks, the mineral sequence as well as some mineral associations within the deposits. (For comparison of some geological features of deposits from both areas see Table 54.)

In this text favourable conditions for the occurrence of sedimentary epigenetic types of uranium mineralization in Canada were mentioned. The most suitable comparison is with analogous conditions in uranium-bearing areas of the United States, but that is not the aim of this paper. For our purposes the examples of the blanket and roll types are briefly characterized in Tables 55 and 56. The Mecsek deposit in Hungary was selected as an example of the blanket type and the low temperature uranium deposit Hamr in Czechoslovakia as an example of the roll type.

The uranium mineralization in lignites and coals from the Cypress Hills and Tertiary and Permo-Carboniferous basins in Czechoslovakia was formed by epigenetic processes within different geological environments. Some geological features of its formation are mentioned in the first and third parts of this paper.

Other examples for comparison may be selected from the variety of uranium deposits that occur within those comparative uraniferous provinces. On the basis of the material treated in this paper the following brief conclusions about the distribution of uranium deposits and the localization of uranium mineralization are made.

REGULARITIES IN DISTRIBUTION OF URANIUM DEPOSITS AND IN LOCALIZATION OF URANIUM MINERALIZATION

The following conclusions in regard to regularities in distribution of uranium deposits and in localization of uranium mineralization can be made:

1. Most of the uranium deposits are distributed within uranium-bearing provinces or areas, where rocks favourable for primary enrichment with uranium through syngenetic differentiation and accumulation processes occur.
2. The syngenetic differentiation and accumulation processes may be related to all phases of the petrogenetic cycle.
3. By comparison between the absolute ages of uranium mineralization from the Canadian uranium deposits and the main orogenetic events, close relationships of uranium mineralization to certain phases of the tectonic cycles and to certain tectonic epochs can be recognized.
4. The distribution of endogenetic uranium deposits is as a rule structurally controlled. The regional deep fault and fracture systems, and their intersections or ramifications, are the favourable loci for accumulations of uranium mineralization, if other favourable conditions for the uranium mineralization processes are present.

5. The distribution of the exogenetic uranium deposits is mostly lithologically controlled, but also structural conditions govern in the formation of deposits in accordance with their types.
6. The precipitation of uranium from the fluids is dependent upon their uranium contents as well as on the pH and Eh factors of the environments. The sorption and ion exchange processes participate also in the formation of uranium mineralization.
7. The elements comprising the uranium minerals as well as the minerals accompanying the uranium mineralization were in many cases identified in the host rocks or in the rocks from the vicinity of deposits. As a rule they are characteristic not only for a certain type of deposit, but also for the certain metallogenetic zone, area or province. Some of the mineral assemblages appear to be present in deposits, the distribution of which is structurally and/or lithologically controlled.
8. A comparison of the mineralization from the Great Bear Lake with that of Jachymov uranium deposits shows that in both deposits the main period of pitchblende mineralization was not simultaneous with periods of bismuth, cobalt, nickel and silver mineralization. Thus the traditional term "five element formation" cannot be used for a paragenetical designation of such type of deposits. Many occurrences with (Bi)-Co-Ni-Ag mineralization contain no uranium.
9. The presence of igneous plutons as a metallogenetic factor in the formation of uranium deposits must be considered from several points of view: (a) as a place for the magmatic differentiation and accumulation of uranium through syngenetic and epigenetic processes, (b) as a source of heat for the mobilization of uranium in the adjacent uranium-enriched rocks, (c) as a source of uranium that may be leached by weathering processes and so be entered in the hydrologic cycle, and (d) as a factor which could cause the folding and faulting in a broad environment as well as change the petrogenetic processes there.
10. The metamorphic processes (including granitization) took part in the formation of large uranium deposits and in many cases they can be used as a criterion in searching for uranium deposits within areas with original primary uranium enriched rocks which were affected by those processes.
11. The sedimentary types of deposits and the epigenetic deposits in sediments represent the principal economic source of uranium at the present time. The lithological control that participated in the localization of uranium mineralization within them has its own characteristic features dependent on the character of uranium-bearing solutions, hydrodynamic conditions and the physical, chemical and biological environment.
12. The uranium mineralization may be concentrated under various temperature conditions from hypothermal to epithermal, and in addition most deposits of sedimentary types and epigenetic deposits in porous sediments were formed under low-temperature conditions.
13. Although the isotopical ratio in natural uranium is stable the preferred leaching of U^{238} from uranium minerals causes the fractionation of uranium isotopes. This phenomenon can be used for scientific and practical purposes in uranium geology, e.g. for the investigation of the recent migration of uranium in soils, waters and rocks, as well as for determination of certain anomalies for prospecting purposes (Rosholt and Tatsumoto, 1963; Syromyatnikov, 1965).

Evidence of all those processes, factors and favourable conditions that led to formation of some uranium occurrences in Canada and East Europe (including the Asian part of U.S.S.R.) was the main subject of this paper.

Plates I to VII

Plate I. Discovery outcrop on Fuki-Donen prospect, Dear Creek, 32 miles north of Rock Creek, British Columbia. Polymictic radioactive conglomerate of post-Marron Group. GSC photo 153295.

Plate II. Uraniferous lignite seam of the Oligocene Ravenscrag Formation. Four miles southeast of Eastend, Cypress Hills, Saskatchewan. GSC photo 153269.

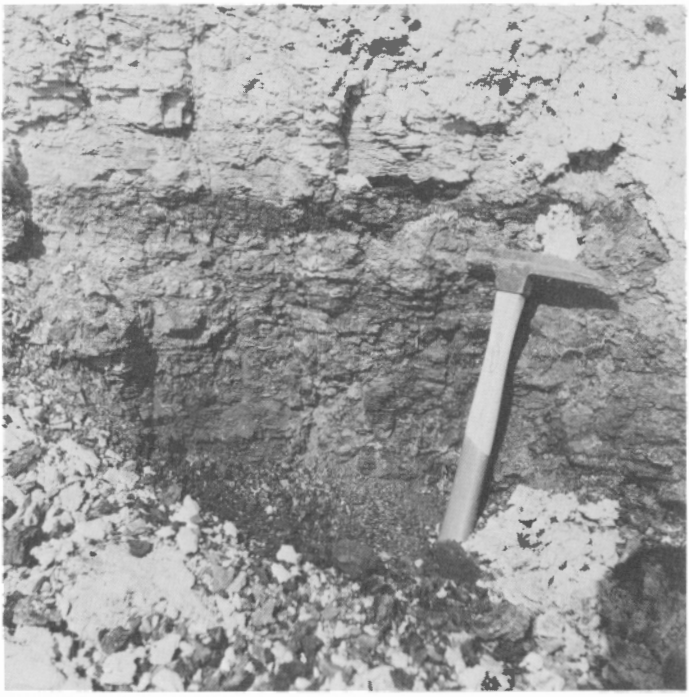


Plate III. Gunnar Mine, Beaverlodge area. Remnants of uranium ore remain in safety pillars (arrow). GSC photo 154928.

Plate IV. Gunnar uranium deposit, Beaverlodge area. Uranium mineralization in "Gunnar granite" is finely disseminated, it occurs in places where red alteration of host rocks is present and in the vicinity of tiny fractures. Dotted line shows roughly the distribution of uranium mineralization. Location of mineralized spot is shown on the Plate III. Highest reading on Scintrex, model GIS 3: 10,000 cps. GSC photo 154927.

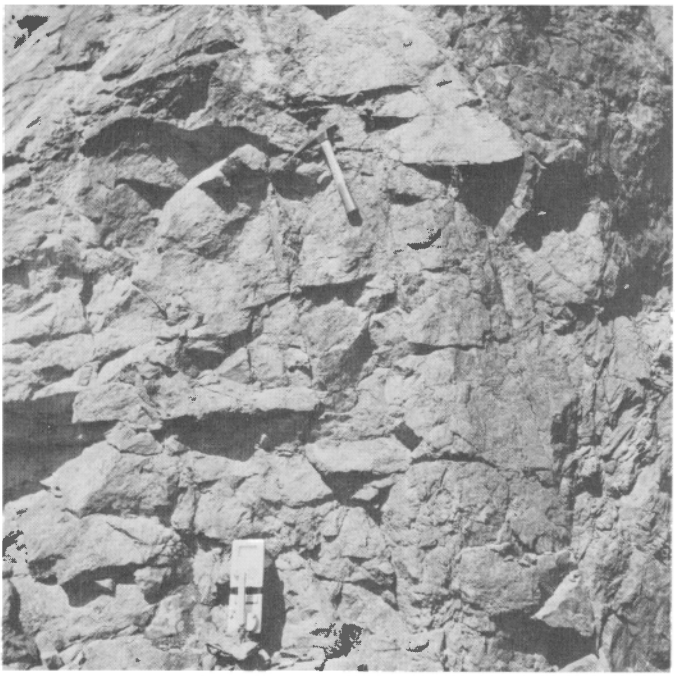
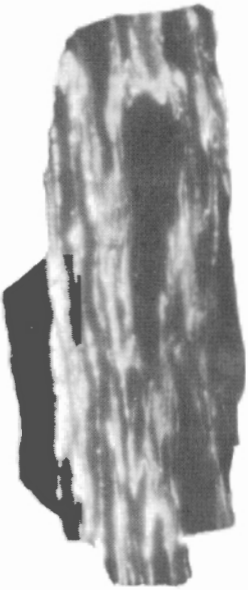
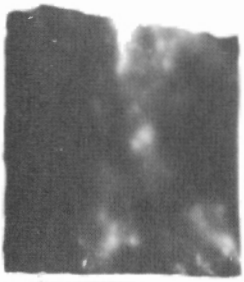
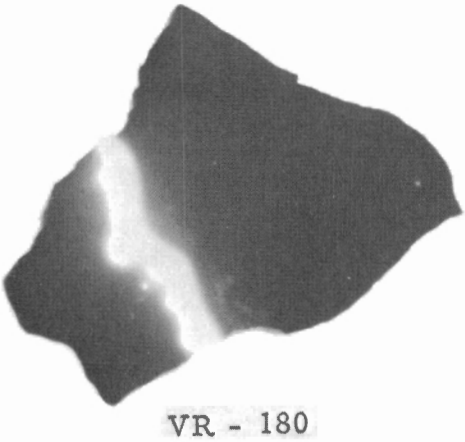
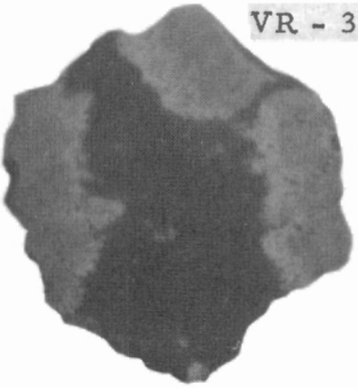


Plate V. Uraniferous feldspathic quartzite. Pitchblende mineralization is confined to quartzite (roughly in place where geological hammer lies) and also to fracture filling (right of the hammer: a dark zonelet). Michelin showing, trench No. 4, Makkovik area, Labrador coast.
GSC photo 154930.









Specimens were taken from the following localities:

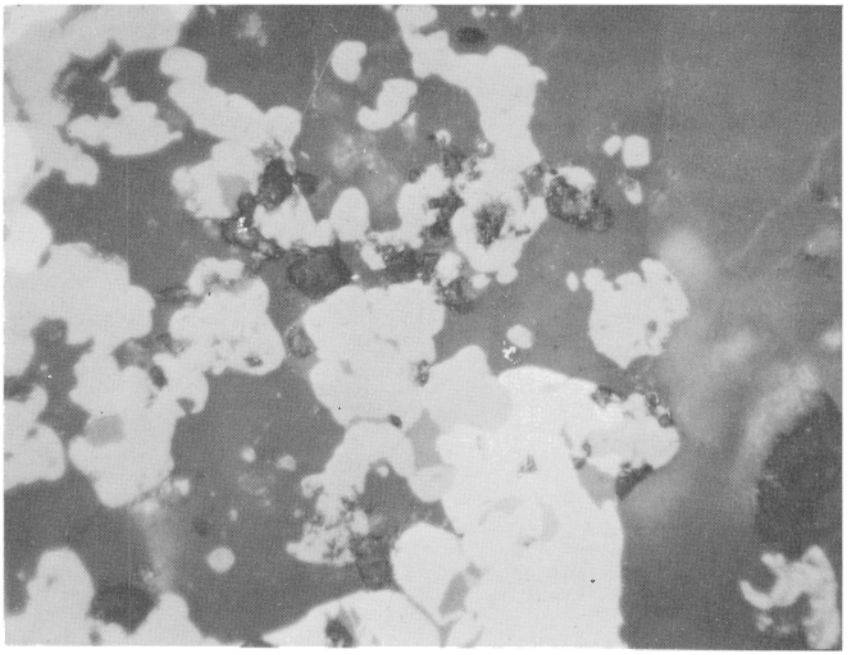
VR-102, Rexspar deposit.
VR-180, Echo Bay Mine, Adit No. 2, 206 DE, Port Radium, Great Bear Lake.
VR-182, Echo Bay Mine, Adit No. 3, Port Radium, Great Bear Lake.
VR-302, Michelin Showing, No. 4 trench, Makkovik area, Labrador.
VR-355, Mount Pleasant, Fire Tower, New Brunswick.
VR-306, Henry Gear Showing, Makkovik area, Labrador.

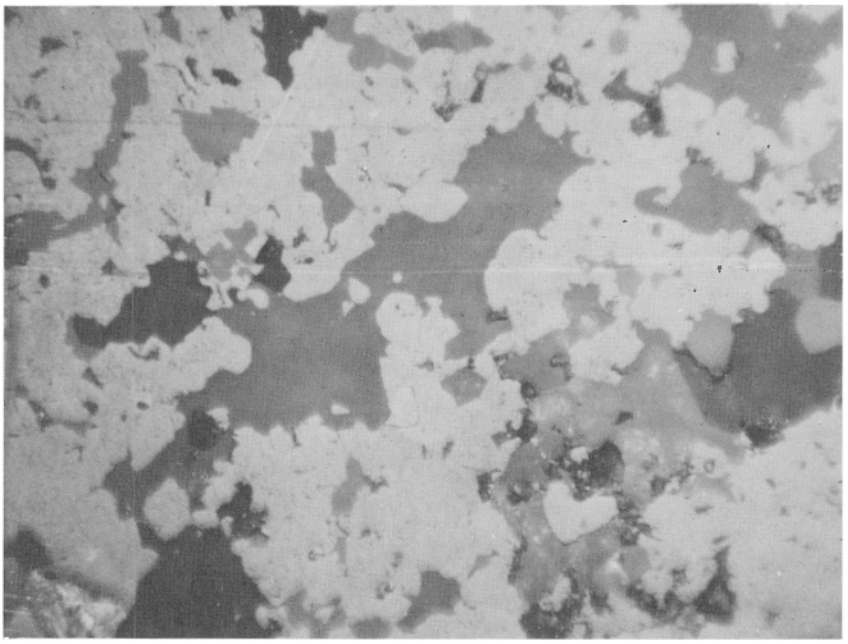
Plate VI. Autoradiographs of hand specimens taken on radioactive occurrences (exposure 72 hours). Explanation see text. GSC photo 201756.

Plate VII. (a) Botrytoidal pitchblende (light grey) replacing hematite (white), x470. GSC photo 201757.

Plate VII. (b) Botrytoidal and coalescing botrytoids (light grey) in, apparently, plagioclase, x470. GSC photo 201758.

Mineral identification done by H.R. Steacy, 1969.





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