CANADA
DEPARTMENT OF MINES
HON. W. A. GORDON, MINISTER; CHARLES CAMSELL, DEPUTY MINISTER

GEOLOGICAL SURVEY
W. H. COLLINS, DIRECTOR

ECONOMIC GEOLOGY SERIES
No. 13

Platinum and Allied Metal Deposits of Canada

BY
J. J. O'Neill and H. C. Gunning

OTTAWA
J. O. PATENAUDE
PRINTER TO THE KING'S MOST EXCELLENT MAJESTY
1934

Price, 50 cents

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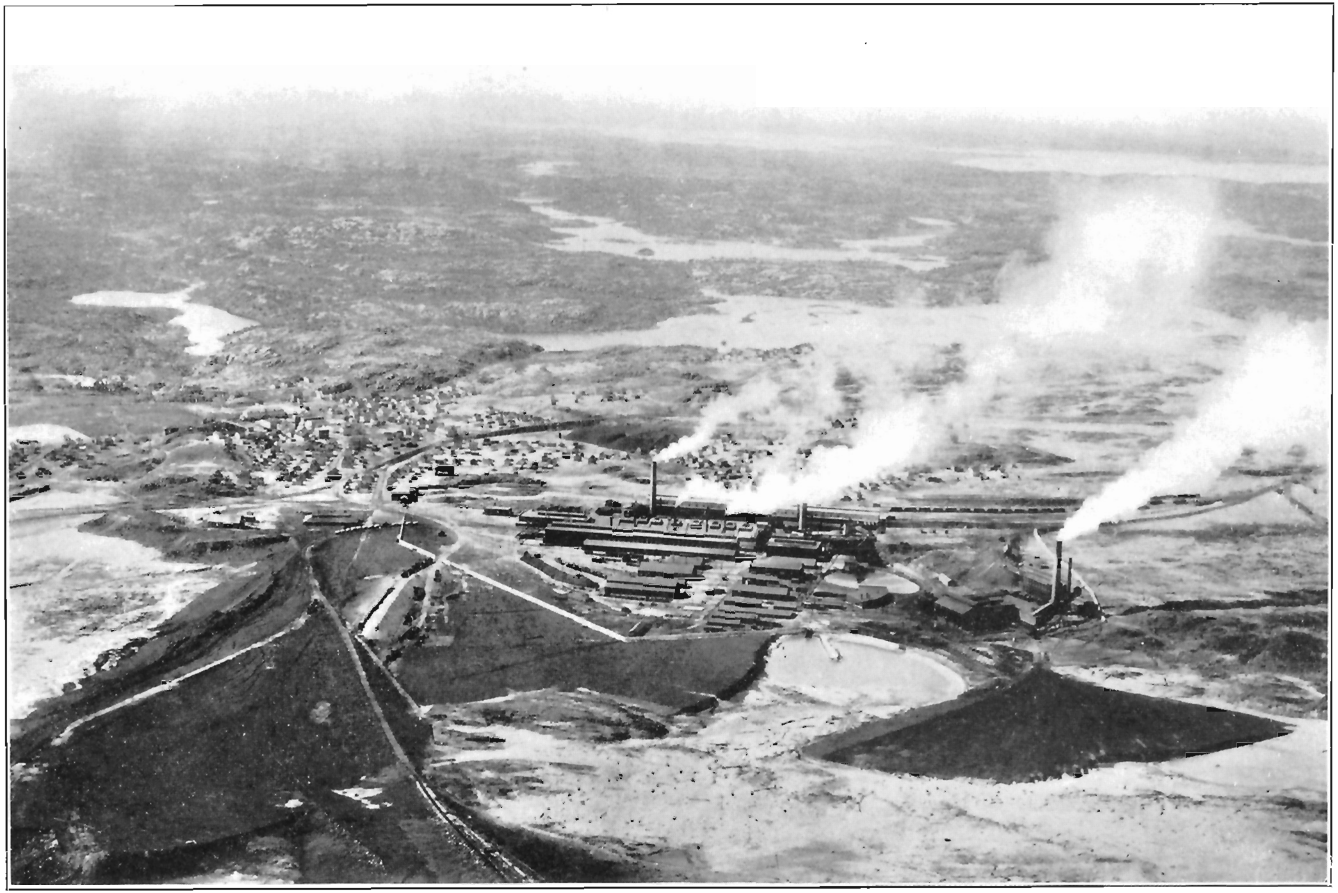

Reduction Works at Copper Cliff, Sudbury district, Ontario.

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PREFACE

This report is an outcome of an investigation begun by the senior author in 1918, when he was on the staff of the Geological Survey. At that time a larger supply of platinum was needed for war purposes. At the request of the Imperial Munitions Board Dr. O'Neill was assigned the task of ascertaining quickly to what extent and how the production of platinum in Canada could be increased. He devoted the summer of 1918 to field work. A condensed report of his findings was published in the Summary Report, 1918, Part G. A full report was also written before Dr. O'Neill resigned from the Geological Survey in 1920, but was not published because, with the end of the war, it was no longer needed for the particular purpose for which it had been written, although it contained much useful information.

In 1928 an effort was made to utilize this unpublished information by converting it into one of the series of reports (Economic Geology Series) that had been started in 1926. These Economic Geology reports, each of which deals with one metal or mineral or a related group, are designed not only to tell industrialists about the known deposits but also to tell prospectors where and how to look for new deposits. Dr. O'Neill's report had, therefore, to be greatly amplified and changed. He was engaged in 1928 to do some further field work and to reconstruct the report. This work was concluded in 1930, but owing to various circumstances it was decided to modify the scope of the report as submitted. Accordingly, the junior author was invited to revise the report and to make other changes, which have involved much study of the subject and rewriting of Chapter II, and parts of Chapters III and IV, as well as revision to July, 1933, of information elsewhere in the report.

W. H. COLLINS,
Director

Platinum and Allied Metal Deposits of Canada

CHAPTER I

HISTORY, PROPERTIES, USES, AND MINERALOGY

HISTORY

The metals commonly referred to as "the platinum group" are ruthenium, rhodium, palladium, osmium, iridium, and platinum. Platinum is by far the best known and most useful. It "appears to have been first observed in the sixteenth century; for Scaliger, who died in 1558, in his work *Exercitationes Exotericae de Subtilitate*, combatted the views of Cardanus that all metals are fusible; for, he adds, in the mines of Mexico and Darian a metallic substance is found 'quod nullo igni, nullis Hispanicis artibus, hactenus liquescere potiut'. As platinum occurs in the above districts, it appears very probable that this is the metal here referred to".[1]

It was not until two centuries later, however, that native platinum first began to attract the attention of chemists and others. William Watson, in 1750, was the first to describe it as a "semi-metal", the material he examined having been taken to England from Carthagena, in Granada (Colombia); and two years later it was described in more detail by Schaffer in a paper entitled "On White Gold, or the Seventh Metal, termed in Spanish 'platina del Pinto'"; *platina* being the diminutive of *plata*, the Spanish for silver, and *Pinto* being the name of the river in whose gravels the metal was found, associated with gold.

For many years, however, platinum was little known in Europe, largely because the Spanish Government did not permit its exportation from Colombia. The new metal had about the same specific gravity as gold, and like it was insoluble in nitric and other acids. Unlike gold, however, platinum had very little value, since no special uses had been found for the metal. In 1810, for instance, it was worth only about 40 cents an ounce Troy. Here were all the elements necessary for successful counterfeiting, and coiners were not slow to take advantage of the situation and manufacture Spanish doubloons (a gold coin with a value of about $8), either by gilding the platinum or alloying it with gold.

Colombia remained the only source of the world's platinum for about seventy years. Then, in 1819, grains of a white metal were noted in the auriferous gravels of streams in the Urals, and in 1823 these grains were shown to be native platinum. With the development of these deposits and the discovery of others, the Russian output of platinum soon outstripped that of Colombia, and Russia became the most important pro-

[1] Roscoe and Schorhammer: "A Treatise on Chemistry"; from which work also a large part of the data relating to the history of the metals has been taken.

ducer of metals of the platinum group. Like the Spanish counterfeiters, the Russian Government recognized that platinum is peculiarly suitable for coinage, and in 1828 they began to make 3-, 6-, and 12-ruble pieces of the metal. The 3-ruble piece weighed 10·31 grammes, and as it was worth about $2.40 this gave the platinum in the coin a face value of about 23 cents a gramme, or $7.15 an ounce troy. However, a number of other uses were already being found for platinum, and with the increased demand for the metal there was a corresponding advance in its price. As a result, the platinum in these coins soon came to be worth as much as, or more than, their face value, and consequently in 1845 the Government stopped minting them.

Meanwhile, although Russia[1] has maintained supremacy as the largest producer of platinum, the metal has been found in alluvial deposits in many other parts of the world, and also in certain lode deposits, as for example in the nickel-copper ores of Sudbury district, and, more recently, in the remarkable and very extensive Transvaal deposits.

The history of the remaining five metals of the group is concerned not so much with discovery in the field as with research in the laboratory.

Osmium and iridium were discovered in 1803-4 by Smithson Tennant who was the first to prove that two new metals were present in the residue that remains when platinum ores are dissolved. To one of these he gave the name *iridium,* in allusion to the varying colour of its salts, and to the other the name *osmium* (ὀ σ μ ή, a smell) on account of the peculiar odour of its oxide. The two metals are generally present in "native platinum," and they also occur, more or less free from other members of the group, in the alloy iridosmine, or osmiridium.

Palladium was discovered, or recognized as a new "noble" metal, by Wollaston in 1803, and in the following year he described the process by which he had obtained it from the platinum ore. He named it after the planet Pallas, which had been discovered by Olbers in 1802. This metal is found in a fairly pure state in some of the Brazilian platinum placers, and it is also one of the principal metals of the group present in the Sudbury ores.

Wollaston was also the discoverer of rhodium, whose isolation from platinum ore he described in 1804. He gave the new metal the name *rhodium* because solutions of its salts have a rose-red colour (ϱ ό δ ο ν, a rose).

Ruthenium was the last of the six metals to be discovered. In 1828, Osann believed he had detected three new metals in platinum ore from the Urals, and to one of these he gave the name *ruthenium,* from the name for Russia. The matter remained in some doubt until 1845, when Claus proved the presence of a new metal in the ore and retained for it the name ruthenium, since it was also present in small amount in Osann's so-called ruthenium oxide, which was found to consist mainly of silica, zirconia, and oxides of titanium and iron.

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[1] Officially, Union of Soviet Socialist Republics, but throughout this report the name "Russia" is used for brevity.

PROPERTIES

Of the six metals of the platinum group ruthenium, rhodium, and palladium have nearly the same atomic weight and so have osmium, iridium, and platinum, but in their case the value is much higher. The six metals, therefore, fall into two sub-groups of three each and these find their place (together with another triad of metals—iron, cobalt, and nickel) in Group VIII, the transitional group, of Mendelejeff's periodic classification of the elements. As might be expected, they have certain chemical and physical similarities. All are white with a high lustre on polished surfaces and have high melting points. They are highly resistant to corrosion, although osmium, when finely divided and heated, oxidizes quite readily. When the compact metal is strongly heated in air it oxidizes and gives off poisonous tetroxide fumes. Ruthenium oxidizes less readily when heated. Palladium is soluble in concentrated nitric acid, but the other metals are unaffected by ordinary acids and rhodium, iridium, and crystalline osmium are insoluble even in *aqua regia.* The following table (Carter, 1928)[1] shows some of the properties of the six metals, which, on a basis of atomic weight and specific gravity, fall naturally into the two sub-groups mentioned above.

TABLE I

Properties of the Platinum Group Metals

—	Light			Heavy		
	Palladium	Rhodium	Ruthenium	Platinum	Iridium	Osmium
Atomic weight	106·7	102·9	101·7	195·23	193·1	190·8
Specific gravity	12·16	12·44	12·10	21·40	22·4	22·50
Melting point	1550°C.	1950°C.	2450°C.	1755°C.	2350°C.(?)	2700°C.(?)
Boiling point	4300°C.	>4800°C.	>5300°C.	2200°C.	>2500°C.	>2700°C.
Hardness	4·8	....	6·5	4·3	6·5	7·0
Crystal system	Isometric	Isometric	Hexagonal	Isometric	Isometric	Hexagonal

Ruthenium. The pure fused metal has a silvery white colour and is hard and brittle. It is very refractory, being next to osmium the most infusible metal of the group. It combines with oxygen more readily than any of the others except osmium, becoming superficially oxidized at a bright red heat. The pure metal is scarcely acted on by *aqua regia,* but at red heat it combines with chlorine.

Rhodium. This white, hard metal is ductile and malleable at a red heat. The pure metal is almost insoluble in all acids, including *aqua regia.* Rhodium is more easily attacked by chlorine and sulphur than any other member of the group.

Palladium. This silver-white metal, between platinum and silver in colour, has about the same hardness as platinum, but, unlike platinum, is sometimes fibrous. It is ductile and malleable and its melting point is lower than that of any other platinum-group metal. It is also the most

[1] *See* Bibliography, page 156.

easily acted upon by acids, being with difficulty soluble in boiling hydrochloric or sulphuric acids and readily soluble in concentrated nitric acid and *aqua regia.* Spongy palladium is even more active than platinum as a catalytic agent; if heated in hydrogen the metal can absorb over 800 times its own volume of the gas and retains it until heated again in a vacuum.

Osmium. This metal has a bluish white colour, is brittle, and, like iridium and ruthenium, is so hard that it will scratch glass. It is the heaviest of all metals. Osmium is the most refractory metal of the group, but, when finely divided, it becomes oxidized and volatilized easily when heated in air below 212° and in oxygen below 170°, but not below 155°, and gives off very poisonous tetroxide fumes when the compact metal is strongly heated. The crystalline metal is insoluble in all acids, including *aqua regia,* but when in the finely divided, amorphous state it dissolves in fuming nitric acid, and less readily in *aqua regia.*

Iridium. Iridium is white to steel-grey in colour, and, like osmium, is harder than glass, and brittle; at a white heat, however, it is somewhat malleable. The solid metal is not attacked by acids, including *aqua regia,* but in the extremely fine, powdered form (iridium black) it is soluble in *aqua regia.* In this form it is an even more powerful catalyzer than platinum black.

Platinum. This metal has a tin-white colour and is easily scratched by the knife-blade. The pure metal is very highly malleable and ductile, being exceeded in these characters only by gold and silver; but the malleability and ductility are greatly reduced by the presence of even small amounts of other metals of the platinum group, or by traces of arsenic, antimony, etc. Pure platinum can be drawn into wire having a diameter of only one one-hundred-thousandth of an inch. Such a wire has been produced by Messrs. Baker and Company, of Newark, N.J., by coating a piece of ordinary platinum wire with silver, drawing it, and then removing the silver. A section of the resulting thin wire was then taken and the operation repeated several times. Reduced to the thinness stated, 1 gramme of platinum would furnish a wire 351·42 miles long, or 1 ounce troy would yield 10,929 miles of wire—enough to go nearly half-way round the earth at the equator.

Platinum does not become oxidized when heated in air or in oxygen, but it volatilizes in the electric furnace. Its coefficient of expansion is lower than that of any other metal, being about the same as that of glass, and some of the uses of the metal depend on this feature. Its electrical conductivity is also low, 13·4 at 0° C. Platinum readily forms alloys with most metals, and the pure metal, like iron, can be welded without flux at a white heat.

Neither hydrochloric nor nitric acid acts on pure platinum, but hot concentrated sulphuric acid attacks it slightly, and *aqua regia* dissolves it readily. It is corroded if heated in contact with caustic alkalis, sulphides, sulphates, phosphates, and arsenides.

Very finely divided platinum, in the form of "spongy" or "black" platinum, is a very powerful catalytic agent.

Platinum, unlike gold and silver, will not amalgamate with mercury unless sodium or some other "activator" is present.

USES[1]

As will be evident from the above résumé of their more important physical and chemical properties, the metals of the platinum group have certain characteristics that divide them rather sharply from all other metals, with the possible exception of gold, which resembles them in many respects. Thus, they are all relatively inert chemically, and have high melting points. Platinum is highly malleable and ductile, can be welded without a flux, and readily forms alloys with many metals. As a result of this rare combination of properties, platinum, and in lesser degree the other members of the group, are employed for a number of purposes, both industrially and in the arts. For many of these uses, platinum is indispensable, as no other known substance possesses the requisite properties; in other cases, where platinum was formerly employed, it has been, or is being, replaced successfully by more easily obtained, and, therefore, cheaper substitutes; and in still other cases the main reason for the employment of platinum appears to be its rarity and high price, so that here it would be useless to seek a cheaper substitute.

No attempt is made in this volume to discuss in detail all the uses of the platinum metals and their alloys. International Nickel Company of Canada, Limited, and others, are working on the development of new uses. The quarterly publication " Literature and Patent References to Platinum Group Metals," compiled by J. S. Negru and issued by International Nickel Company, is a very complete annotated bibliography of current literature. Major developments are generally noted each year in " The Mineral Industry." The paper by F. E. Carter, quoted above, contains an interesting discussion of uses, as well as much valuable information concerning the properties, of the numerous alloys of the platinum metals.

The accompanying tables, taken from " The Mineral Industry " and showing the consumption of platinum metals in the United States over a period of years, will give some indication of the relative amount of platinum absorbed by the several industries in which the metal is used. The United States is the largest consumer of platinum metals and Germany ranks second.

TABLE II

Consumption (In Troy Ounces) of Platinum Metals in the United States By Industries

(From *The Mineral Industry*)

—	Platinum	Iridium	Palladium	Others	Total	Per cent of total
1920						
Chemical	13,226	43	240	....	13,509	9·58
Electrical	23,029	2,673	1,784	....	27,486	19·49
Dental	6,413	114	8,898	....	15,425	10·94
Jewellery	77,267	3,108	593	....	80,968	57·40
Miscellaneous	3,119	116	418	....	3,653	2·59
	123,054	6,054	11,933	....	141,041	100·00

[1] Dr. Paul D. Merica has kindly aided the authors by reading the manuscript of this section and by contributing some of the information contained in it.

Table II

Consumption (In Troy Ounces) of Platinum Metals in the United States By Industries—Concluded

—	Platinum	Iridium	Palladium	Others	Total	Per cent of total
1926						
Chemical	10,253	145	213	288	10,839	6·32
Electrical	16,765	1,608	3,508	185	22,066	12·87
Dental	8,542	131	11,063	....	19,736	11·51
Jewellery	85,908	2,949	7,770	454	97,081	56·54
Miscellaneous	17,381	581	2,181	1,751	21,894	12·76
	138,849	5,414	24,735	2,618	171,616	100·00
1927						
Chemical	11,010	101	180	175	14,466	7·66
Electrical	14,905	1,618	2,491	121	19,135	12·77
Dental	7,504	153	12,194	....	19,851	13·25
Jewellery	86,036	4,059	3,706	329	94,130	62·81
Miscellaneous	3,176	305	312	1,311	5,104	3·41
	122,631	6,236	18,883	1,936	149,686	100·00
1928						
Chemical	18,529	113	1,252	135	20,029	10·68
Electrical	21,316	1,525	9,150	2	31,993	17·07
Dental	10,993	167	12,270	10	23,377	12·47
Jewellery	93,468	3,260	4,965	815	102,508	54·77
Miscellaneous	5,431	963	2,136	850	9,380	5·01
	149,674	6,028	29,773	1,812	187,287	100·00
1929						
Chemical	20,260	113	1,345	233	21,951	11·45
Electrical	20,746	1,014	18,856	89	40,705	21·24
Dental	13,051	788	12,156	236	26,231	13·68
Jewellery	84,039	3,737	4,451	851	93,078	48·59
Miscellaneous	7,234	347	1,048	1,025	9,654	5·04
	145,330	5,999	37,856	2,434	191,619	100·00
1930						
Chemical	15,022	34	854	49	15,959	13·42
Electrical	8,529	864	9,569	70	19,032	16·00
Dental	11,810	111	15,436	6	27,363	23·00
Jewellery	44,801	2,407	2,807	526	50,541	42·51
Miscellaneous	3,324	208	1,621	876	6,029	5·07
	83,486	3,624	30,287	1,527	118,929	100·00
1931						
Chemical	11,483	18	979	64	12,544	11
Electrical	8,215	609	22,628	17	31,469	26
Dental	10,135	74	9,394	13	19,616	17
Jewellery	41,261	2,185	2,988	264	46,698	39
Miscellaneous	5,896	373	1,934	667	8,870	7
	76,990	3,259	37,923	1,025	119,197	100
1932						
Chemical	5,157	52	495	218	5,922	7
Electrical	3,456	431	6,309	23	10,219	12
Dental	8,683	73	12,900	9	21,665	26
Jewellery	33,376	1,719	5,817	314	41,226	50
Miscellaneous	3,896	274	204	27	4,401	5
	54,568	2,549	25,725	591	83,433	100

PLATINUM

Before 1914 the greater part of the world's production of platinum went into chemical and other technical uses. The war, and subsequent disturbances in Russia, the world's leading producer, led to a scarcity and consequent increase in price of platinum which encouraged the development of substitutes for the purposes named. These proved so successful that the requirements of this, the largest field for consumption of platinum, were very drastically reduced. On the other hand, however, the demand for platinum in jewellery has increased enormously since the beginning of the war, and for many years this trade has been by far the largest consumer.

Jewellery

Laws governing the hall-marking of platinum articles are gradually coming into effect and are referred to on page 12. In jewellery, platinum is used principally as a setting for gemstones, particularly diamonds, and in the manufacture of wedding and engagement rings. It is also used in brooches, watch chains, pins, necklaces, ear-rings, watches, medals, and other articles. Because pure platinum is too soft, an alloy containing 5 to 10 per cent of iridium is generally used.

Chemical Industry

Very extensive use of platinum in the chemical industry depends on its remarkable property, when in the finely divided or spongy state, of absorbing or condensing many times its bulk of oxygen, in consequence of which it acts as an extremely powerful oxidizing agent. The platinum itself remains unchanged in the process, and can be used over and over again. This type of chemical activity is known as "catalytic action," and platinum in this spongy or finely divided form is said to be a strong "catalyzer" or "catalytic agent". It finds its principal application in the manufacture of sulphuric acid by the "contact" process. In this process sulphur or pyrite is burned in a furnace and the sulphur dioxide (SO_2) gas so produced is passed over the heated, platinized "contact mass," which converts the gas to sulphur trioxide (SO_3): this oxide, a crystalline solid, is then passed into water to form sulphuric acid (H_2SO_4). The "contact mass" usually consists of asbestos coated with a film of the finely divided platinum black, and it may contain as much as 7 or 8 per cent of platinum or as little as 0·2 per cent. The contact process for making sulphuric acid has come to the fore very rapidly during the past fifteen years. It has some important advantages over the older "chamber" process, in which platinum is also employed, and is used especially for making the highly concentrated acid, or "oleum," which is employed in the manufacture of high explosives. Platinized magnesium sulphate has long been used as a successful substitute for platinized asbestos in the contact process and recent developments (Thomson, 1931) indicate that platinized silica gel may be an even more efficient contact mass. The article referred to presents an interesting study of the efficiency of platinum masses, as opposed to vanadium ones, their chief competitors, in the manufacture of sulphuric acid by the contact process.

Platinum or platinum with 10 per cent rhodium gauze is also employed as a catalyzer to convert ammonia into nitric acid by a process of oxidation, and it is probable that there will be a large future demand for platinum to be used in this way in the manufacture of nitrates (by the fixation of atmospheric nitrogen) for use as fertilizers. Platinum is used, in the same process, to produce nitrogen required in the chamber process for sulphuric acid manufacture.

Although high prices have led to the introduction of cheaper substitutes in recent years, platinum is still used quite extensively in laboratory ware in articles such as crucibles, dishes, tips for tongs, wire, filter cones, electrodes, spatula, foil, retorts, and other apparatus. In some chemical operations where cost is important platinum-clad base metal has received considerable attention.

Dentistry

Platinum, in the form of sheet, wire, and foil, has been used in the dental industry; it has been used for tooth pins and bracings of artificial teeth. Platinum is used both pure and in the form of alloys, the main requisites of which are hardness and resistance to the action of organic acids. Bare platinum foil is used as matrices on porcelain inlays.

Electrical, Physical, Etc., Appliances

At one time platinum was used for the lead-in wires of incandescent lamps, but was replaced by copper-clad nickel iron wire. It has been found that an alloy of 80 parts of platinum and 20 of iridium gives best results in magneto contacts where severe conditions exist and absolute dependability is required and this alloy is standard for aeronautical work. Platinum electrodes are used in certain electrochemical processes where a truly insoluble anode is required.

An alloy containing 33 per cent platinum and 67 per cent silver is used as a standard of electrical resistance. In certain pyrometers the thermoelectrical couple consists of pure platinum and an alloy of platinum with 10 or 13 per cent rhodium. Alloys of platinum with other metals have been employed extensively in various telegraph and telephone instruments and apparatus, but for this purpose have been generally supplanted by palladium alloys.

Miscellaneous and Minor Uses

Miscellaneous and minor uses are: as anodes and cathodes in electrolytic determination of metals; for making standard weights for balances; in surgical needles; in the manufacture of certain gunnery appliances and signalling apparatus; in photographic paper; in fuse wire in detonators for explosives; as heating filament in radio amplifying tubes where long life is desired, and in electroplating. In the rayon industry platinum and palladium alloys are used extensively in spinnerets. An interesting recent development is the production of platinum and palladium in leaf form, for uses similar to those of leaf gold. In 1933 the International Nickel Company established a platinum medal to be given by the Canadian Institute of Mining and Metallurgy for meritorious achievements in metallurgy. Another medal, the Wollaston, is made of palladium in recognition of the discovery of this element by Wollaston.

PALLADIUM

Palladium is used to an increasing extent for dental and electrical purposes, and in jewellery. Prior to the war, there was practically no use for the metal, but it was introduced at that time as a substitute for platinum, owing to the high cost and great scarcity of the latter.

Dentist's alloys are made of palladium and gold in various proportions, with or without platinum. Alloys with silver are used for dental and for electrical purposes, as for example in electrical contacts. As a substitute for white gold in jewellery, palladium is hardened by other platinum metals and at times alloyed with silver; it is also used in making non-magnetic, brownish red, hard, malleable " watch alloys," which contain in addition to palladium, both silver and copper, and either gold or nickel.

Palladium may be effective in the hydrogenation of certain organic products where nickel is shown not to be sufficiently effective. The recent development of palladium leaf opens up interesting possibilities in the fields of architecture and interior decoration. It is stated that leaf palladium can be applied to surfaces as easily as gold or other metal leaf and that a book of 500 leaves, to cover about 35 square feet, weighs less than one-quarter ounce. Palladium has been used to some extent recently for making medals. Palladium has been used as an electroplate on silver and other metals to prevent tarnish.

IRIDIUM

As noted under platinum, that metal, when used in jewellery or for electrical purposes, usually has a certain amount of iridium alloyed with it, the main reason for this being that these alloys are harder than pure platinum. An important use of iridium is in forming the tips of gold pens, because of its greater hardness (H=6-7). For this purpose, however, either native osmiridium or synthetic osmium-iridium alloy is generally used. Alloys of platinum and iridium containing 10 to 25 per cent of the latter metal are very hard, highly elastic, perfectly unalterable in air, and capable of taking a high polish. The " Standard meter," prepared by Messrs. Johnson, Matthey, and Company, of London, in 1870, and adopted by the French International Commission on Weights and Measures, is such an alloy, containing 10 per cent of iridium; and similar alloys have been used for making standard balance-weights.

OSMIUM

In the form of pure metal, osmium has practically no uses in the arts. It is the most refractory metal of the group, and on this account was formerly employed as a filament in incandescent lamps. To a very slight extent its salts are used medicinally for staining fatty tissue in microscopic work, and in the dyeing of silk. The metal occurs most commonly associated with iridium in the natural alloy iridosmine (or osmiridium), and this is used for tipping gold pens, and occasionally for the bearings of the mariner's compass, being non-oxidizable and non-magnetic.

RHODIUM

This metal is an excellent alloying element—with other platinum metals or some base metals. As stated under platinum, alloys of platinum and rhodium are used in thermoelectrical couples. Rhodium electroplates have been extensively developed within the past few years for non-tarnishing coverings for optical frames, white gold and base metal jewellery, and other objects of art. Large reflectors, developed in conjunction with the United States Army, for coast defense, have rhodium plate as the reflecting material.

RUTHENIUM

So far as can be ascertained, ruthenium has no important industrial uses. It is, however, an excellent hardener for other platinum metals. Certain of its salts are used in the dye industry.

The accompanying table (Dunstan, 1920) gives the composition of some typical platinum and palladium alloys. Since the list was compiled many changes have, of course, been made. The paper by F. E. Carter discusses the more important binary alloys of the platinum metals, but makes only brief mention of the ternary and quaternary ones which are very numerous.

TABLE III

Composition of Patinum and Other Alloys

Alloys	Pt	Cu	Ag	Au	Ni	Pd	Other constituents, etc.
	Pts.	Pts.	Pts.	Pts.	Pts.	Pts.	
Electricians' alloy			3			2	For spark plugs
Jewellery alloys							
Platinum alloy	1	0–1[2]	2–5[3]				White alloy
Platinor	2	5	1		1		Brass, 2
Palladium alloy						9	Rhodium, 1
Palladium alloy			14			5	Cobalt, 1: white alloy
Mock gold	7	16					Zinc, 1
Mock gold	1		1		6		Brass, 1
Mock gold	1	4					18-carat gold colour
Cooper's pen metal	4	1	3				Once used for tipping pens
Watch alloy		13	11	18		6	Non-magnetic, brownish
Watch alloy		25	4		1	70	Red, hard, malleable
Watch alloy	63	18			17		Cadmium, 1
Platinum bronze	1				90		Tin, 9: proportions vary
Dentists' alloy[1]	5			3		4	White, hard metal
Dentists' alloy	7		3	2			White, hard metal
Dentists' alloy	6		1	2			White, hard metal
Dentists' alloy				4		1	White, hard metal[4]
Dentists' alloy			2			3	Also for electrical work

[1] Copper sometimes added to increase the hardness.
[2] The amount depends on hardness required.
[3] Varying with the quality required.
[4] Also for jewellers' work.

SUBSTITUTES FOR PLATINUM

Even before the war the relative high price and scarcity of platinum had led to a search for more abundant and cheaper substitutes. The greatly increased demand for the metal for the manufacture of munitions and armaments during the war caused a rapid increase in price and created a shortage that was further aggravated by the disruption of Russian production during and after the war. Restrictions placed on platinum consumption from 1914 to 1918 and the high prices that prevailed for ten years after that were responsible for renewed activity in the development of substitutes and many of these that the test of years has proved satisfactory have been generally adopted. The drop in price of platinum since 1929 may lead to increased consumption in industrial and technical lines, but it is doubtful if the same will apply to the jewellery trade, platinum's largest consumer.

In the section dealing with the uses of the platinum metals, several instances have been given of the partial or complete substitution of other metals of the group for platinum. A number of other examples, mainly where cheaper and more abundant metals or substances have successfully replaced platinum, may here be referred to.

Alloys Containing Gold

Both gold and silver, alloyed in various percentages with palladium, make fairly satisfactory substitutes for platinum in jewellery.

Rhotanium is a general name for gold-palladium alloys containing anywhere from 60 to 90 per cent of gold, and these are suitable for most chemical purposes—as, for example, in making stills, evaporating dishes, and crucibles—except for use with concentrated nitric acid, which attacks the alloy when hot. These alloys can also be used for electrolytic anodes. Some of them go under the name of *palau.*

Instead of palladium, the gold may be alloyed with platinum. *Platino* is such an alloy, containing approximately 89 per cent Au and 11 per cent Pt, and exhaustive tests have proved that evaporating dishes and crucibles made of this material are extremely resistant to the action of acids and fluxes, and the ware is said to be fully as good as, and in some respects even superior to, pure platinum.

Palorium is another of these alloys of gold with metals of the platinum group. It is white, somewhat resembling platinum, and is comparable with the latter also in hardness, tensile strength, and coefficient of expansion. It may, therefore, be sealed in glass without danger of cracking. The alloy is malleable and ductile, and melts at 1,310° C.

A satisfactory alloy for cathodes consists of 90 per cent gold with 10 per cent copper, and if electrically coated with platinum and then burnished the same alloy can be used to replace platinum anodes.

No entirely successful substitute appears to have been found for platinum in certain high-duty electrical contacts, but for those in ordinary telegraphic and telephonic appliances, an alloy consisting of 10·50 per cent Au, 88·25 per cent Ag, and 1·25 per cent Cu has been recommended.

White gold, used in jewellery, contains 75 to 85 per cent Au, 10 to 18 per cent Ni, and 2 to 9 per cent Zn; and another white alloy that is used in some cases instead of platinum for chains, etc., has 42 per cent Au, 54 per cent Ag, and 4 per cent Cu.

An alloy used in Germany for many technical purposes consists of tungsten and nickel with gold or silver. It may be cast, rolled, or forged, is acid-resisting, and capable of taking a high polish.

Base-Metal Substitutes

Platinum is no longer used for the connexion wires of incandescent lamps, having been replaced by certain alloys that have, as is necessary, a coefficient of expansion about the same as that of glass. One of these is platinite, an iron-nickel alloy containing 46 per cent nickel and about 0·15 per cent carbon. This is coated with copper, and in some cases is plated over copper with platinum. Nickel-chromium, tungsten, and molybdenum wires are also used for this purpose.

Vanadium is now used quite extensively as a substitute for platinum as a catalyst, particularly in the manufacture of sulphuric acid. Molybdenum is replacing platinum for resistance coils in small electric furnaces, etc., and tantalum, tungsten, nickel and nickel-chromium alloys, as well as rustless iron, are used in its place in laboratory ware, as are various non-metallic substances such as fused quartz and porcelain. In this respect tantalum is an important competitor as it is much cheaper than platinum, and either pure, or alloyed with platinum, is very resistant to corrosion, the alloy containing up to 20 per cent tantalum being more resistant to *aqua regia* than platinum itself. Tungsten and nickel have largely replaced platinum in spark plugs for internal combustion engines.

Incidentally it may be mentioned that the alloy platinoid, which resembles German silver and is used in electrical work, contains no platinum; and that platinum lead or Birmingham platinum is a zinc-copper alloy.

PLATINUM STAMPING LAWS

On April 10, 1928, the Canadian Parliament passed an amendment to the Gold and Silver Marking Act, bringing platinum within its provisions and changing the title to Precious Metal Act, 1928. The new law became effective on January 1, 1929, and, so far as it relates to articles composed wholly or partly of platinum, it stipulates that the word platinum, or any abbreviation or colourable imitation thereof, may not be applied to any articles of merchandise unless at least 95 per cent of the metallic content is platinum, either alone or in conjunction with iridium. The trade-mark of the manufacturer must be applied to all articles coming under the act. The Governor-in-Council is authorized by the act to establish regulations designating the quantity and quality of the materials of which platinum-plated articles shall be composed.

France, Spain, and Switzerland also have laws governing the hall-marking of platinum articles and legislation governing the manufacture and sale of such articles has been enacted in the states of New York, Illinois, and New Jersey. The New York law went into effect on January 1, 1928, and a summary of its more important provisions may be found in "The Mineral Industry," volume 35, 1926, page 541. It may be noted, however, that some leading jewellery firms maintain a standard higher than that set by some stamping laws, particularly in regard to substitution of other platinum group metals for platinum.

MINERALOGY

NATIVE ELEMENTS

Native Platinum

The name " native platinum " is given to those alloys that contain upwards of about 50 per cent Pt, the balance being other metals of the group, usually with varying amounts of iron. It was in allusion to its very complex character that Hausmann, more than one hundred years ago, proposed to name the mineral polyxene, meaning many strangers or guests.

Native platinum crystallizes rarely in cubes; these cubes are often distorted. Generally it occurs in small grains and scales, and occasionally in larger, irregular lumps, or nuggets, weighing up to 20 pounds. There is no cleavage. Platinum has the hackly fracture common in metals, and is highly malleable and ductile. $H=4-4\frac{1}{2}$; sp. gr.=14-19, being always much lower than for the pure metal (21·4) owing to the presence of lighter metals, especially iron. Apparently due to the latter, native platinum is in many cases magnetic, and occasionally exhibits polarity; but there does not seem to be a quantitative relation between the magnetic character and iron content, as some specimens containing 11 per cent and more of iron are non-magnetic. Breithaupt described material having approximately the composition $PtFe_2$ under the name iron-platinum, but this is not now regarded as a definite compound. The colour varies somewhat with the composition, from whitish steel-grey to black; when in the form of a fine-dust, it is often a matter of difficulty to distinguish the dark-coloured varieties from chromite or magnetite, which minerals are in many cases associated with the platinum in alluvial deposits. If not too finely divided it is readily distinguished by its malleability.

The general physical and chemical characters of the metal have been given in an earlier section. From colours of gold, it is separated by mercury, with which the gold but not the platinum amalgamates. A miners' term for the metal is " white gold."

Native Iridium

This metal is isomorphous with native platinum and resembles it very closely. It has, however, an indistinct cubic cleavage, is somewhat brittle, and is sufficiently hard to scratch glass rather easily (H=6–7). Considerably heavier than platinum, its colour is tin-white, with a tinge of yellow.

Native iridium always contains a fair amount of platinum, and when the latter is in excess of the iridium, the material is known as platiniridium. Specimens from Ava, in India, containing 60 per cent Ir and 20 per cent Pt were named avaite by Heddle.

Iridosmine or Osmiridium

Instead of platinum, the main metal associated with iridium may be osmium, and the material is named iridosmine or osmiridium, according as iridium or osmium is in excess. It is of interest to note that this material is not isometric, like platinum and iridium (and also palladium), but crystallizes in the hexagonal system (rhombohedral division) and is isomorphous with allopalladium (*See* below). Like the latter, also, it has a perfect basal cleavage. Usually, however, the mineral occurs in irregular, flattened grains, which are tin-white to light steel-grey in colour, harder than glass (H=6–7), and rather brittle. The specific gravity ranges from about 19 to over 21, depending on the composition. Formerly, Haidinger's names were used to distinguish two varieties: *nevyanskite,* containing over 40 per cent Ir and having a specific gravity below 20; and *siserskite,* with less than 30 per cent Ir and specific gravity above 20.

An interesting feature of the composition of iridosmine is that whereas platinum is either entirely absent or present in very minor amount, rhodium and ruthenium are both almost invariable constituents and may reach 8 per cent or even higher; on the other hand, native platinum seldom, if ever, contains ruthenium.

Native Osmium

It is doubtful whether osmium ever occurs sufficiently pure in nature to warrant its acceptance as a distinct mineral species. However, it has been thought that the grains of crude iridosmine from Brazil and the Urals may include a certain percentage of native osmium, and for this the name osmite has been suggested. This name has also been applied to an iridosmine from Borneo containing 80 per cent Os, 10 per cent Ir, and 5 per cent Rh, which represents a fair approach to pure osmium. In the past (1836), iridosmine with as little as 40·83 per cent Os has been termed " osmite."

Native Palladium

This metal crystallizes in the isometric system, usually in octahedra, but it is found generally in grains, which may have a characteristic, radiated, fibrous structure. It resembles native platinum in appearance, has the same hardness ($4\frac{1}{2}$ to 5), and like it is malleable and ductile. It differs, however, in its very much lower specific gravity (11·3 to 11·8). A little platinum and iridium are almost invariably present.

Palladium is also found alloyed with gold, which is then termed palladium-gold or porpezite, from the name of the locality, Porpez, Brazil. According to Derby (quoted by Dana in his " System of Mineralogy "), Porpez is probably a corruption of Pompeo, an old mining settlement near Sabara, in which vicinity palladium-gold occurs rather abundantly. It is pale coloured and contains about 10 per cent Pd, besides some silver. Similar material also occurs at Taguaril, Minas Feraes, Brazil.

Allopalladium

This is an hexagonal (rhombohedral) modification of palladium, which has been recorded from only one locality—Tilkerode, in the Harz Mountains. Apart from the crystal form—small six-sided tables—and the perfect basal cleavage, it closely resembles the isometric variety.

Some doubt has recently arisen concerning the true nature of allopalladium. White grains of a palladium-rhodium mineral occurring in the diamond washings near Oewang, near the Kaieteur Gorge, on Potaro River, British Guiana, were at one time thought to be allopalladium, and were described as such; but subsequent examination has shown that they contain also mercury, and are the amalgam, or mercuride, of palladium, potarite, which is described below. Spencer has confirmed the presence of mercury in this "allopalladium" from British Guiana, and says "the doubt now passes on to the original allopalladium from the Harz Mountains."

Rhodium

Rhodium has not been noted as a major constituent of any of the native platinum-metal alloys that have been analysed.

Rhodium-gold

Rhodium-gold, with a content of 34 to 43 per cent Rh, has been described under the name rhodite. This material is brittle and has a specific gravity of 15·5 to 16·8. According to Dana, it needs re-examination.

Ruthenium

This metal is exceedingly rare, and apart from the sulphide described below it has been found only as a minor constituent alloyed with other platinum-group metals, and especially in iridosmine.

COMPOUNDS

Sperrylite

This, the diarsenide of platinum, $PtAs_2$ (Pt=56·5 per cent, As=43·5 per cent), was discovered in Canada, at the Vermilion mine in Sudbury district (Wells, 1889), in October, 1885. The mineral was named after Mr. F. L. Sperry, chemist of the Canada Copper Company (later the International Nickel Company), who was the first to call attention to it. Since that time, sperrylite has been found in several other localities, notably in the Transvaal, where the mineral occurs in exceptionally large crystals on the Tweefontein farm, in Waterberg district, and elsewhere.

Sperrylite is isometric, and isomorphous with pyrite. The crystals are usually cubes or cubo-octahedra, in some cases highly modified with other forms. Those occurring in the Sudbury ore are extremely minute, but within the past few years a number of superb and relatively enormous crystals have been found at the Tweefontein locality. Spencer describes one, now in the British Museum, which weighs 33·75 grammes, or more than an ounce (either troy or avoirdupois), with dimensions $18\frac{1}{2}$ by $16\frac{1}{4}$ by 15 mm. measured along the cube axes, and a diameter of $22\frac{2}{3}$ mm. along the dodecahedron axis; and a crystal in the McGill University mineral collection, presented by Mr. C. B. Kingston, of the Anglo-American Corporation of South Africa, Limited, measures about 15 by 10 by 10 mm.

Sperrylite has a tin-white to steel-grey colour brilliant metallic lustre, and a black streak. H=6–7, sp. gr. = 10·6. The mineral breaks with a conchoidal fracture, and has no cleavage. Before the blowpipe, it decrepitates slightly. In the open tube, it gives a sublimate of arsenic trioxide, but does not fuse if heated slowly. On the other hand, when heated rapidly, it melts easily after losing a part of its arsenic. A polished surface is isotropic and gives negative reactions to acids, including *aqua regia*.

The Sudbury sperrylite contains up to over 50 per cent Pt, with 0·5 to 0·75 per cent Rh, but only traces of palladium. Another interesting constituent is tin, which may, however, be present as admixed oxide. G. R. Mickle has shown that, at Sudbury, the sperrylite occurs mainly in the chalcopyrite of the nickel-copper ore.

Cooperite

This is a newly discovered platinum mineral, reported recently from the platiniferous norites of Transvaal. Analysis of material from the Rustenburg district gave: Pt 64·2, Pd 9·4, S 17·7, As 7·7 per cent, the palladium being perhaps due to admixture. Similar material from the dunite of Onverwacht, Lydenburg district, gave Pt 59·3, S 3·7, As 36·9 per cent. These analyses give the formula $Pt\ (As, S)_2$. The colour of the mineral is greyish white or yellowish white.

Cooperite appears to be orthorhombic, isomorphous with marcasite, and hence not merely a variety of sperrylite with sulphur replacing some of the arsenic. The mineral is insoluble in *aqua regia* and other acids, but when heated even to a moderate temperature it gives off arsenic and sulphur and the metallic residue remaining is fairly readily soluble in *aqua regia*. Cooperite is distinctly anisotropic in polarized light and is not etched by any acid. $H = 4$ to 5.

More recent analyses (Bannister, 1932) indicate that the cooperite originally analysed was not homogeneous but contained admixture of sperrylite, and that the formula for the pure mineral is probably Pt S rather than $Pt\ (As, S)_2$; also the mineral is tetragonal and not orthorhombic as formerly thought.

Irite

This name was given by Herman (1841) to a mineral from the Urals, which occurred in black, shining octahedra and had a specific gravity 6·506. The composition he gave as: Ir 56·04, Os 9·53, Fe 9·72, chromium 9·40 per cent, traces of manganese, with a loss of 15·25 per cent, which he reckoned as oxygen. Claus, in 1860, showed that the substance was really a mixture of iridosmine with chromite and other minerals.

Palladinite

M. Adam, in his "*Tableau Mineralogique*" (Paris, 1869), gives palladinite, PdO, as a mineral species, crediting it to Lampadius. It appears improbable, however, that palladium oxide occurs as a natural compound.

Potarite

This is the amalgam, or mercuride, of palladium, PdHg. It occurs as white grains, and nuggets up to 12 grammes in weight, in diamond washings in Kangaruma district, Potaro River, British Guiana. The mineral is isometric, so hard that it will scratch rolled nickel, and has a specific gravity of 13·33 to 15·82. When heated, it loses weight in successive stages up to about 1,400 degrees C. The residual metal is porous, with specific gravity 10·0 to 11·0, which increases to 11·33 to 11·9 after hammering; it consists of palladium, with variable amounts of rhodium. The total loss in weight on heating is 54·4 to 65·2 per cent. The material lost is mercury, and on this basis the mineral is assigned the composition PdHg (Pd=34·7, Hg=65·3).

As mentioned under allopalladium, certain white grains found in the diamond washings near Oewang, near Kaieteur Gorge on Potaro River, British Guiana, were first described as allopalladium; but these have proved on re-examination to contain mercury, and are now believed to be potarite. The two potarite localities are only about 16 miles apart.

Stibiopalladinite

This is a white mineral with a peculiar yellowish or bronzy pink tint, found as irregular, tiny grains that sometimes show crystal faces, in contact metasomatic or pegmatitic ores of the Potgietersrust district, Transvaal, the locality where the large sperrylite crystals occur. H=4–5 and specific gravity 9·5. Two published analyses give: Pd 70·35, Sb 27·95 per cent; and Pd 70·4, Sb 26·0, insoluble 1·4, and Fe (as Fe_2O_3) 0·9. These correspond to the formula Pd_3 Sb. The mineral is soluble in hot *aqua regia.* A polished surface is isotropic or faintly anisotropic and is negative to concentrated HCl and HNO_3. *Aqua regia* etches it, bringing out grain structure, and by a mixture of concentrated HCl and solid $KClO_3$ the surface is deeply etched to show internal structure.

At Potgietersrust, the pentlandite, and more rarely the chalcopyrite, includes minute, regular intergrowths of an unknown mineral which was found, on spectroscopic analysis, to contain Fe, Ni, some Co, Pd, and traces of Ir, Sb, As, Au, Ag. This is believed to be essentially a ferriferous nickel disulphide. The occurrence is of special interest as affording a possible explanation of the mode of occurrence of the palladium in the Sudbury ores.

Laurite

This is the sulphide of ruthenium, containing some osmium but probably essentially RuS_2. Crystals, which are minute, are isometric, usually octahedra, with distinct cleavage parallel to the octahedron faces. The mineral is very brittle, and breaks with a subconchoidal fracture. It has a dark iron-black colour and bright, metallic lustre. H = 7·5, sp. gr. = 6·99. When heated, the mineral decrepitates, and gives off first sulphur dioxide and then osmic fumes; but it does not fuse.

Laurite is extremely rare. It occurs in the platinum washings of Borneo, and has been reported with platinum in Oregon.

CHEMICAL COMPOSITION OF NATIVE PLATINUM

Native platinum is not pure. It is essentially an alloy of platinum with iron or palladium that also contains, usually, other metals of the platinum group as well as gold, silver, copper, nickel, cobalt, or manganese. It commonly holds inclusions of osmiridium. On the basis of content of iron, palladium, and iridium the following classification of native platinums, proposed by Moukhine in 1842, is still about the best (Duparc, L., and Tikonowitch, M.N., 1920).

TABLE IV

Classification of Native Platinum

—	Pt Per cent	Fe Per cent	Ir Per cent	Pd Per cent
1. Platinum	100	0	0	0
2. Iridium	20	0	77	0
3. α Ferroplatinum	73–78	16–20	1–1·5	0·2–0·3
4. α Polyxene	80–90	6–10	1·3	0–2·5
5. β Ferroplatinum	73–78	16–20	0	2
6. β Polyxene	80–90	6–10	0	2
7. Platiniridium	56	28	4	0
8. α Palladic platinum	73–74	0	0·1–0·9	21·8
9. β Palladic platinum	83–84	0	1·3–3·6	3·0–3·7

On this basis ferroplatinum, which is dark grey to almost black, includes those varieties of native platinum that contain from 73 to 78 per cent platinum and 16 to 20 per cent iron, whereas polyxene, light grey to silver white, includes those that contain 80 to 90 per cent platinum and 6 to 10 per cent iron. Further, the α varieties of both these forms contain iridium and the β varieties do not. It should be noted, however, that N. Vysotzki (1928) has recently suggested that the limits of ferroplatinum be changed to 71 to 78 per cent platinum and 16 to 21 per cent iron and of polyxene to 6 to 11 per cent iron, platinum content remaining unchanged.

In addition, there are natural alloys of gold and metals of the platinum group (Wagner, 1929, page 13) for which the names platinic, iridic, palladic, and rhodic gold have been suggested, and ferrite is a variety consisting largely of iron with minor amounts of nickel, cobalt, and platinum. Professor Zavaritsky (Kovaloff, 1929) has recently described a new variety of platinum that contains 8 to 13 per cent copper and for which Wagner (1929, page 11) suggests the name cupro-platinum. It occurs as thin shells around platinum grains from primary unweathered dunite deposits of the Niznie Tagilsky region in the Urals and is very readily etched by *aqua regia.*

During the past century many hundreds of analyses of platinum have been published and are readily available (Duparc, L., and Tikonowitch, M.N., 1920; Kemp, 1902, etc.). Particularly detailed studies have been made of the Ural platinum and Professor L. Duparc has shown (Duparc, L., and Tikonowitch, M. N., 1920, page 253) that each of the ten principal platiniferous dunite centres of the Ural Mountains is characterized, to some extent, by the chemical composition of its platinum. Also, that the platinum of closely adjoining centres may differ considerably and that there are even some differences in the composition of platinum from the same mass. All his analyses were made on placer platinum the primary source of which could be ascertained with considerable certainty.

The following table of analyses of platinum gives a general idea of the variations in composition.

TABLE V

Analyses of Native Platinum (in Per Cent)

—	Pt	Ir	Os	Rh	Pd	Ru	Au	Fe	Cu	Ni	Mn	Os-Ir	Total
I. Taguil, U.S.S.R.	83·07	1·9	......	0·59	0·26	......	......	10·79	1·30	......	......	1·89	99·72
II. " "	75·34	2·20	......	0·25	0·20	......	......	13·80	3·96	0·70	......	1·95	98·40
III. Iss, "	85·10	1·38	......	0·30	0·30	......	0·09	7·86	0·63	......	......	4·47	100·13
IV. Goussewi-Kamen, U.S.S.R......	88·06	1·65	......	0·61	0·90	......	......	7·03	0·88	......	......	0·33	100·38
V. Colombia (El Choco)...	76·82	1·18	......	1·22	1·14	......	1·22	7·43	0·88	Sand 2·41	......	7·98	100·28
VI. " "	86·16	1·09	0·97	2·16	0·35	......	......	8·03	0·40	......	0·10	1·19	101·17
VII. Onverwacht, Transvaal.....	84·75	0·95		n.d.	0·53	......	......	11·98	1·28	0·48	......	......	99·97
VIII. Tulameen, B.C...	68·19	1·21	......	3·10	0·26	......	......	7·87	3·09	......	......	14·62	98·34
IX. Brazil—platiniridium	55·44	27·79	Tr.	6·86	0·49	......	......	4·14	3·30	......	......	25·00	98·02

References:
I. Duparc and Tikonowitch, 1920, p. 238.
II. " " p. 239.
III. " " p. 231.
IV. " " p. 247.
V. Kemp, 1902, p. 19.
VI. " " p. 18.
VII. Wagner, 1929, p. 19.
VIII. Poitevin, 1923, p. 85.

From the mass of information that is available the following more important generalizations have been deduced.

The platinum content is variable. For true native platinum it varies from about 70 to 90 per cent, but in platinum-iridosmine mixtures the tenor depends on the amount of the latter alloy that is present and is, of course, generally lower than in native platinum. In platiniridium the content of platinum is very variable and falls at least as low as 19·64 per cent in published analyses.

Iridium is invariably present in true native platinum and, compared with platinum, the content is apparently quite constant. It seldom rises above 5 per cent and averages probably about 1·5 per cent or less. This, of course, is not true in platiniridium or where osmiridium is admixed with platinum.

Rhodium is generally present in small amount, seldom more than 3 per cent. Analyses of Russian platinum suggest that the percentage of rhodium increases slightly with decrease in platinum. In platiniridium rhodium may amount to considerably over 3 per cent.

Palladium is always present in native platinum, but generally in amounts less than 2 per cent. In Russian analyses it decreases with platinum.

Osmium, except as in osmiridium, is present only in very small amount. It is definitely recorded in a number of Russian analyses, but in most cases is listed as absent or as a trace.

Ruthenium is not generally present in platinum. On the other hand, it is usually present in osmiridium.

Gold is generally absent in Russian platinum, but is commonly present in material from Colombia and other sources. In some cases it forms as much as 1·5 per cent. Presumably it is alloyed with platinum metals, but free gold is sometimes included in native platinum, or plated or welded upon it.

Iron is one of the principal constituents. In platinum from Russia it increases as platinum decreases, but not at the same rate. In platinum from other countries this does not appear to hold and the iron content in Colombian material appears to be relatively low and constant.

Copper is practically always present, generally in amounts not much over 1 per cent; nevertheless, some analyses show several per cent and cuproplatinum, as stated above, contains from 8 to 13 per cent.

Manganese, cobalt, and nickel are rarely present in native platinum and then only as a fraction of 1 per cent.

Mercury has been recorded in one analysis, of Californian platinum, to the amount of 0·60 per cent, and lead has been noted, as a trace, in one instance at least.

Iridosmine or osmiridium, the natural alloy of iridium and osmium, occurs very commonly, mixed with native platinum, as the analyses indicate. The percentage varies between wide limits and the alloy also occurs alone in natural form. In the latter case there is generally, but not always, a small percentage of platinum present, but palladium and gold are practically always absent. Rhodium, however, is invariably present and is known in amounts at least as high as 12 per cent. Ruthenium is as often as not present in iridosmine and sometimes in considerable quantity, as much as 8 or 9 per cent. Iron and copper, on the other hand, are generally absent or are present in but very minor amount. The following analyses indicate the variations in composition.

TABLE VI

Analyses of Iridosmine

	1. Russia	2. Colombia	3. Russia	4. Russia	5. Borneo	6. Australia	7. Colombia	8. Russia	9. California	10. Russia	11. Russia	12. Russia
Ir.	77·20	70·40	70·36	64·50	58·27	58·13	57·80	55·24	53·50	46·77	43·94	43·28
Os.	21·00	17·20	23·01	29·90	38·94	33·46	35·10	27·32	43·40	49·34	48·85	40·11
Pt.	1·10	0·10	0·41	2·80	0·15	......	......	10·08	......	......	0·14	0·62
Rh.	0·50	12·30	4·72	7·50	2·64	3·04	0·63	1·50	2·60	3·15	1·65	5·73
Pd.	......	......	......	......	......	......	......	Tr.	......	......	......	......
Ru.	0·20	......	......	......	......	5·22	6·37	......	0·50	......	4·68	8·49
Au.	......	......	......	......	......	......	......	......	......	......	......	......
Fe.	......	......	1·29	1·40	......	......	0·10	Tr.	......	0·74	0·63	0·99
Cu.	Tr.	......	0·21	0·90	......	0·15	0·06	Tr.	......	......	0·11	0·78
Total	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00

Notes to Table VI

1. Russia, Deville and Debray. Annales Chem. et Phys. III, vol. LVI, p. 449.
2. Colombia, El Choco. Idem.
3. Russia. Idem. Sp. gr. 20·5.
4. Russia. Idem. Sp. gr. 18·8.
5. Borneo. Idem.
6. Australia, undoubtedly New South Wales and from the Richmond or Clarence Rivers. Idem.
7. Colombia, El Choco. Idem.
8. Russia. Nizhni Tagilsk. Claus Beitrage zur Chemie der Platinmetalle. Dorpat, 1854. Jahresber. Chemie, 1855, pp. 423, 444, 814, 905.
9. California. Deville and Debray. As under 1.
10. Russia. Berzelius, Poggendorff's Annalen, vol. XXXII, p. 232 (1833). Sp. gr. 19·386-19·471, Ir. Os.
11. Russia. Deville and Debray. As under 1. Sp. gr. 20·4.
12. Russia. Idem. Sp. gr. 18·9.

CHAPTER II

GENERAL CHARACTER AND ORIGIN OF DEPOSITS OF THE PLATINUM GROUP METALS

Metals of the platinum group occur in primary[1] deposits and in placers. Until recently the world was very largely dependent upon placers for its supply of these metals, but within the last ten years the situation has changed. Important primary platinum deposits have been discovered and developed in the Transvaal and new discoveries and improved methods of extraction have greatly increased the production of platinum metals from the nickel-copper ores of Sudbury district, Canada. Today, primary mineral deposits probably contribute about 40 per cent of the world's platinum production and in addition contain enormous reserves that will permit of great increase in output whenever the demand arises.

PRIMARY DEPOSITS

Introduction

Most primary occurrences of the metals of the platinum group are very definitely related to basic and ultrabasic intrusive igneous rocks and the relationship is so pronounced that it serves as a fundamental guide to those in search of platinum-bearing deposits. This being so, a brief description of the principal types of these rocks is justified.

Peridotite is the general name for intrusive igneous rocks that consist essentially of olivine or peridot. Some form of pyroxene is generally present and chromite is a very common accessory mineral. Since olivine has a specific gravity of about 3·3 peridotite is appreciably heavier than more acidic rocks, such as granite, the specific gravity of which is about 2·7. When fresh, peridotite is very hard. In some cases it is olive-green, but generally is very dark green to almost black. According as the pyroxene present is orthorhombic, monoclinic, or both together the rock may be named harzburgite, wehrlite, or lherzolite. Peridotite free from pyroxene is called dunite or, when the olivine contains MgO and FeO in about the ratio of 1 to 1 (as opposed to the ordinary ratio of between 12 to 1 and 2 to 1), hortonolite-dunite. When chromite is the main constituent the rock is called chromitite.

Pyroxenite is the general name for intrusive igneous rocks composed mainly or entirely of pyroxene. Like peridotite, it is a hard, heavy, dark-coloured rock. Depending on the character of the pyroxene present, several varieties of pyroxenite are distinguished, and, in connexion with platinum deposits, the most important is that in which the pyroxene is

[1]In this volume " primary " is used in the sense of " hypogene "; that is, it applies to minerals or mineral deposits that have been formed by ascending waters or as direct segregations from rock magma. The ascending waters are also "primary".

the orthorhombic variety, hypersthene or bronzite, and which is hence called hypersthenite or bronzitite. The name chromite-bronzitite is sometimes used when the rock contains much chromite. Basic plagioclase feldspar may be present, and with increase in its amount the rock becomes norite if the pyroxene is orthorhombic or gabbro if the pyroxene is monoclinic. Finally, the rock may be composed essentially of plagioclase feldspar and is then known as anorthosite.

Both peridotite and pyroxenite alter readily to serpentine, peridotite more readily than pyroxenite.

Primary deposits bearing platinum metals are of two principal types: (1) disseminations or local concentrations in ultrabasic igneous rocks, particularly in dunite, and very commonly associated with chromite; (2) magmatic nickel-copper sulphide deposits that are generally associated with norite. In the first type native platinum or osmiridium is the principal metallic constituent; in the second much palladium is usually present and part at least of the platinum occurs as the arsenide sperrylite or the sulpharsenide cooperite. Of these two types the second is of greater economic importance and today yields practically all the platinum metals that are won from primary mineral deposits. On the other hand, the first type, though it affords comparatively few minable deposits, is of great importance because it is by erosion of such deposits that all the great platinum-bearing placers have been formed. In addition, platinum metals occur in other types of primary mineral deposits such as quartz veins, contact metamorphic deposits, copper deposits, etc., which, however, are of but minor importance compared with the two principal types.

Deposits in Dunite and Related Rocks

These deposits are widespread. Important examples are known in Europe, Africa, North and South America, and Tasmania. Although all have certain similar characteristics, differences exist that justify grouping the occurrences in two subdivisions, based on type deposits in the Ural Mountains and at Onverwacht, Transvaal, South Africa.

URAL TYPE

Much of our knowledge of this type of deposit has come from the works of Professor Louis Duparc (1920), Zavaritsky (1928), Kemp (1902), and others that describe the well-known occurrences in the Ural Mountains, U.S.S.R. Along the axis of that ancient range many large bodies of Palæozoic intrusive rocks have been exposed by deep denudation. They are elongated from north to south and thus correspond in trend with the main axis of the mountains. Bodies of dunite occur at at least eleven different localities and nine of them are commercially important from the standpoint of platinum. The typical geological conditions at these places are as follows: a central mass of dunite is partly or entirely surrounded and covered by a belt that consists very largely of pyroxenite which in turn passes outward and upward into gabbro (*See* Figure 1). In the outer and upper parts of these masses more acidic rocks, including diorite and granite, are occasionally present and dykes of pyroxenite, issite, basic pegmatite, albitite, etc., cut the dunite or pyroxenite. The largest and most deeply eroded dunite mass, at Taguil, is, however, practically free from dykes. The lengths of the dunite bodies vary from

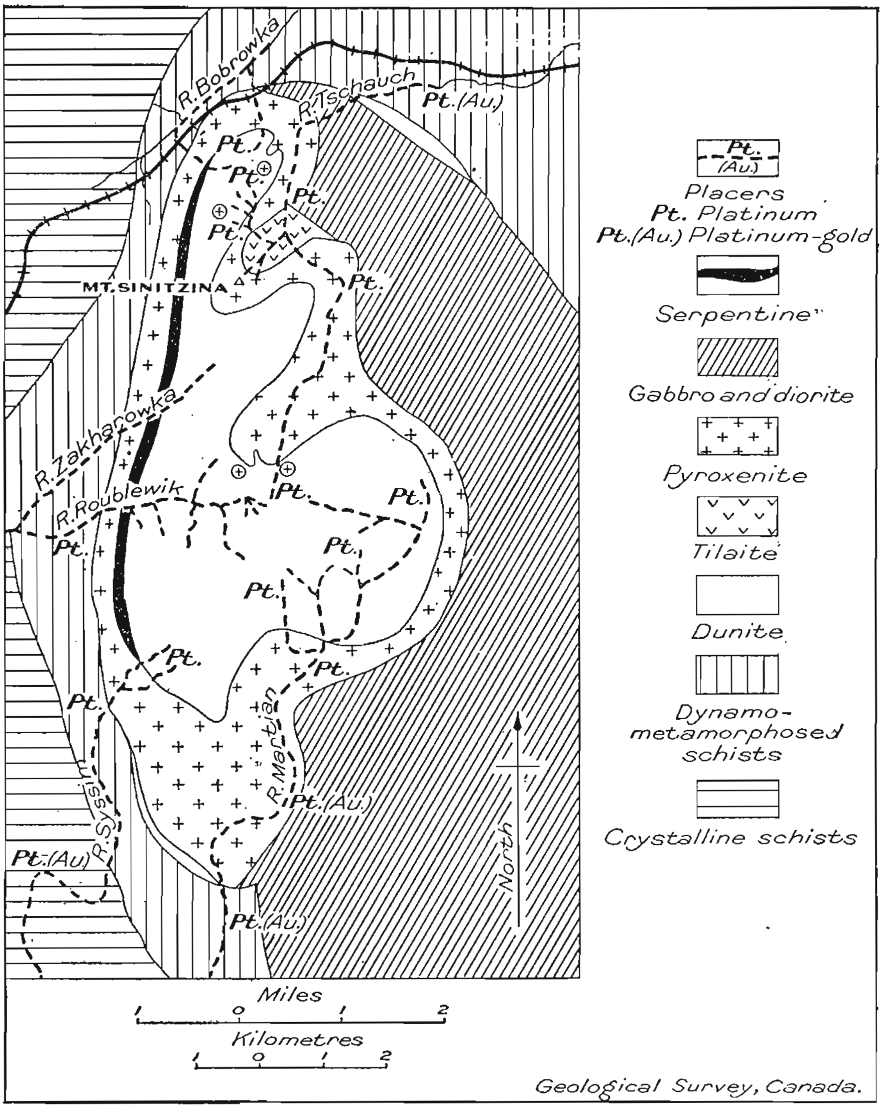

Figure 1. Vicinity of Taguil, Ural Mountains, U.S.S.R.
(After N. Wyssotsky and E. Poitevin.)

1,200 to 10,584 metres and the widths from 1,000 to 5,250 metres. Olivine forms from 97 to 99 per cent of the dunite, is relatively fresh, and varies in composition from $Fe_2SiO_4 + 8Mg_2SiO_4$ to $Fe_2SiO_4 + 11Mg_2SiO_4$, the latter variety being more common. Duparc (1920, page 62) give as an average of twenty-four analyses of fresh dunite: 40·19 per cent SiO_2; 49·94 per cent MgO; 8·83 per cent FeO; 0·51 per cent Cr_2O_3; and 0·53 per cent Al_2O_3. Chromite, however, forms up to about 3 per cent of the rock in different bodies and occurs as disseminated grains or in segregations taking the form of nests, shoots, or vein-like masses. These segregations are small, a few centimetres wide and generally less than 1 metre long. Pyroxene is very rare in the true dunites. Periodite is not common but does occur in the northern Urals in considerable quantity and there harzburgite is the most abundant variety, although wehrlite and lherzolite are also known. Duparc distinguishes two types of pyroxenite in the Urals—true pyroxenite consisting of monoclinic pyroxene with some olivine, and koswite, of the same pyroxene with much olivine and magnetite. The gabbros include a number of varieties that need not be discussed here.

Duparc (1916, page 290) distinguished three types of primary platiniferous deposits according as they occur: (1) in dunite (the most important type); (2) in pyroxenite that is practically koswite (such occurrences are rare); or (3) in peridotite containing rhombic pyroxene and some accessory monoclinic pyroxene. The peridotite may grade into dunite but rarely to pyroxenite, and is frequently almost completely serpentinized. As examples he mentions occurrences at Khrebet, Salatim, in the northern Urals, and in Ronda Mountains, Spain.

In the dunites native platinum occurs crystallized with olivine or more commonly with chromite. Some type of ferroplatinum is the most common variety. All the native platinum contains some intergrown osmiridium and some contains iridium; the amount of the latter may be large enough to warrant calling the mineral platiniridium. Palladium, on the other hand, is very rare or absent. The amount of platinum in dunite is very, very small. Duparc reports that out of eighty-five assays only three showed small amounts of the metal, although he notes that later investigations gave somewhat higher results. The platinum occurs as tiny, isolated grains or globules intergrown with the olivine. Occasionally, however, small local concentrations are found in the olivine, particularly where the rock is altered. Duparc estimated, by calculating the amount of platinum recovered from streams and the quantity of dunite eroded, that the Taguil dunite mass averaged about 0·17 grains a cubic metre, or about 6·6 cents a ton with platinum worth $40 an ounce.

More important concentrations of native platinum occur with the chromite of the dunite, but even the best of these deposits in the Taguil centre are very small, a few inches wide and a few yards long, and of proportionate depth. Nevertheless they have been receiving attention of late (Kovaloff, 1929, page 503) and are said to have produced some 2,000 ounces of platinum in 1925 and 1926. The platinum occurs moulded upon the chromite as tiny, brilliant grains, either isolated or in small, nest-like concentrations in some cases lying in the centre of the chromite segregations or along the contact with the surrounding rock, but in many cases very irregularly distributed. Zavaritsky (Kovaloff, 1929, page 547) has noted a mineral that he tentatively identified as cubanite intergrown with the chromite and containing inclusions of iridosmine.

Duparc states that up to 1920 no primary platinum deposits have been found in situ in pyroxenite in the Urals. Nevertheless, nuggets of native platinum with adhering gangue of pyroxene or magnetite have been found in several streams. From a study of these nuggests and of the geology of the areas drained by the streams Duparc concluded that native platinum does occur in pyroxenite, and in two different ways: (1) in the pyroxenites, segregated among crystals of pyroxene; and (2) with magnetite in pyroxenite. The platinum crystallized last, after magnetite, olivine (if present), and pyroxene. The native platinum of pyroxenite as compared with platinum in dunite, is distinguished by a poorness in osmium, a high content of platinum, and particularly by richness in palladium.

Duparc concludes that there is some evidence pointing to the occurrence of platinum in the gabbros, but only very rarely and they are generally considered barren.

Platinum occurs in Tulameen district, British Columbia, under conditions very similar to those in the Urals (*See* page 89). No commercial primary deposits have been found.

Other occurrences of the Ural type are known in different parts of the world. In Tasmania (Reid, 1921; Nye, 1929) important osmiridium-bearing placers have been formed by erosion of serpentine and related rocks in the western part of the island. The osmiridium occurs in serpentinized peridotite consisting of olivine and bronzite and not in serpentine derived from pyroxenite or gabbro. It forms pockety accumulations distributed irregularly along structural planes—seams, joints, etc.—in the rock and is accompanied by chromite. Gold occurs in the placers and some is alloyed with osmiridium, but, remarkably, platinum is very scarce and where found is attached to gold.

The platinum in the placers of California is believed to have been derived from serpentine and olivine-bearing rocks of the Sierra Nevada and other ranges.

In Colombia, platinum-bearing Tertiary conglomerates that are said (Kunz, 1918) to be the immediate source of the platinum in the present stream gravels contain boulders of peridotite, dunite, and other basic rocks. This suggests an original source of the Uralian type. Duparc and Tikonowitch (1920, pages 478-483) state that the primary source of the Colombian platinum in the Choco district is a belt of minor intrusives and brecciated masses of ultrabasic rocks including dunite, picrite, and pyroxenite lying west of Mount Irro, at the headwaters of San Juan River. The exact source of the placer platinum is not determined, but the authors say that only streams that drain this belt of ultrabasic intrusives are platiniferous. Masses of gabbro and diorite farther east do not yield platiniferous gravels.

Platinum in placers on streams draining the Ronda Mountains, southern Spain, is derived from peridotite (Duparc and Grosset, 1916; Duparc and Tikonowitch, 1920, pages 471-476). The largest body of this rock, about 40 by 15 kilometres in outcrop, intrudes gneiss and consists of olivine, largely converted to serpentine, and rhombic pyroxene, somewhat altered to bastite. Chromite, dark brown spinels, and monoclinic pyroxene are accessory. Thus the rock belongs to the harzburgite family, but lherzolite and dunite phases also occur, the latter in small bodies, however, that grade into pyroxenite. The typical concentric structure of the primary dunite centres of the Urals is lacking.

In Borneo (Uglow, 1919) platinum is associated with gold in placers on the southwest side of the island. The placers contain chromite and olivine and these minerals and the platinum may have been derived from dykes of dunite and olivine gabbro that occur in the mountains drained by the streams.

Osmiridium in the Rand conglomerates is invariably accompanied by chromite and the probable source is basic rocks, including serpentine, harzburgite, hornblendite, etc., of the Swaziland system in Transvaal (Wagner, 1929, page 29).

There are a few examples in the Lydenburg district, Transvaal, of platinum in normal dunite, but they are subsidiary to deposits in hortonolite-dunite. They are at Mooihoek, Driekop, Onverwacht, and Twyfelaar (Wagner, 1929, page 91). At the first two localities platinum values are found in dunite both within and without the pipes of platiniferous hortonolite-dunite. Outside, at Mooihoek, the platinum is invariably associated with schlieren, nests, etc., of chromite, thus closely paralleling Uralian deposits. The average values, however, are low, possibly not over 0·45 dwts. a ton. At Onverwacht dunite surrounding the main platiniferous hortonolite-dunite pipe carried up to 1 dwt. of platinum a ton and again the metal seemed to be associated with segregations of chromite. At Twyfelaar, 9 miles north of Mooihoek, a pipe-shaped body of dunite, apparently containing wehrlite and harzburgite, as well as chromite, yielded up to 4 dwts. of platinum a ton, the values being very erratically distributed. None of these dunite deposits has produced any important quantity of platinum.

ONVERWACHT TYPE

Deposits of this type are known only in the Bushveld Igneous Complex of Transvaal (Wagner, 1929, page 50 *et seq*) and they occur in a dunite of which the olivine is the iron-rich variety hortonolite, rather than normal olivine as in the Ural type. At the end of this section the Driekop deposit is discussed. It represents a type that is intermediate between the Ural and Onverwacht types, in that the platinum-bearing dunite is a peculiar, iron-rich olivine variety between normal and hortonolite-dunite in composition.

The deposits of the Onverwacht type are found in the lower, differentiated part of the norite zone of the Bushveld Complex and Wagner subdivides them into two groups. One group includes those deposits in hortonolite-dunite bodies that form pipe or parsnip-shaped segregations, lenses, and patches in normal dunite or serpentine derived from it. The other group includes those deposits in hortonolite-dunite that form irregular sheets, lenses, and schlieren in coarse pegmatitic diallagite or diallage-ilmenite-pegmatite. The two groups occur together in some areas. Although over sixty occurrences of hortonolite-dunite have been discovered, only two merited exploitation for their platinum content, the rest being barren or very sparingly mineralized. Each of the hortonolite-dunite bodies that has been exploited lies in normal dunite that, although the boundaries are imperfectly known, apparently forms steeply dipping, pipe-like bodies that cut sharply across the gently dipping pseudostratification of the differentiated norite zone.

The hortonolite-dunite is a very heavy (sp. gr. 3·75 to over 4), dark, phanerocrystalline rock consisting essentially of resinous hortonolite accompanied by subordinate amounts of black hornblende, diallage, magnetite, chromite, phlogopite, apatite, and sulphides. The sulphides include pyrrhotite, chalcopyrite, chalmersite, and probably pentlandite, dispersed among the silicate grains as tiny specks. Platinum occurs as native metal, in the form of crystals and irregular nuggety forms up to 0·8 cm. across, either in or between grains of hortonolite and moulded on chromite grains. In some cases it is completely embedded in magnetite or magnetitiferous ilmenite. Considerable amounts of sperrylite and probably cooperite are contained in the concentrates from these deposits, although neither mineral has yet been noted in situ. The values varied considerably between nil and about 1,200 dwts. a ton. The best average obtained in the Onverwacht mine was 18·4 dwts. over an area of 2,270 square feet on the 250-foot level. The boundaries of the "ore" are commercial and commercial values at times extend out into the surrounding, normal dunite. The average tenor of the ore developed in the Mooihoek mine was between 6 and 7 dwts.

The Driekop deposit, also in the Lydenburg district, is the outstanding example of a type in which platinum is associated with iron-rich olivine dunite between hortonolite-dunite and normal dunite in composition. In this occurrence iron-rich olivine dunite and wehrlite occur as small segregations, veins, or schlieren in a large body of normal dunite that, so far as is known, appears to form a steeply dipping pipe in norite. Platinum values are, on the whole, higher in the iron-rich segregations than elsewhere, but do extend into the surrounding normal dunite. The actual Driekop ore-body, therefore, is that part of the large dunite pipe in which there are many closely spaced, platinum-rich segregations. Operations have shown that this ore-body has a steeply dipping cylindrical form and thus is of the nature of a "pipe" within the larger dunite body. At the surface the "pipe" measured approximately 80 feet by 60 feet and it is known to maintain its size to a depth of at least 500 feet. Its boundaries are commercial and can be determined only by sampling. Values are very variable. The ores sent to the mill averaged from 3 to 4 dwts. of platinum a ton.

Chromitite Deposits

In the lower part of the norite zone of the Bushveld Complex there are a number of platiniferous chromitite deposits (Wagner, 1929, Chapter 8). They consist of seams and lenses, some very small but others up to 14 feet thick and extending for miles, of chromitite or chromite bronzitite principally, and thus are related to the pyroxenites by their silicate content. The principal constituents are chromite and bronzite; minor amounts of diallage and plagioclase are also present. The larger deposits are of very regular dimensions and appear as sharply defined, black to dark grey layers bounded by lighter coloured bands of norite, anorthosite, and other rocks associated with them. The platinum values vary from 2 to 11 dwts. in considerable stretches in the Lydenburg and Rustenburg districts, but in many places are very irregular. The platinum occurs as native metal, as very thin plates and wires with the silicates and not with the chromite. Palladium is usually very subordinate, but crude platinum from the upper chromite horizon in Lydenburg district contains 55 per cent of that metal. After a good deal of development in 1925 and 1926 all operations were suspended.

Origin of Deposits in Dunite and Related Rocks

Much has been written concerning the origin of the primary platiniferous deposits described in the preceding paragraphs and although authorities differ in details yet a main fact is generally recognized that the platinum group metals are siderophile elements and tend during differentiation of basic magmas containing them to become concentrated in the most basic magma fractions, like dunite or chromite. Duparc felt that the primary platinum deposits of the Urals were the direct product of magmatic differentiation. He pointed to the fact that the native platinum is moulded as an original constituent of the rock upon chromite, magnetite, pyroxene, and olivine (some olivine crystallized after the platinum) and stated that the extent and richness of primary platinum deposits in dunite depended directly upon the size of the original magma and the degree to which it had differentiated. He showed that the basic rocks of the Urals constituted thick sills and considered the differentiation to have been concentric and to have resulted in the formation of a central core of dunite. He believed that, during differentiation, platinum was concentrated in the dunitic magma fraction. Further, he considered that when differentiation of the original gabbroic magma did produce dunite only a little or no platinum remained in the pyroxenite fraction. And that when a relatively large amount of platinum occurs in pyroxenite, then differentiation has been only partial and has not produced dunite. As evidence he states that when pyroxenites are platiniferous (*See* page 26) they are sometimes associated with gabbro but never with dunite.

Vogt (1927), basing his statements principally on Duparc and Tikonowitch's great work, summed up the situation as follows:

"the original gabbroidic magma, rather basic and rich in magnesia, by the initial cooling in the upper parts, gave rise to the crystallization of olivine, pyroxenes, etc., which after subsidence were separately resorbed (by a 'selective resorption') in the deeper and hotter parts of the original magma. In the new pyroxenitic and olivinitic magmas, a pronounced enrichment of Cr_2O_3 took place and a part—probably even only a rather small part—of the platinum-metal content of the original gabbroidic magma was transported to the new basic magmas, ultra rich in magnesia... A renewed process of magmatic differentiation took place, delivering the rather frequent segregations of chromite... and here crystallizing at an early stage of the cooling."

Zavaritsky (Kovaloff, 1929), after a detailed examination of the platinum deposits of Taguil Centre, concludes that the basic intrusives of the Urals are laccolithic and that differentiation in place led to the separation of a liquid dunite magma in the lower part of the intrusion. He holds the platinum to have been concentrated in this magma fraction which he believes solidified first, before the overlying gabbroic fraction. The pyroxenite he considers as a reaction rim between the dunitic and gabbroic fractions. During crystallization and consolidation of the dunite fraction, chromite and platinum, possibly in the form of some hypothetical chemical compounds associated wth volatile substances, were concentrated in a mobile residual fraction that remained in a liquid state until the last stage of consolidation. This mobile fraction finally gave rise to shoots and schlieren of chromite and platinum in the consolidating dunite or, under stress, was forced into local fissures in the already consolidated dunite to form vein-like bodies of chromite and platinum. Zavaritsky explains thus the two principal types of deposit in Taguil Centre—one characterized by the absence of definite boundaries and another distinguished by sharp boundaries.

Thus all three authors agree in believing that by some process a considerable part of the original platinum content of a basic rock magma was concentrated in a liquid phase of the composition of dunite.

Wagner (1929, page 86) has discussed the origin of the hortonolite-dunite and allied deposits of the Bushveld. The evidence, he states, indicates that the hortonolite-dunite, and other dunites of similar occurrence, are the subsilicic end-products formed during differentiation of the original magma that produced the various rock types of the Differentiated Zone of the Complex. In some cases this dunitic residue was intruded into the other rocks of the norite zone, and apparently replaced the more acidic members; in others the mode of emplacement is doubtful. At any rate, Wagner believed, with good reason, that, during cooling after emplacement, the dunitic magma separated, presumably by liquation, into iron-poor, magnesia-rich, and iron-rich, magnesia-poor, fractions, the latter giving rise to hortonolite-dunite or merely iron-rich olivine dunite. The iron-rich fraction remained fluid the longer of the two, possibly partly because of the higher content of mineralizers such as HO, F, and H_2S, the presence of which is indicated by minerals such as phlogopite and fluorapatite and indirectly by the coarse grain of the rock. The separation of the two fractions was fairly complete in some cases and quite incomplete in others, like the Driekop deposit. At all events, platinum metals were concentrated, although not always entirely, in the iron-rich fractions, the last to consolidate. Whether this was due to the presence of mineralizers is open to question, although Wagner emphasizes the fact that at the Mooihoek mine, and in the upper part of the Onverwacht, phlogopite and black hornblende, both of which contain fluorine and hydroxyl, are good indicators of platinum.

As was noted above, the native platinum is moulded upon grains of chromite or occurs between grains of hortonolite. Sometimes it is embedded in magnetite. It evidently formed during the crystallization of the rock, after the chromite had solidified, and, therefore, was a constituent of the magma. Its ultimate source, however, is open to question, as Wagner points out. Any explanation has to account not only for the productive deposits, but also for the fact that the majority of the known hortonolite bodies are barren. Although this may be explained by assuming that only some of the iron-rich magma fractions contained indigenous platinum, there is evidence that these fractions were capable, in some cases, of extracting platinum from the rocks they traversed. In Rustenburg district where normally barren hortonolite-dunite has been intruded across the platiniferous Merensky Horizon, it becomes platiniferous near that horizon which is itself impoverished near the dunite. Just how this transfer of material was accomplished is not apparent, but the facts indicate that some at least of the platinum in hortonolite-dunite was not indigenous to the magma.

Poitevin (1930 and personal communications) has recently presented a most interesting contribution to the study of ultrabasic rocks. He finds, from a study of chemical analyses of chromite from the Black Lake-Thetford district in Quebec and from the Ural Mountains that a direct relationship between the composition of the chromites and that of their enclosing rocks is indicated. He states that the peridotites and pyroxenites of Quebec are poor in iron and the contained chromites are likewise low in iron. On the other hand the analogous ultrabasic rocks of the Urals are much richer in iron and so are the chromites contained in them. The Quebec chromite carries no platinum, whereas, of course, the Ural chromite deposits contain notable amounts of that metal. The inference is that platinum tends to occur with chromite that is rich in iron spinels and not with chromite poor in them or rich in magnesian spinels, like the Quebec varieties. Poitevin believes, after more extensive researches, not yet published, that there may be considerable truth in this generalization and that, by study of chemical analyses of chromite, particularly the iron content, one might estimate the probability of platinum occurring with it with some degree of accuracy. The hypothesis is an intriguing one and well worthy of more extensive investigation, especially in its apparent relation to the whole question of differentiation in basic or ultrabasic magmas and the concentration of platinum in the rocks derived from them.

Platinum Metals in Magmatic Sulphide Deposits

Metals of the platinum group occur in important amounts in magmatic, nickel-copper-iron sulphide deposits in different parts of the world. The more important of these deposits, which now produce a considerable percentage of the world's platinum and constitute the greatest known reserves of that metal, can be subdivided into two groups that, after their most noteworthy representatives, may be termed the Merensky Horizon Type and the Sudbury type. In these deposits, as opposed to those in dunite and related rocks where the platinum is generally native metal, the platinum occurs principally as sperrylite or cooperite, or possibly in solid solution in the sulphides. Moreover, palladium is present in substantial proportion, frequently more abundant than platinum, but its manner of occurrence is not definitely known. The two sulphide types differ, apart from details of occurrence, in the relative importance of platinum metal and base metal values in them. In the Merensky Horizon type, sulphides of copper, nickel, and iron are present in relatively small amount and the deposits are valuable primarily for their content of platinum metals. They are true platinum deposits. In the Sudbury type, platinum metals constitute only a small part of the total values and are saved as by-products during the extraction of the much more important nickel and copper contents of the deposits.

MERENSKY HORIZON TYPE

The most important deposits of this type are in the norite belt of the Bushveld Igneous Complex of Transvaal, South Africa (Wagner, 1929; Hall, 1932). The complex is a huge, composite body of plutonic and volcanic rocks that outcrops as an irregular oval with a maximum major axis trending east-northeast 288 miles long, and a maximum minor axis 169 miles in length. The total area embraced within the limits of the complex is over 23,000 square miles, but nearly 11,000 miles of this is hidden by a cover of younger strata. The outer, lower part consists of norite, anorthosite, and related basic rocks and the central, upper part of red granite, granophyre, basalt, and pyroclastic volcanic rocks.

The lower part, known as the norite belt, is a huge lopolithic sill that varies in thickness from 1 to 3½ miles and in width of outcrop from about 4 to 19 miles. The norite belt has a central sag and dips everywhere toward the heart of the complex, at angles between 5 and 50 degrees. In eastern Transvaal it has been subdivided by Hall, into five zones. The Upper Zone, of bronzite norite grading upwards into gabbro and syenite, is approximately 800 feet thick. This merges downward into the Main Zone, which consists largely of bronzite norite with, near the top, prominent bands of magnetite and anorthosite, and has a maximum thickness of about 10,000 feet. Below this is the Critical or Differentiated Zone. It reaches a thickness of 5,000 feet in some places and is so remarkably differentiated into layers of rock of different composition and colour that it appears stratified. The rock types include bronzite norite, diallage norite, bronzitite, dunite, chromitite, anorthosite, etc., and serpentine. Beneath this is the Transition Zone—of bronzite-norite with some layers of pyroxenite—which is up to 2,000 feet in thickness and lies on top of the relatively thin (up to 400 feet) Basal or Chilled Zone of norite.

The Merensky Horizon is in the upper part of the Differentiated Zone and contains the most important and extensive platinum deposits in South Africa. The horizon has been traced for a total distance, in three separate districts, of 320 miles, and over great stretches exhibits the regularity of a coal seam. It dips everywhere towards the centre of the complex, generally at angles between 6 and 25 degrees, and the average thickness varies between 3 and 30 feet, although in one place, in Potgietersrust district, the phenomenal thickness of 143 feet is attained. The horizon consists essentially of dark-coloured "sulphidic, pseudoporphyritic, pyroxenitic diallage-norite" and is overlain and underlain by considerable thicknesses of light-coloured norite and anorthosite. It lies some distance above an horizon of chromitite and below a persistent sheet of anorthosite or anorthositic norite and these formations constitute "markers" that have been of great assistance in prospecting for the Merensky Horizon. In some places the horizon is composite, consisting of distinct layers of the typical sulphidic norite and pegmatitic norite, pyroxenite, or chromitite. As a general rule the contact with the overlying and underlying rocks is smooth and regular, either sharply defined or exhibiting some gradation into the hanging-wall. Occasionally, however, irregular tongues and apophyses of the Merensky Horizon extend down into the underlying rocks and the horizon is itself intruded, in a similar manner, by the overlying norite, and in some places fragments of the foot-wall are enclosed in the horizon.

The sulphides are magmatic and occur as small specks and patches either interstitial to and moulded upon the silicates or as minute globular inclusions in them, particularly in diallage and feldspar. They consist largely of pyrrhotite, pentlandite, and chalcopyrite, but include lesser amounts of cubanite, nickeliferous pyrite, and an unidentified nickel-iron mineral. The percentage of sulphides present is not often over 3 per cent. The platinum values are everywhere closely associated with these sulphides, or, in the oxidized zone, which varies from 5 to 100 feet in depth, with rock that is stained with malachite and limonite. Values range from a trace to as much as 13 ounces a ton in picked specimens. In Rustenburg district sections that have been systematically developed averaged 6 dwts. of platinum metal a ton across a width of 30 inches and an average of 10 to 12 dwts. was maintained across a milling width of 12 inches. The platinum is accompanied by palladium, the proportion of palladium to platinum ranging from 11·8 -76·3 to 62-38. Rhodium and osmiridium are generally present, in amounts constituting up to about 5 per cent of the total platinum metals. Iridium is indicated in some analyses and gold is an important minor constituent.

Platinum occurs as cooperite and sperrylite, but apparently not entirely so. Indeed, microscopic examination of many polished surfaces by Prof. Schneiderhöhn of Freiberg failed to reveal any platinum or palladium minerals. Wagner concluded that part of the platinum is, as Schneiderhöhn suggested, in solid solution in the sulphides, and that the bulk of the palladium occurs in a similar manner. Small plates of osmiridium have been noted in concentrates obtained from treatment of sulphide ore.

Values appear to be highest in Rustenburg district. There the horizon is everywhere composite in character, and the main platinum carriers are a layer of coarse, feldspathic harzburgite and a thin (from about ½ inch to 3½ inches) chromite layer which either underlies or overlies it. The workable values are concentrated in a thickness of some 12 inches of this zone, which over considerable sectors carries 10 to 12 dwts. of platinum metals a ton. In general, the highest values are in the narrow chromite layer and in the immediately adjacent harzburgite. Beyond, the platinum is more sparsely disseminated, and an average value over a stoping width of 30 inches is 6 dwts. or less. In the oxidized ore, however, the values are more evenly distributed over a thickness up to 30 inches. The zone of oxidation extends to a depth of from 15 to 1,000 feet measured on the incline, corresponding to a vertical depth of from 5 to 100 feet.

In Lydenburg district the occurrence of the platinum is similar to the above, the best values being found in and near narrow chromite bands. The average tenor of the ore is lower than in Rustenburg district, however, being, as at present known, only about 2 dwts. of platinum metals a ton.

In Potgietersrust district, the platinum-bearing member of the Merensky Horizon is commonly a feldspathic bronzitite, which in places has a thickness of over 140 feet, and within which the workable ore is confined to irregular shoots which can only be defined by careful sampling.

Deposits similar to those of the Merensky Horizon occur in the Norite Belt both above and below that horizon. Some are identical in character with the Main Horizon, but none is of much economic importance. In one, in the Lydenburg district, the platiniferous sulphides are disseminated in boulder-like masses of feldspathic norite in anorthosite; in another the sulphides are in small, irregular bodies of diallage norite in the Main Zone of the Norite Belt, a short distance below a layer of titaniferous magnetite. One is interesting in that it differs greatly from the Merensky Horizon type. It is the Blaawbank deposit, Middelburg district, and consists of relatively small, irregular boulder or sheet-like and carrot-shaped segregations of light-coloured anorthositic quartz norite in dark, diallage norite. The platinum occurs as sperrylite, with irregularly disseminated copper, iron, and nickel sulphides. Values are spotty but encouraging, ranging up to 13 dwts. a ton.

Deposits of the Merensky Horizon type also occur in the Great Dyke of Southern Rhodesia (Wagner, 1929, Chapter 18). This great intrusion is some 350 miles long and about 4 miles wide and is probably genetically related to the Bushveld Complex. Like the latter, it is pseudostratified. Serpentine, derived from dunite, with chromite seams and some harzburgite, forms the lower part of the intrusion and is overlain by pyroxenite, including bronzitite and olivine-bronzitite. Above this a cover of feldspar-rich norite is preserved in some places. The platinum, in the form of sperrylite and cooperite, is found principally in the upper 3 or 4 feet of a well-defined "reef," 8 to 10 feet thick, of pyroxenite, and in an overlying layer of nodular bodies of pyroxenitic norite in pyroxenite. These platiniferous horizons lie from 20 to 60 feet below the base of the norite part of the dyke and are in part stained with limonite, malachite, and, more rarely, secondary nickel minerals. The values are associated with these secondary minerals and this indicates that the platinum occurs with disseminated magmatic sulphides as in the Merensky Horizon. In some places the platinum bearer is fairly typical Merensky Horizon, i.e. sulphidic diallage norite. The average values of these deposits are about 3 dwts. or less of platinum metals a ton.

SUDBURY TYPE

In the Sudbury type, as defined in this volume, are grouped those ore deposits of direct magmatic affiliations, in which the platinum metals are present in small amount in massive or disseminated nickeliferous sulphides and are saved as a by-product during the extraction of the commercially more important nickel and copper content. These deposits are closely associated with, and occur in, alongside, or close to, intrusive bodies of basic rock, particularly norite, but also serpentine, pyroxenite, and associated types. The tenor of the ores in platinum metals is quite variable but is generally low; 0·1 ounce a ton (2 dwts.) would be considered fairly high. Palladium is always present; in some cases in greater amount than platinum. The other metals of the group occur much more sparingly. As a result of these values, the ores cannot, with very few if any exceptions, be mined for their content of platinum metals alone—they are primarily base metal, and predominantly nickel, deposits. Platinum is known to occur in some of the deposits as sperrylite; it may occur in other forms not yet ascertained, but is not known as free native metal. No palladium mineral has been identified, nor is the manner of occurrence of this metal understood. Possibly it and some of the platinum may exist in solid solution in the base metal sulphides.

The best known deposits of the Sudbury type occur in Sudbury district, Ontario, and they are described in some detail in Chapter III of this volume. Therefore it is sufficient to note here that they are found around the periphery of the basin-shaped laccolithic intrusive known as the Sudbury irruptive. This consists of a lower, outer portion of norite and an upper, inner one of micropegmatite. Long stretches along the base contain a small proportion of disseminated sulphides and are really pyrrhotite norite. But the largest ore-bodies consist of massive or disseminated sulphides, principally pyrrhotite, chalcopyrite, and pentlandite, either immediately below the base of the norite or in the so-called offset deposits. The latter form dyke-like masses in the older rocks surrounding the norite and are associated with dykes of diorite or norite that, by some authorities at least, are believed to represent offshoots from the main norite mass.

Very similar in occurrence are numerous nickel-copper deposits in Norway (Beyschlag, Vogt, and Krusch, 1914, page 294) most of which have been worked out or are no longer worked. The sulphides occur in or at the contact of norite or gabbro bodies of fairly small size and irregular outline and are evidently magmatic segregations. The content of platinum metals tends to be highest where chalcopyrite is most abundant, and palladium is present in excess of platinum (Vogt, 1927, page 336). The tenor of these ores in platinum metals averages lower than at Sudbury, however; apparently it is about 50 cents a ton of ore (Royal Ontario Nickel Commission, 1917, pages 265-485).

Deposits of the Sudbury type also occur in South Africa. At Vlakfontein, in Rustenburg district, traces of palladium and platinum are present in irregular or pipe-shaped masses of disseminated and massive sulphides, principally pyrrhotite, pentlandite, and chalcopyrite, that occur in bronzitite in the lower part of the Norite Belt of the Bushveld Complex. Sperrylite has been found in the oxidized ore, but palladium is the principal platinum metal present. Similar deposits are known in the Marico District (Wagner, 1924, and 1929, Chapter 9). In Griqualand, Cape Province, great basin-shaped, sill-like masses of gabbro-norite are intruded into the Carboniferous-Triassic Karroo sediments and are differentiated, from top to bottom, from gabbro and micropegmatite through olivine gabbro and norite to picrite (essentially olivine and augite). At Insizwa, the ore minerals, pyrrhotite, pentlandite, chalcopyrite, and cubanite, with minor amounts of bornite, niccolite, and zinc blende, occur with the picrite, along the lower, fairly flat-lying portion of the sill, either disseminated as a large, sheet-like body of low grade or as veins, stringers, and tabular bodies of massive ore. Nickel and copper are present in about equal proportions, the disseminated ore averaging from 2·5 to 3·5 per cent in these metals combined. Platinum metals, apparently principally palladium, average from ½ to 1 dwt. a ton of ore. The deposits are not being worked.

The last occurrence is an example of deposits of the Sudbury type associated with ultrabasic rocks. They are by no means uncommon. Wagner (1929, Chapter IV) mentions some occurrences in the ultrabasic members of the Swaziland system. The most important is the Uitkomst deposit in eastern Transvaal. At this place, the usual magmatic sulphides are disseminated or in patches in a gently dipping large sill (?) of highly altered pyroxenite. A sample that assayed 2·8 per cent nickel and 1·72 per cent copper contained 6·4 dwts. of platinum a ton and the platinum appears to be irregularly distributed through a thickness of about 35 feet. Such a content of platinum, in relation to the base metal content, is rather high for deposits of the Sudbury type and suggests a relation to the Merensky type. Vogt suggests a similar relation for certain deposits of magmatic sulphides in the lower part of an olivine diabase dyke in the Norylsk district of Siberia (Vogt, 1927, page 339). Native platinum, carrying some palladium, is visible to the naked eye in polished surfaces of this ore.

The Alexo mine, in Porcupine district, Ontario, is a Canadian representative of this type. The deposit is described elsewhere. The sulphide ore, carrying platinum and palladium, occurs in and at the edge of an intrusive mass of peridotite that is now altered to serpentine. Other deposits of the same type are known in different parts of Ontario, as for instance in Strathy Township, but are, as yet, of no great economic importance. Possibly some of the platiniferous copper deposits of apparent magmatic origin in Franklin Camp, British Columbia (*See* page 104) should also be included in this category, in spite of the absence of nickel.

Mention should be made at this point of certain occurrences in Sierra Leone (Anon., 1929; Junner, 1930A; Pollet, 1931). Recently discovered promising placer platinum deposits in the peninsula of that colony are apparently derived from intrusives of anorthosite and anorthosite gabbro. Sulphides are rare and have been found most abundantly in certain coarse-grained basic dykes. Assays show small amounts of platinum, but no systematic examinations have been made. The sulphides include chalcopyrite, pyrrhotite, and pyrite. Large quantities of ilmenite, some magnetite, and a little chromite are found in the gravels with the platinum. Further study will be awaited with interest, for preliminary investigations indicate an interesting array of igneous rocks somewhat similar to those of the Bushveld Complex (Junner, 1930 B).

Possibly the deposit at Salt Chuck mine, Prince of Wales Island, Alaska, should be included in this type, although it is not a typical representative (Mertie, 1920, 1921). Copper sulphides, principally bornite, but including some chalcopyrite, disseminated or in patches, form ore shoots, in a zone possibly 250 feet wide, in a body of feldspathic pyroxenite containing abundant augite. There are practically no gangue minerals and the general occurrence of the sulphides suggests magmatic segregations. However, Mertie finds evidence of replacement and veining and some of the ore cuts across a basic dyke that is intrusive into the pyroxenite. He concludes that the deposit is epigenetic, but this may not preclude a magmatic or near-magmatic origin. It is really a copper-palladium deposit, but contains, also, appreciable amounts of gold, silver, and platinum. Twenty-five thousand ounces of palladium were recovered in 1925, but the mine has been closed since the autumn of 1926.

Origin of Platiniferous Magmatic Sulphide Deposits

These deposits, of both the Merensky Horizon and Sudbury types, are quite evidently the product of differentiation of rock magmas that contained greater or less amounts of sulphur and the base metals iron, nickel, and copper. It has been demonstrated above that the Merensky Horizon deposits in Transvaal are confined to those parts of the Norite Belt of the Bushveld Igneous Complex in which there is evidence of extreme magma splitting that gave rise to an extraordinary diversity of basic rock types. Because of this diversity the portion of the belt in which they occur is known as the Differentiated or Critical Zone. The intimate genetic relation between deposits of the Sudbury type and bodies of noritic or more basic rock is also apparent; although the manner of emplacement of the sulphides has occasioned much discussion. Nevertheless, many of these deposits are undoubtedly direct magmatic segregations and others are no more than one step removed from that category.

Vogt (1923, page 351) has established that during differentiation of rock magmas nickel is concentrated in the magnesia-rich parts. As platinum, where present at all, is concentrated in the nickeliferous magmatic sulphide deposits, presumably the same is true for that metal. In the Merensky Horizon type the platinum bearer is invariably underlain or overlain by anorthosite or anorthositic norite, that is, by rocks relatively rich in lime and alumina and poor in magnesia compared with the noritic or pyroxenitic platinum bearer. Wagner has suggested (1929, page 194, and 1924) "that the excessive precipitation of lime and alumina which led to the formation of the anorthositic rocks may merely have established in the portion of the magma from which crystallization was taking place, the degree of magnesia concentration requisite under certain conditions for the precipitation in quantity of platinum-bearing nickel-copper-iron matte."

With this brief preliminary statement the attempt may be made to reconstruct the essential steps in the formation of platiniferous sulphide deposits of the Merensky Horizon and Sudbury types. The first essential is evidently a magma that contains at least minute amounts of the platinum metals, sulphur, iron, nickel, and (or?) copper. With the original composition of this magma this report need not concern itself, except that, under suitable conditions, the magma must be capable of producing basic or ultrabasic rocks; norite, peridotite, and pyroxenite are the most common.

In some cases, dykes or irregular bodies of these rocks are intruded under conditions not favourable to further differentiation. On solidification, the sulphides and associated platinum metals occur disseminated throughout the rock, or throughout certain parts of it. Not often are such deposits of commercial importance. In other cases, frequently when the intrusive body is tabular and inclined at a moderately gentle angle, further differentiation takes place during cooling. The sulphides, being heavy and about the last part to solidify, sink toward the bottom or lower part of the rock mass and become concentrated there in disseminated or massive form. Evidence of differentiation in the rock itself may be practically absent. As examples the Alexo mine, the Uitkomst deposit in eastern

Transvaal, the Norylsk occurrence in Siberia, and some Norwegian deposits may be cited.

Of more importance are those occurrences in or around bodies of igneous rock that exhibit abundant evidences of extreme differentiation in situ. Such bodies of rock, typified by the Sudbury Irruptive and the Norite Belt of the Bushveld Complex, tend to occur as large sheet-like or lopolithic (basin-shaped) masses. The original magma, injected along a flat-lying plane of weakness under a thick cover of rock, cooled slowly and differentiated either relatively simply, as at Sudbury, or very complexly as in the Transvaal, into a number of fractions of different composition. As indicated above, the sulphides, with the platinum metals, were concentrated in the more basic, magnesian fractions. In the case of Sudbury and some other deposits, apparently gravitative settling was predominant and consequently the sulphides, along with the most basic rock-forming fraction, settled to the bottom of the intrusive mass and formed marginal sulphide deposits near or at the base. Some of the sulphides may have settled to a more deep-seated reservoir and later have been injected, possibly with some aqueous products, along zones of weakness, to form deposits like some of the offset and massive marginal deposits of Sudbury district.

In deposits of the Bushveld Complex the case is more complicated. Although the complex as a whole exhibits good evidence of gravity differentiation, with heavier rocks towards the base and lighter ones on top, and in certain deposits like that at Vlakfontein, gravity was evidently a controlling factor, yet the typical Merensky Horizon deposits cannot be explained so simply (Wagner, 1929, page 196; Hall, 1932, page 278 *et seq*). In some sections the heavier, platiniferous, sulphide-bearing portions of the horizon, containing peridotitic or pyroxenitic rocks and some chromite, lie above less basic, lighter rocks. Wagner offers the suggestion that a sort of flotation phenomenon, whereby platiniferous sulphides, chromite, and heavy silicates were carried upwards by adhering gas bubbles, may have operated. The gas would be supplied by water vapour, H_2S, and other mineralizers present in the magma fractions. However this may be, the ore horizons do occur in sections that show ample evidence of extreme differentiation or magma splitting. Wagner argues (1929, page 195) that the magma fractions in which the sulphur and other mineralizers were concentrated remained fluid for an abnormally long period, that the small amounts of platinum present were concentrated in the matte droplets which the sulphur formed by combination with nickel, copper, and iron, and that these matte droplets in turn were concentrated in magnesia-rich fractions that gave rise to the Merensky Horizon. Further, he cites evidence (1929, page 113) to indicate that the platinum metals were in part at least in a gaseous state in the sulphides, even after the latter had solidified; that where crystallization and cooling proceeded quietly the metals ultimately entered into solid solution in the sulphides, as indicated by Schneiderhöhn, but where compressive stresses occurred during the final stages of consolidation, the platinum metals were driven off and dissipated. This accounts for the fact that in some places, where minor folds, shears, and rolls occur in the horizon and are dated as having formed during a late stage of consolidation, the sulphides are barren of platinum values.

In other places, however, where fissuring occurred during consolidation, the sulphides, with their platinum metals, were squeezed out of the Merensky Horizon into fissures and cracks in the adjoining and underlying rocks: for example, at Elandsfontein in Pretoria district.

Platinum Metals in Other Types of Primary Mineral Deposits

The most important types of primary mineral deposits that contain platinum metals have now been discussed. Nevertheless, these precious metals have been found, and in some cases exploited, in deposits that do not fall within the types outlined above. They belong to types of deposits that, although they occasionally carry important amounts of platinum metals are by no means generally platiniferous. Therefore, though such deposits are possible carriers of the platinum metals, they are not such as would be especially sought after while searching for primary platinum deposits.

CONTACT METAMORPHIC DEPOSITS

Instances are known in several parts of the world of platinum metals occurring in metamorphosed sediments, particularly limestone, at their contact with intrusive masses that may be acid or basic. An assay of an unusual deposit on one of the plates of the stamp mill treating ore from Nickel Plate mine, at Hedley, British Columbia, is reported by Camsell (1910, page 137) to have revealed 0·5 per cent platinum. At the mine, auriferous arsenopyrite occurs in contact metamorphosed limestone at the contact of intrusive sheets of gabbro. Recent work (Bostock, 1929, page 251) seems to indicate, contrary to previous conceptions, that the sheets themselves were not the agents that produced the mineralization, but that their influence was important structurally.

At Sipongi, Sumatra, platinum is known in wollastonite-grossularite rock and palladium-gold has been mined from lime-silicate rock in Brazil (*See* Chapter IV).

The most important deposits of this type are northwest of Potgietersrust, particularly at Vlakfontein and Zwartfontein, in Transvaal (Wagner, 1929, Chapter 13). In this district the Norite Belt of the Bushveld Igneous Complex intrudes and lies on top of dolomite and other sediments of the Transvaal series and huge blocks of these rocks are caught up and engulfed in the norite and associated rocks. The dolomite and dolomitic marls particularly are profoundly altered to contact metamorphic silicates including diopside, grossularite, malacolite, hornblende, and actinolite. The richest section extends for about 1,300 feet along the contact of the intrusive and the altered sediments, dipping about 25 degrees to the west, under the norite. Platinum values are in large, irregular shoots, with surface widths up to 70 feet, in both the igneous and contact metamorphosed rocks. The ratio of platinum to palladium in the ores is about 38 to 62 and the two metals occur as sperrylite and stibiopalladinite respectively, in scattered grains of the usual sulphides, pyrrhotite, pentlandite, chalcopyrite, and cubanite. Values in platinum metals range from 4 to 16 dwts. a ton. The base of the intrusive is a narrow belt of platiniferous, coarse-grained, feldspathic bronzitite, and this is overlain by Merensky "Reef" which, however, is usually barren.

In other parts of the district the relations between intrusives and sediments are exceedingly complicated. The platinum metals in the bronzitite, however, are of magmatic origin, similar to occurrences elsewhere in the Differentiated Zone of the Norite Belt. Wagner considers that the ore in the metamorphosed sediments was formed by the action of vaporous solutions emanating from the overlying platiniferous norite magma and penetrating the dolomite which was rendered porous by expulsion of carbon dioxide. This explanation, which seems well founded, places the deposits as typically Contact Metamorphic. Vogt (1927, page 343), however, questioned such an origin and preferred one by intrusion of very thin molten sulphides from the adjoining norite. He bases his argument on certain similarities in Norwegian magmatic deposits and the similar ratio that exists between Fe, Cu, Ni, S, and Pd and Pt in the magmatic and contact metamorphic ores. As Wagner has pointed out, however, the ratio of palladium to platinum in this district is considerably higher than in the normal magmatic deposits of the Norite Belt.

QUARTZ VEINS AND OTHER SILICEOUS DEPOSITS

The occurrence of platinum in quartz veins is unusual. Once again Transvaal, South Africa, supplies the most outstanding examples. In the Waterberg district (Wagner, 1929, page 257) brecciated quartz lodes occupy faults of post-Karoo age in felsite and felsite tuff of the Bushveld Igneous Complex. The most important concentrations of platinum are found in the Main and Branch Lodes of Transvaal Platinum, Limited, the Main Lode being persistent for 2½ miles, varying in width from 6 to 60 feet, and dipping steeply southeast. The Branch Lode is a hanging-wall offshoot over 1,200 feet long and 4 to 30 feet wide. The lodes are composite, in places consisting of a number of fairly closely spaced quartz stringers, in others of a brecciated mixture of angular fragments of felsite and (or) quartz, generally accompanied by specularite, in a matrix of later, white, partly cavernous quartz. Crustification, with comb structure, is common. In some places chalcedony has been deposited at a late stage, in irregular veins and crusts. Specularite, oxidized pyrite, sericite, chromiferous chlorite, and kaolin are present.

Platinum is rarely visible to the naked eye, but occurs as tiny, grey specks, of two generations, very erratically distributed. The earlier generation is intimately intergrown with or embedded in crystal aggregates of specularite as ragged or colloform grains. Occasionally it is moulded between quartz grains. The later is found in iron oxide derived from pyrite. The platinum contains 7 to 40 per cent palladium, the percentage of palladium being much lower in the Branch Lode than in the Main one. Etching tests revealed that the platinum is made up of alternating layers of palladium-poor and palladium-rich platinum and the colloform structures suggest precipitation as a gel from colloidal solutions. The workable bodies of ore formed irregular patches in the lodes and yielded some very high assays in platinum, up to 167 ounces a ton. Considerable development work was done and a plant erected, but operations were discontinued in 1926, partly at least because of erratic distribution of values and difficulties of extraction. The nature of the deposits indicates formation at fairly high temperature near the surface. The deposits are distinctly younger than the Bushveld Igneous Complex, although they may be, or probably are, underlain by the Norite Belt of the complex. Thus, although the ultimate source of the mineralizing solutions or vapours is not known, Wagner suggests that the platinum and palladium may have been extracted from the rocks of the Norite Belt by these solutions or vapours.

At Tweefontein, Transvaal (Wagner, 1929, pages 185 and 204), sperrylite and stibiopalladinite are found in irregular veins and eyes of pegmatite and graphic granite along crush-zones in banded ironstone which underlies the norite there. The minerals are associated with limonite and malachite or with pyrrhotite and chalcopyrite, and also occur in gossan of limonite in a seam encountered in a shaft. It is believed that the deposits represent acidic differentiates of the norite magma. Somewhat similar occurrences, indeed, are known in the Norite Belt in Lydenburg and Middelburg districts.

Platinum metals have been reported from quartz veins in a number of other localities, but none of the deposits has been of much economic importance. Among them may be mentioned the vein on Mother Lode claim in Burnt Basin, B.C., and the Esperança veins in Minaes Geraes, Brazil. Bell describes the occurrence of platinum in quartz veins, some of which are associated with altered magnesian intrusives, on South Island, New Zealand (1906, page 749). Platinum occurs in amounts only up to about 0·17 ounce a ton and is accompanied by silver.

A most interesting and unusual occurrence at the Boss mine, in Yellow Pine mining district, southwestern Nevada, has been described by A. Knopf (1915). Gold, palladium, and platinum have been concentrated by descending meteoric waters in an irregular siliceous replacement deposit along a series of nearly vertical fractures in nearly horizontal Carboniferous dolomite. The values are associated with bismuth-bearing plumbojarosite, a hydrous sulphate of iron and lead, yellowish green in colour, forming, where concentrated, heavy earthy masses, and resembling green talc in the porous siliceous gangue. Distinctly separate are shoots of oxidized copper ore, principally chrysocolla and limonite. The siliceous replacement forms a zone about 30 feet wide, but the precious metal shoots are confined to a width of about 12 feet against one wall and form irregular pipes that pitch at a low angle. During 1917, 442·50 tons of copper-gold-palladium ore yielded 400 ounces of palladium and 107 ounces of platinum. An analysis of the plumbojarosite made by the United States Geological Survey showed, a ton: 234 ounces gold, 15 ounces platinum, 64 ounces palladium, and a trace of iridium. The palladium and platinum occur as extremely small, black particles that, even under high magnification, are indistinguishable from the rough, black, spongy gold. A small mass of granite porphyry intrudes the dolomite about 600 yards north of the mine, but there are no basic intrusives in the vicinity. The original primary deposit was probably formed at fairly high temperature, and may have contained galena or some other lead mineral. Uglow (1919, page 355) has suggested the possibility of some such mineral as bournonite being present, because platinum has been found with this mineral in dolomite and altered limestone in France (Kemp, 1902, page 66) and with tetrahedrite in quartz veins near Rio Tinto, Spain (Kemp, 1902, page 81).

Kemp (1902, page 49) showed that platinum is present in shear zones in granite about Siwash Creek, Tulameen district, British Columbia, but only in very minute amount. The reported presence of sperrylite in a copper-bearing pegmatite on Copper Mountain is noted on page 103 of this report.

OTHER OCCURRENCES

Platinum metals have been recorded in very small amounts from a number of other sources. Association with tetrahedrite and bournonite was mentioned in a preceding paragraph. Bell (1906, page 749) notes its presence in massive pyrite at Coromandel, New Zealand, and a similar deposit is noted in France by Kemp. The latter authority also cites examples (1902, pages 51 and 59) of platinum obtained by assay of slate or shale from three different localities in the United States. Kemp also records (1902, page 35) that metals of the platinum group have been reported in considerable quantity in the ash of certain coal from Australia, although the amounts are so high in this case that, in view of the fact that no extraction has ever been made from this source, the assays would seem open to question. Further, the metals are apparently present in traces in a great many, if not all, copper ores. The following table, reproduced from the report of the Royal Ontario Nickel Commission, 1917, indicates this:

TABLE VII

Platinum and Palladium in Blister Copper

Refinery	Ounces per 100 tons	
	Pt	Pd
Garfield, Utah	0·342	1·183
Steptoe, Nev.	1·016	4·402
Omaha, Nebr.	1·825	6·486
Mountain, Cal.	1·320	0·607
Tacoma, Wash.	0·710	3·327
Aguas Calientes, Mex.	0·416	0·226
Cerro de Pasco, Peru	0·319	0·589
Mount Lyell, Cal.	0·624	1·374

Migration of Platinum Metals in Solutions

Perhaps the most characteristic property of the metals of the platinum group is their insolubility even in concentrated acids. Yet the nature of platiniferous mineral deposits, as outlined in the preceding pages, indicates clearly that, although the platinum metals are concentrated in nature most commonly as direct products of magmatic differentiation in the ultrabasic rocks or in typical magmatic sulphide deposits under conditions that do not imply migration in solution, in many other occurrences their migration in this way cannot be denied. The available evidence suggests transportation not only in primary, heated solutions of igneous origin, but also, less commonly, in unheated, meteoric waters.

HYPOGENE MIGRATION

Some authorities (*See* page 62) believe that the Sudbury copper-nickel ores were formed by circulating, heated, mineral-bearing waters. They thus explain the presence of quartz and carbonate, and the replacement of country rock by sulphides. If this hydrothermal theory be accepted then the platinum metals in the ores were transported in aqueous solutions and were deposited therefrom. The theory, although supported by a number of geologists, is, however, not unanimously accepted, so that the evidence of aqueous transportation in this case may be questioned. Nevertheless, in view of the replacement of country rock by ore in some deposits, and particularly in the offsets, and because of the presence of the so-called hydrothermal minerals like quartz, carbonates, chlorite, and amphibole in some mines, it does seem probable that aqueous solutions of some sort have played a part in the formation of some of these remarkable ore-bodies. In addition, somewhat similar platiniferous sulphide deposits, for example the Shebandowan Lake ores in Ontario and the palladium-copper deposit at Salt Chuck mine, Alaska, seem to have been formed, in part or entirely, by replacement of country rock by sulphides. Thus, even in this type of platiniferous deposit there is at least a strong suggestion that the precious metals may have migrated in aqueous solutions.

The evidence is more definite in the case of certain pyrometasomatic deposits. Wagner concluded that the important deposits of this class northwest of Potgietersrust, Transvaal, were formed by the penetration of dolomite by vaporous solutions emanating from the overlying norite intrusive, although he admits that liquid magmatic solutions may have co-operated. These deposits carry platinum and palladium in the form of sperrylite and stibiopalladinite. The native platinum and accompanying palladium, gold, and copper, of the wollastonite-grossularite ore at Sipongi, Sumatra, are believed by Hundeshagen to have been introduced by hot solutions emanating from nearby intrusive igneous rocks, and at about the same time that the limestone was altered to silicates. These, and a few other similar deposits, point clearly to transportation of platinum metals by hot solutions of the contact metamorphic type.

Platinum metals have been reported in a few acid pegmatites. The most noteworthy example is that at Tweefontein, Transvaal, described on page 41. Geologists who have studied these deposits, which contain sperrylite and stibiopalladinite in irregular veins of pegmatite and graphic granite, conclude that they are acid, pegmatitic facies of the Bushveld norite deposits. They are believed to have been formed by pegmatitic vapours and solutions at a much lower temperature than that which existed during formation of the associated magmatic or contact metamorphic deposits.

The occurrence of platinum metals in quartz veins is noted on a preceding page. None of these deposits is of much commercial importance, but they indicate clearly that the platinum metals in the veins were deposited from aqueous siliceous solutions. And the colloform, banded nature of the platinum-palladium in the quartz lodes of Waterberg district, Transvaal, suggests deposition as a gel from colloidal solutions. The nature of the deposits indicates formation at fairly high temperature, near the surface. Lindgren (1928, page 876) has called attention to the similarity that exists between these lodes and the colloidal cassiterite deposits in rhyolite of Nevada, New Mexico, and Mexico.

The peculiar platiniferous copper-nickel lodes at Mulga Springs and elsewhere in Broken Hill district, New South Wales, were thought by Jaquet (1892) to have been formed near or at the surface by springs. More recently, however, Andrews (1922, page 191) has concluded that they were deposited by solutions or emanations from dykes or sills of serpentine or other basic rocks with which they are associated. He thought they were deposited "under conditions of decreasing pressure at or near the margins" of the intrusive. Platinum, iridium, and palladium are present in a finely divided condition.

The available field evidence, then, as perhaps might be expected, indicates that most platiniferous deposits of hydrothermal origin were formed at high or fairly high temperature. The pressure range, however, is more variable, and some deposits were evidently formed quite close to the surface. Also, there are a few examples, noted elsewhere in this report, where platinum is associated with tetrahedrite or bournonite in deposits that were probably formed at quite moderate temperature. The way in which the metals are carried in solution is not known, but they were deposited as native metal or alloy or as sperrylite and stibiopalladinite. The probability of transportation in colloidal solutions has been indicated.

Shaw (1921) has conducted experiments to investigate the solution and deposition of platinum. Chloride solutions are among the best natural solvents. Ferric and cupric chloride dissolve platinum at ordinary temperature and pressure and much more rapidly when heated to 160° C. Alkali chloride is also a solvent in the presence of an oxidizing agent such as manganese dioxide.

SUPERGENE MIGRATION

Knopf considered it quite likely that a certain amount of redistribution of platinum and palladium had been effected by descending surface solutions in the oxidized deposit at the Boss mine, Nevada. The ore is plumbojarosite and Knopf points to the fact that the precious metals are known to be rather soluble in hydrochloric acid in the presence of this mineral.

Better evidence of supergene migration has been given by Wagner (1929, pages 188-193). He points out that, although the platiniferous sulphide deposits of the Merensky Horizon, Transvaal, have suffered enormous denudation, yet there is no residual concentration of platinum or palladium in the weathered portions of the "reef;" indeed, in some places the outcrop is impoverished in these metals. It would seem, therefore, that platinum metals have been carried away in some manner during weathering. Now, in the oxidized ore, platinum is present partly as crystals of cooperite and sperrylite, and partly as minute, colloform, nuggety grains. Microscopic examination of these grains has revealed concentric shells of platinum surrounding a core of palladium, suggesting deposition from colloidal solution. These hints of migration in supergene solutions are reinforced by more convincing evidence. In parts of the Rustenburg district, platinum and palladium have definitely been leached out of the Merensky Horizon and redeposited, mostly as colloform nuggety grains, in the underlying anorthosite. Again, transportation in colloidal solution is suggested. Wagner points out that, in the primary ore of the Merensky Horizon, platinum and palladium are present partly in solution in the sulphides. Apparently on destruction of these sulphides during weathering, the precious metals go into colloidal solution in the groundwater, to be carried away and lost, or redeposited, depending on the presence or absence of conditions suitable to redeposition.

It is of interest to note, also, that Hussak (1904, pages 452, 464) considered that certain platinum nuggets he had found in Brazil were of secondary origin, formed by deposition, in botryoidal and stalactitic forms, from meteoric solutions. He believed that the platinum had been derived, by circulating groundwaters, from platiniferous sulphides or sperrylite in conglomerate quartzite in the east slope of the Serra do Espinhaça. Today, derivation from platiniferous sulphides would seem more probable than from sperrylite, a very stable mineral.

Bearing on this discussion also is Duparc's conclusion that osmium has been leached from native platinum during transportation in streams in the Urals.

In conclusion, then, it seems that platinum and palladium are, under favourable conditions, dissolved, transported, and redeposited by supergene waters. That this process would operate, to any important extent, on deposits in which platinum is present only as native metal, sperrylite, or cooperite, may be doubted. When, however, the precious metals are present in solid solution or some very finely divided state in base metal sulphides, supergene migration may be of considerable importance. Indeed, under ideal conditions, it may, apparently, lead to commercially important secondary enrichment in platinum metals.

ALLUVIAL DEPOSITS (PLACERS)

Placers have contributed a very large percentage of the world's platinum and still supply the greater part of the annual output. The most important placer fields are in the Perm district in the Ural Mountains, and in Colombia. Of less importance are placers in Abyssinia, Tasmania, British Columbia, western United States, Australia, Sierra Leone, and a few other places.

The origin of placers that contain metals of the platinum group is similar to that of the more familiar and widespread gold placers. The first necessity is a primary deposit that contains platinum metals. When such a deposit is exposed to erosion it is decomposed and disintegrated, by chemical or mechanical agencies, or a combination of both. During this process the resistant constituents are freed, or partly freed, from their less resistant matrix. If, now, this decomposed material is transported by water, in a stream or river, the heavy resistant particles are further freed and, unless they be excessively minute or flaky, sink towards the bottom of the moving material. A concentration of these particles is, therefore, effected in the lower parts of layers of gravel or sand deposited by the stream. Platinum metals, like gold, are heavy and very resistant to decomposition and are, therefore, well suited to concentration in alluvial deposits.

In all the important known platinum or osmiridium placers it has either been definitely established, or it is highly probable, that these precious metals have been derived from basic igneous rocks such as dunite, peridotite, and pyroxenite, or from serpentine produced by their alteration. The widespread occurrence of platinum metals, principally native platinum and osmiridium, in these rocks, has already been pointed out. Although the metals are present, generally, in very minute amount and frequently cannot be detected in samples, yet long-continued erosion, and concentration of the metals from countless thousands of tons of originally solid rock, many and do produce very valuable placer deposits. This result, however, is dependent upon certain conditions.

In the first place it is obvious that the platiniferous rocks that are being eroded must form bodies of fairly large size. Secondly, they must have been subjected to processes of weathering and erosion either for an extremely long time or at a very rapid rate. The Russian occurrences afford an example of the first and those in Colombia of the second. In the absence of orogenic movements or of long-continued uplift of the land surface as a whole weathering will eventually result in a mature topography, when the districts will be characterized by broad valleys and low relief and be drained by rivers with low gradients, as is the case, for example, in the Russian platinum fields. It is in such districts that the richest placers are found, for not only do the slow-moving streams deposit most of their burden of rock and mineral along the valleys, but they also frequently change their course and thus the valuable metals are subject to reconcentration, perhaps many times. The Tulameen country, on the other hand, has not reached this stage of maturity, and this probably is one of the main reasons why the platinum placers are not more extensive and richer than they are. The same applies to southern Spain, where the topography is youthful, and the streams transporting the platiniferous sands flow rapidly through narrow, steep-walled valleys, a condition that is unfavourable to concentration of the platinum. Similarly, in the Transvaal fields, the land has been rising almost continuously since early Tertiary time, and, as a result, the rivers draining the area have had to continue cutting their channels downward, and so have remained youthful. The situation there is further aggravated by the seasonal character of the rainfall—which apparently has prevailed for long ages—as a consequence of which during the torrential downpours of the rainy season the swollen waters travel so swiftly to the sea that they carry with them much of their burden of detritus, including the platinum, which is in an extremely fine state of division. This is believed to be the explanation of the apparent lack of extensive alluvial platinum deposits in the Transvaal, although some placers have been discovered, particularly in Lydenburg district.

Reconcentration, already mentioned, is an important factor in the evolution of a placer, perhaps an essential one if the deposit is to be of great economic value. It may be said that in all the richest platinum placers there is evidence that the material has been worked over and reconcentrated, sometimes repeatedly. Colombia furnishes an excellent example of this factor. Thus, in Choco district, the bulk of the platinum comes from the gravels of the present stream channels and has been reconcentrated from older gravels. Further, according to Kunz (1918, page 17), the stream beds in which platinum occurs are those in which Tertiary conglomerates have been eroded, the present deposits being reconcentrates from these much older gravels. The conglomerates contain rounded boulders of basic rocks, including peridotite and dunite. Somewhat similar conditions are known in Russia.

Glaciation, or the lack of it, is a most important factor. In areas that have suffered intense glaciation, as, for example, large parts of Canada, the chance of important pre-Pleistocene placers being preserved is small, for these poorly consolidated surface deposits are easily eroded and dissipated by the scouring ice. Tulameen district, in British Columbia, for example, has undoubtedly been adversely affected by glaciation. The main valleys, which probably contained the richest platiniferous deposits of the area, were severely glaciated and the present platiniferous gravels are greatly impoverished. On the other hand, the Great Russian and Colombian fields have not been glaciated. The time that has elapsed since the Ice age is not sufficient to permit of the formation of very large, rich placer deposits, but the material eroded by ice in one place is always deposited at some other place in the form of glacial deposits of boulder clay, gravels, etc. Although any original precious metals are greatly scattered and the resulting glacial deposits are commercially worthless, in the vast majority of cases, yet they do contain, in many cases, small amounts of platinum and gold. These unconsolidated or poorly consolidated glacial deposits are easily eroded by post-glacial streams and, in this way, under favourable conditions, worth-while reconcentrations of the precious metals in them may result. Considerable amounts of platinum and gold in the gravels of some of the present streams in British Columbia have had such an origin.

In this connexion another consideration is of importance. In relatively flat regions, like the Canadian Shield, it has been definitely established that Pleistocene ice spread out from centres of accumulation, forming great, fan-like sheets. The materials eroded during advance were widely scattered, due to the fan-like, spreading nature of the flowing ice, and were finally deposited, at the ice front, over a tremendous area. Any valuable contents were effectively dissipated beyond chance of important reconcentration. In the case of alpine glaciation, such as prevailed over large parts of the Cordilleran region in Canada, different conditions exist. In many of the mountainous districts there the principal glaciers, and the greatest glacial erosion, were limited to the more important valleys. Consequently the ice, being hemmed in by mountain barriers, did not spread out to the same extent as in the case of the great continental ice-sheets, and the materials it eroded were not scattered to the same extent. The chances of subsequent worth-while reconcentration of the valuable heavy constituents of the glacial deposits are consequently much greater.

One other factor in connexion with Cordilleran glaciation should be mentioned. Many of the smaller valleys, tributaries of the larger ones along which the ice moved in the mountains, lie in directions transverse to the direction of ice movement. Consequently, where they did not develop their own valley glaciers, the ice moved across rather than along them, and, when fairly deep, they were protected from excessive erosion. In many cases they were probably occupied by a filling of practically stagnant, non-eroding ice, over and across which the main glacier flowed.

In such protected valleys pre-Pleistocene placer deposits may, and have been, preserved. They may, of course, be covered by a considerable thickness of glacial debris, dumped upon them, as the ice finally withdrew. Similarly, interglacial placers, lying between glacial deposits, are known in British Columbia.

Associated Minerals in the Placers

In placers, the platinum metals invariably occur as native elements, although usually in the form of natural alloys. Platinum and osmiridium are the most common. No mineral compound of any of the platinum metals has been recorded from an alluvial deposit. By far the largest percentage of the particles of metals of the group that are found are relatively pure and do not adhere to or form parts of nuggets of other minerals. They are associated, however, with a number of other heavy resistant minerals. The most characteristic associate is chromite. Magnetite and ilmenite, the other principal constituents of a normal "black sand" with which platinum is generally associated, are also common; others include gold, silver, copper, cassiterite, garnet, zircon, rutile, diamond, topaz, quartz, etc.

Of more interest, perhaps, are the minerals that have occasionally been found securely attached to or intergrown with placer platinum, in nuggets, for such occurrences give evidence of the nature of the primary deposit from which the platinum was derived. Chromite is the most common. It has been found with platinum in the Russian, Colombian, and Tulameen fields as well as elsewhere. The logical conclusion is that the parent rock was peridotite or some related very basic rock that contained platiniferous disseminations or segregations of chromite. Olivine, serpentine, and pyroxene have all been observed in platinum nuggets and these occurrences also suggest a basic, or ultrabasic, igneous rock as the original host. Mica has been noted, and a number of composite nuggets of gold and platinum. On the whole, however, such occurrences are rare. Kemp has discussed the subject at some length in Bulletin 193 of the United States Geological Survey.

In conclusion it should be noted that many gold placers contain a small proportion of platinum, usually in a very finely divided state. As examples may be cited numerous fields in British Columbia, placers of California, and beach placers of Oregon and British Columbia. The exact origin of the platinum, which is usually present only to the extent of a small fraction of the amount of gold, is frequently unknown, but the amount in some cases is commercially important. During extraction of gold the platinum tends to collect in the heavy, black sand concentrate. Its extremely fine state of division and the fact that it will not amalgamate in an ordinary operation, render extraction difficult. Many devices have been suggested for saving this fine platinum, but no very great success has as yet been attained. An economic solution of the problem is greatly to be desired.

On many ocean beaches the usually small and erratically distributed pockets or streaks of black sand that are formed by the action of waves contain small amounts of platinum. Not often are these deposits of much commercial importance, although occasionally they can be worked profitably by individuals or small operations.

Fossil Placers

In some parts of the world ancient deposits of alluvial material have been buried by overlying strata and become consolidated to form beds of sandstone or conglomerate. Any precious metal content of the original deposit remains incorporated in the solid rock. Such deposits may be referred to as fossil placers. The best known example of this type of occurrence of platinum metals is in the great gold deposits of the Witwatersrand, Tranvaal (Wagner, 1929, Chapter V). The principal production is derived from the Main Reef Leader conglomerate on the Far East Rand, but notable amounts are also recovered from the Battery Reef on the West Rand and the metals are known in other conglomerates. The " osmiridium " that is saved as a by-product during gold extraction is actually a concentrate containing 50 to 75 per cent osmiridium (or iridosmine) and also some platinum, ruthenium, rhodium, and gold. The production of 5,000 or 6,000 ounces per annum in recent years gives South Africa first place as producer of osmiridium. The distribution of the platinum metals in the conglomerate corresponds to that of the gold and, as with the latter, values are highest where the pebbles of the conglomerate are relatively large. Although there has been renewed discussion in recent years, it seems to be the consensus of opinion, particularly among South African geologists, that all the precious metals were deposited at the same time as the conglomerate. Unlike the gold, however, the " osmiridium " did not undergo solution and recrystallization; the fragments exhibit all gradations from well-preserved crystals to completely water-worn grains. The proportion of platinum metals in the conglomerate, it should be noted, is very, very small. In 1924, 1 ounce was obtained, at different mines, from about 1,200 to over 9,000 tons of that rock that passed through the mills; the average recovery, however, is probably less than 50 per cent.

The presence of platinum in Tertiary conglomerate in Colombia has already been noted. The platinum of certain streams in the Urals is believed to be derived from Permo-Carboniferous conglomerates that contain pebbles of basic igneous rock (*See* Chapter IV, page 121). Platiniferous and auriferous Tertiary conglomerate is known in Alaska (*See* Chapter IV, page 140). Certain platiniferous greywackes near Westphalia, Germany, perhaps also should be classed as fossil placers (Chapter IV, page 114).

ELUVIAL DEPOSITS

In some places in the Urals and in Transvaal, weathering of the outcrops of platiniferous dunite bodies has produced considerable surface accumulations of eluvium or rubble that is itself platiniferous. This loose, partly decomposed material covers the original outcrop or lies on the slopes adjoining it. The native platinum of the original deposit is partly or largely set free during the weathering process and forms crystals, irregular grains, or nuggets in the surface rubble, and can generally be panned easily. The largest deposit in Transvaal covered the slopes below the original outcrop of dunite on a knoll at Onverwacht mine and the platinum values were sufficiently high to justify passing all the material through the treatment plant. Iridosmine is somewhat similarly concentrated at certain places in Tasmania.

CHAPTER III

OCCURRENCES OF PLATINUM METALS IN CANADA

TYPES OF DEPOSITS AND THEIR DISTRIBUTION

Canada today is the world's second largest producer of platinum metals, her production being exceeded only by that of Russia. Although platinum is known to occur in every province except New Brunswick and Prince Edward Island practically the entire output comes from nickel-copper deposits of Sudbury district, Ontario. British Columbia is the only other producer and its output consists, generally, of a few ounces of placer platinum won principally from streams in Similkameen district and an irregular, small amount of platinum metals saved in the Trail metallurgical plants. The Ontario production is obtained as a by-product during refining of nickel-copper ores and, consequently, varies with the output of these metals.

Mineral deposits in Canada that are known to contain metals of the platinum group represent a number of different types. In the following paragraphs they are grouped according to the subdivisions adopted in the preceding chapter.

Deposits in Dunite and Related Rocks

No deposits of the Onverwacht type, in hortonolite-dunite, are known in Canada. The Ural type, in which native platinum occurs in dunite, pyroxenite, periodotite, or serpentine, generally associated with chromite, is known at only one place—Tulameen district in British Columbia. No commercial primary deposits have been discovered there, but platinum does occur in dunite or peridotite surrounded by koswite, under conditions that very closely parallel those of the primary platiniferous dunite centres in the Urals. The primary deposits, however, have supplied the platinum found in placers in Tulameen district. A reported occurrence in Reaume Township, Ontario, may belong to this type. Somewhat similar are deposits of chromite on Scottie Creek in Clinton mining division, and near Cascade, British Columbia. The chromite has been reported to carry small amounts of platinum.

No platiniferous chromitite deposits similar to those found in Transvaal are known in Canada.

Platinum Metals in Magmatic Sulphide Deposits

No platinum-bearing disseminated sulphide deposits analagous to those of the Merensky Horizon of the Bushveld Igneous Complex are known in Canada.

Deposits of the Sudbury type are fairly numerous and of great importance. The most important and typical ones are in Sudbury district, Ontario, and are mined primarily for nickel and copper. These are associated with norite of the Sudbury irruptive. At the Alexo mine, and in Strathy Township, nickel-copper sulphides are related to serpentinized peridotite intrusives. The origin of as yet unproductive deposits at Shebandowan Lake is still in doubt; platiniferous and palladium-bearing copper and nickel sulphides are found as replacement bodies in schist that is probably derived from peridotite.

In Manitoba certain platiniferous sulphide deposits in Oiseau and Maskwa Rivers areas perhaps should be included in this class. The nickel and platinum values may be related to peridotite and gabbro intrusives.

In British Columbia, platinum is found in small amount in copper deposits associated with shonkinite-pyroxenite in the Franklin Camp, Grand Forks mining division, and in copper ore near pyroxenite at the Sappho property, east of Midway.

The only deposit known in Northwest Territories is on Rankin Inlet. There platinum and palladium are found in copper-nickel sulphides in an altered pyroxenite? sill.

Other Primary Deposits

Platinum is not known to occur in appreciable amount in any typical contact metamorphic deposit in Canada. A minute amount has been reported from the Nickel Plate mine at Hedley, B.C. Records of recoveries of palladium at the Trail plant lead one to suppose that this metal must be present in small quantities in the high-temperature lead-zinc deposit of the Sullivan mine.

Platinum has been reported from a quartz vein on the Mother Lode claim, Grand Forks mining division, B.C., and from a few quartz veins elsewhere in Canada, but no production has been attained from any such source, nor do the possibilities seem particularly promising. The same conclusion would appear to apply to a few reports of platinum in widely scattered sulphide deposits of different types.

Placers

With the exception of certain gravels on North Saskatchewan River, near Edmonton, Alberta, all Canada's platinum-bearing placers are found in British Columbia and Yukon. The total production, at present, is only a few ounces a year. Tulameen district is the most important field. At other places, as, for example, Quesnel River district, certain parts of Fraser River, Thibert Creek, Finlay River, some of its tributaries, and a few other streams in Omineca mining division, and some other localities, platinum is found in auriferous placers, generally in much smaller amount than gold and very finely divided. Its recovery depends largely on gold-saving operations and the development of an economic method or methods of extracting the platinum from the black sand concentrates in which it collects. Some of the beach placers along the Pacific coast also contain small quantities of platinum.

No " fossil placers " or noteworthy eluvial deposits that carry platinum are known in Canada.

Conclusions

It is indicated elsewhere in this volume that, given a reasonable prosperity in the nickel industry, the Sudbury deposits are capable of producing a large, if not major, part of the world's supply of platinum metals for many years to come at a cost that is at present considerably below that of most of the other important producers.

It is almost a certainty that, as time passes, additional discoveries of platiniferous nickel-copper sulphides of the Sudbury type will be made in Canada. The resources of Sudbury district itself are by no means fully explored and in recent years little attempt has been made to develop new properties or, indeed, to fully explore the extent of some of the known deposits. Yet the known ore reserves are enormous. As these are depleted it may be confidently expected that additions and some new discoveries will materalize. Basic and ultrabasic rocks, varying from norite and gabbro to peridotite, pyroxenite, and serpentine, are known to be fairly abundant in the Canadian Shield from Lake Athabaska to the Gulf of St. Lawrence. In Ontario, Manitoba, Saskatchewan, and on Hudson Bay, discoveries of platiniferous sulphides have been made near or in these rocks. Although, away from Sudbury, none is at present producing, they represent resources that, in time of need, could be exploited. In addition, large areas where similar rocks are known or may be confidently expected have never been carefully prospected.

In British Columbia these basic and ultrabasic rocks are not as abundant as in eastern Canada. Nevertheless, some platinum-bearing sulphide deposits have been found, and the future may bring additional discoveries.

The nature of the Sudbury type of deposit renders discovery relatively simple. The platinum metals are contained in massive or disseminated iron, copper, and, generally, nickel sulphides that constitute base-metal ores. These sulphides weather readily to form rusty gossans that, unless they are covered by a heavy mantle of surface drift, are easily perceived. Somewhat different are deposits of the Merensky Horizon type, no true representatives of which have as yet been discovered in Canada. They should be borne in mind by the prospector, however. In these deposits, as typically developed in South Africa, iron, copper, and nickel sulphides occur sparingly disseminated in highly differentiated, pseudostratified basic intrusives and are associated with pyroxenitic phases in norite and anorthosite. The percentage of sulphides in the mineralized sections is small, ranging, generally, from 2 to 3 per cent. Yet the platinum values, ordinarily invisible to anything but a very careful examination, are high, sufficiently so to warrant exploitation for platinum metals values alone. In regions like the Canadian Shield, where the surface has been heavily glaciated and consequently many outcrops are practically fresh and unweathered, such deposits may not exhibit any extensive or striking surface gossan. Where gossan does occur, the broken rock beneath may appear so low grade in sulphides as to discourage any further attention, unless samples be assayed for the platinum metals. Although there is no assurance that such deposits do occur in the Canadian Shield, the possibility is evident and should be remembered when a favourable geological setting is encountered.

There is also some possibility of further discoveries of deposits of the Ural type, in which native platinum, or osmiridium, is associated with dunite, or serpentine derived from it typically surrounded by, or passing gradationally into, pyroxenite and less basic igneous rocks. No differentiated intrusives really typical of this type are known in the Canadian Shield and, indeed, the only true analogy of the Ural bodies is in Tulameen district, British Columbia. There are distinct possibilities of additional discoveries of this kind in British Columbia, particularly in the southern and north-central, and possibly the northwestern, parts of the province, and also in Yukon, in the St. Elias range. Not entirely dissimilar are certain intrusives in the Mount Albert region of Gaspe and some other parts of southeastern Quebec. At the best, though, platiniferous deposits of the Ural type are apparently small and very erratic. The platinum is associated particularly with disseminations or irregular segregations and vein-like masses of chromite. Considerable deposits of chromite are known in Canada, both in the east and in British Columbia, but with the exception of a few deposits in British Columbia, they are not known to be platiniferous. Nor, apart from those deposits very similar to the Ural type, should they be expected to contain platinum metals, although the possibility is always worth consideration, for some chromitite deposits in Transvaal, not at all similar to the Uralian deposits, carry appreciable, although not at present commercial, quantities of platinum.

The other types of primary platiniferous deposits enumerated in Chapter II should also be borne in mind. Any of them might occur in Canada. They are, however, so far as we know at present, less common and consequently less important than the types already discussed in this section. To re-emphasize them at this point would merely confuse the issue.

The possibilities of increased production of placer platinum seem to lie almost entirely in British Columbia and Yukon. Improved methods of extraction of finely divided platinum, and gold, from known placers, might swell the output that is at present almost negligible. Also, from time to time new discoveries of platinum, and other metals of the group, in gravels, are reported from British Columbia and it is not all unlikely that these will continue for some time, as large sections in the north are but poorly known. As the province is explored and becomes more fully known geologically, particular attention should be paid to the streams in those districts where ultrabasic rocks like peridotite, pyroxenite, and serpentine are found.

In the following pages an attempt is made to list all the mineral occurrences in Canada that are authentically reported to contain platinum metals and the treatment is geographical, beginning at the east, in Nova Scotia, and continuing westward, by provinces, to British Columbia; then Yukon and finally Northwest Territories.

NOVA SCOTIA

Placers

No placers carrying platinum have been reported in Nova Scotia, and there seems to be little likelihood that any will be found.

Lode Deposits

Ores carrying platinum have been found at a few places, and the following notes on these occurrences have been furnished by E. R. Faribault, of the Geological Survey.

Platinum is reported to have been found in the course of mining operations in some of the gold districts of the province; and in 1918 a trace of platinum was obtained in an assay of concentrates from the tungsten mine at Moose River. All the occurrences so far reported are quartz veins bearing gold or tungsten ore, in the lower quartzites and slates of the Gold-bearing series of the Atlantic coast. The veins are aggregated in groups on anticlinal domes or on plunging anticlines, where they follow planes of stratification and conform with the structure of the folds. The platinum is believed to be present as the arsenide, sperrylite ($PtAs_2$), and the chief associated mineral is arsenopyrite. No attempt has yet been made to determine whether the platinum is present in paying quantity. It might be suggested that tests be made of the old tailings, accumulated for years in some of the gold districts, or of the concentrates of the mills at some of the gold mines now in operation. The gold districts where scheelite has been discovered, as Moose River, Caribou, Oldham, Waverley, Cow Bay, the Ovens, Baker Settlement, Pleasantfield, and Malaga, deserve special attention.

The following three occurrences of platinum have been recorded from gold-mining districts in the eastern part of Halifax County.

(1) The Hall brothers informed E. R. Faribault in 1904 that while operating a gold property at Fifteenmile Stream, Halifax County, about the year 1880, they received from the mint a button of platinum obtained from the refining of a brick of gold derived from the Walton-Doran vein in that district. The vein is a barrel-quartz lead, following the plane of stratification of quartzite and slate and curving on the eastern plunge of an anticlinal fold.

(2) O. W. Knight, a mineralogist of Bangor, Maine, reports (1911-1912, page 93) having found in 1910 several small crystals of sperrylite on a mine dump derived from a vein worked for gold in one of the gold districts, which, he says, he is not permitted to designate; but presumably it is in the vicinity of the Caribou gold mines in Halifax County. The gangue mineral containing the sperrylite was quartz and the chief associated mineral was arsenopyrite. A "magnesia-bearing" dyke was in proximity.

(3) A trace of platinum, and gold estimated at 0·04 ounce a ton, were found by an assay made at the laboratory of the Mines Branch, Ottawa, on a sample of heavy-fines collected from the Wilfley tables in the mill of Scheelite Mines, Limited, at Moose River Mines, Halifax County. The ore is scheelite. Sperrylite is probably the platinum-bearing mineral.

The gangue is quartz, and the chief associated mineral is arsenopyrite, with some dolomite, damourite (mica), tourmaline, and occasionally small, acicular crystals of rutile. The tungsten-bearing veins occur interbedded in the lower quartzite and slate formation, in small, sharp folds developed along the crest of the highest known anticlinal fold in the eastern part of the province. The veins are usually only a few inches in width, and their extent is determined by the structure of the fold. Generally they are very persistent along the folds. One of the veins has been developed continuously for a length of over 1,500 feet along one of the sharp, small folds. Many large veins of barren quartz also occur intersecting or joining the interbedded mineralized veins. No eruptive rock has been observed in the immediate vicinity of the deposit; the nearest is a granite batholith 7 miles to the southeast. The associated minerals show that the deposit is of deep-seated origin, and that these veins are quite different in character from the gold-bearing veins of the district.

QUEBEC

Lode Deposits

Traces of platinum were found in chromite ore from St. Cyr, by the Ore Dressing Division of the Mines Branch, Department of Mines, during some tests that were carried out in 1917 (Timm and Parsons, 1918). This is the only record of platinum occurring in place in Quebec, but very few tests have been made and there are great bodies of peridotite and serpentine in the province, in places carrying much chromite. As noted below, platinum has been reported from placer workings on Rivière des Plantes and Rivière du Loup, and the rocks from which it was derived cannot be far distant. It would seem well worth while to have careful analyses made of representative samples of these rocks and of the chromite from the various mines in the province, in order to determine whether or not platinum occurs in them in important amount.

Placers

In 1852, Dr. T. Sterry Hunt (1852) noted minute grains and scales of platinum and iridosmine in the gold obtained from placers on Rivière du Loup and Rivière des Plantes, both tributaries of Chaudière River, but so far as is known no attempt was ever made to save these minerals commercially, and there is no record of the actual amount present in the placers. Peridotite and serpentine rocks are found in Quebec from Gaspe to the Vermont border and to a certain extent they are similar to those in the Urals and in Tulameen district. They carry considerable disseminated chromite and, in places, workable bodies of that mineral. However, Poitevin (1930) has pointed out certain distinct differences between the Quebec and Ural rocks and chromite.

In Quebec, loose, surface deposits were in most places considerably disturbed during Pleistocene times, but it is just possible that some placers may yet be found to contain platinum metals in sufficient amount to pay for working. In this connexion it is interesting to note that a nugget consisting of 46 per cent platinum and 54 per cent chromite was picked up in glacial drift near Plattsburg, N.Y., and that in the vicinity the ice-sheet had a general southwesterly movement. In discussing this nugget, J. F. Kemp says (1902, page 57): "A southwesterly movement of the ice would have brought glacial material to Plattsburg from the great areas of serpentine that occur in Quebec, north of Vermont, and which are commercially productive of chromite. There seems little reason, therefore, to doubt that the nugget has been derived from this source, but as yet no platinum has been announced in the serpentine region."

ONTARIO

Lode Deposits

Platinum has been reported from a number of places in Ontario. Most of the occurrences are mere prospects, but the nickel-copper ores of Sudbury district produce, each year, very important amounts of the platinum metals, particularly palladium and platinum. The precious metals are recovered as a by-product in the production of nickel and copper and consequently the output depends, to a very considerable extent, upon the world demand for those base metals.

REAUME TOWNSHIP, DISTRICT OF TIMISKAMING

Platinum occurs here with chromite in a very basic rock, much altered to serpentine. An assay gave: Cr. 8·46 per cent; Fe, 14·58 per cent; Pt, 0·066 ounce a ton of 2,000 pounds (Ont. Bureau of Mines, Ann. Rept., vol. XXIII, pt. 1, page 47 (1914)). No further particulars are available concerning this deposit.

EBY TOWNSHIP, DISTRICT OF TIMISKAMING

In April, 1919, it was reported that platinum to the value of $2 a ton of ore had been obtained from a large "sulphide deposit", which extended across a group of claims in Eby Township, Timiskaming district. The sulphide was said to run high in sulphur, and to contain appreciable values in gold and silver. No other information is available concerning this occurrence.

SHEBANDOWAN LAKE, THUNDER BAY DISTRICT

Both palladium and platinum are present in sulphide replacement deposits at, and to the west of, Discovery Point, Shebandowan Lake (Tanton, 1922; Watson, 1928).

The ore occurs in chlorite-serpentine schist (Keewatin?) which is regarded as altered peridotite, and is intruded by sheared granite porphyry on the north. Sulphide replacement bodies have been exposed by trenches along a zone 1 mile long and about 100 feet wide. The zone lies a short distance south of the granite contact. The ore occurs as narrow, discontinuous, approximately parallel bands of sulphides, rarely over 5 feet wide, along the strike of the zone, that is, about north 70 degrees west. In addition, most of the 100-foot zone is itself sparingly mineralized, but not

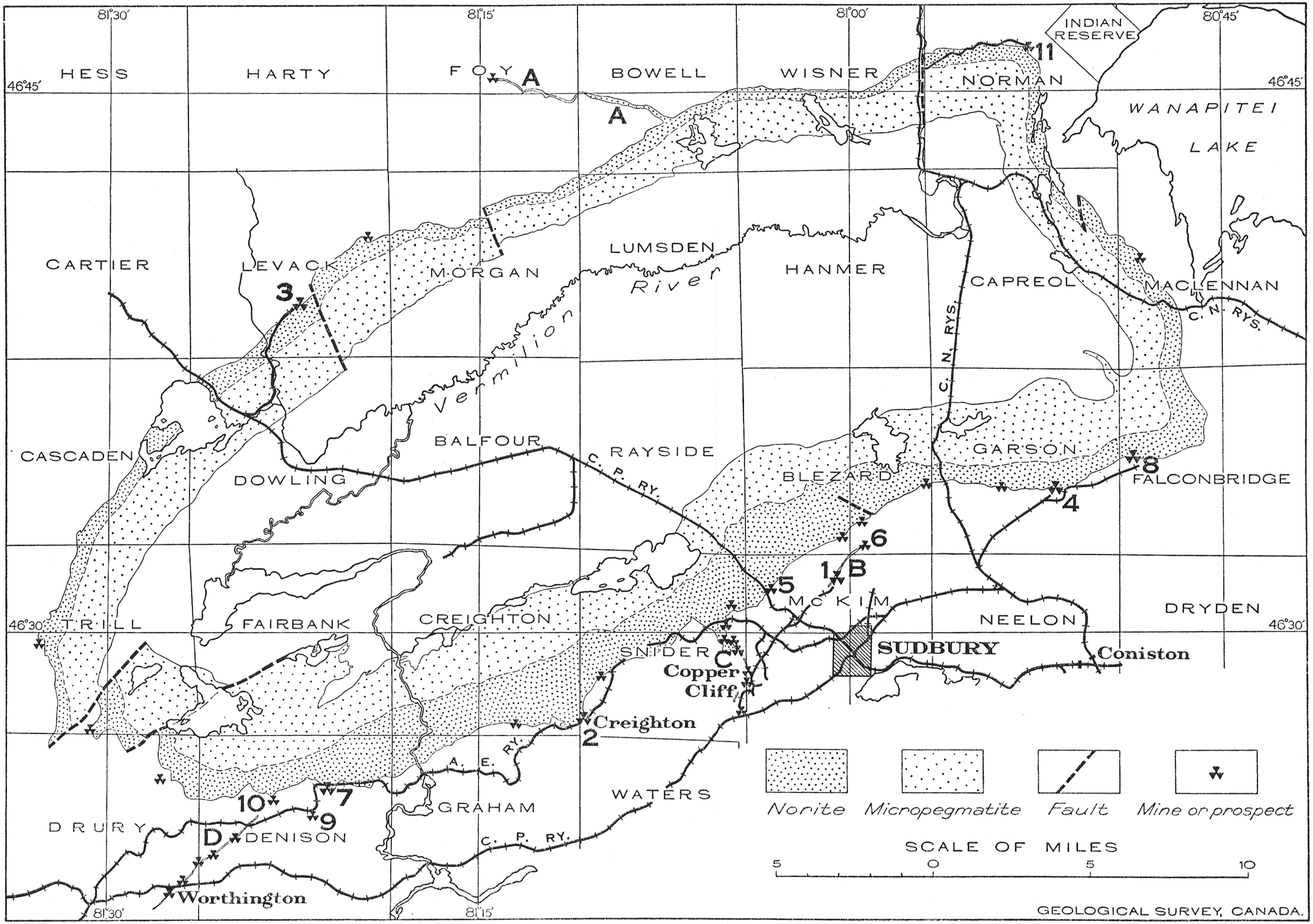

Figure 2. Sudbury Area, Ontario. Offsets: A, Foy; B, Frood; C, Copper Cliff; D, Worthington. Mines: 1, Frood; 2, Creighton; 3, Levack; 4, Garson; 5, Murray; 6, Stobie; 7, Crean Hill; 8, Falconbridge; 9, Vermilion; 10, Victoria; 11, Whistle.

to an extent sufficient to form ore. A few porphyry dykes in the ore zone are less completely replaced by sulphides than adjoining sheared peridotite. Several holes that have been drilled under surface showings encountered massive and disseminated sulphides at shallow depths.

Polished sections of the ore show the following minerals, in their sequence of development: pyrite, magnetite, chalcopyrite, pyrrhotite, an undetermined grey mineral, and polydymite. Samples from several of the pits, assayed at the Mines Branch, gave: Cu, 1·50 to 5·95 per cent; Ni, 0·04 to 5·95 per cent; Pt, 0·02 to 0·04 ounce a ton; Pd, 0·07 to 0·12 ounce a ton; and low values in gold. These replacement bodies were formed subsequently to the regional shearing of both the Keewatin schist and the intrusive granite. There are later (Keweenawan) diabase dykes on the property, and it is thought possible that the mineralizing solutions may have come from the magma of which these dykes are a visible expression. The platinum and other valuable metals may have been present in the original peridotite, and have been brought into solution as a result of this igneous activity at depth, to be later concentrated in the replacement deposits; or they may have been present in the Keweenawan diabase magma, and have been precipitated in the chlorite-serpentine schists owing to the favourable physical or chemical nature of the latter.

A trace of platinum metals has also been found in a similar sulphide replacement of altered peridotite on a mining claim nearly one mile eastward from Discovery Point.

MCTAVISH TOWNSHIP, THUNDER BAY DISTRICT

Platinum values have been reported from the Detroit-Algoma mine near Pearl Station on the Canadian Pacific Railway (Tanton, 1931, page 165). The values appear in assays, supplied to Tanton by the owner, of samples of quartz and calcite in a brecciated fault zone in granite and late Precambrian sediments. The vein zone is about 15 feet wide and carries galena and zinc blende disseminated in quartz or calcite, and some pockets of chalcopyrite.

SUDBURY DISTRICT

By far the greatest part of Canada's output of platinum group metals is obtained from nickel-copper ores of Sudbury district. Within the last few years the output has shown a marked increase because of improved methods of extraction and the discovery of richer ores, so that the district is now the second largest contributor to the world's supply of platinum metals and is capable of exercising an important if not a dominant influence upon world markets. This influence depends not only upon the magnitude of Canada's output but also upon the fact that the platinum metals are obtained at low cost as by-products in the production of copper and nickel. The low cost enables Canadian producers to compete easily with other world producers.

The following notes have been prepared from a study of the available literature and the writer has had the advantage of personal communications from W. H. Collins.

Geological Setting

The geology of Sudbury region is complicated and the literature on the subject is voluminous. All that can be attempted here is a brief summary of the more important geological features. The ore deposits are closely related in position to an elliptical ring of igneous rock 37 miles long, 17 miles across, and from 1 to 4 miles in width (Figure 2). This ring is believed to be the exposed rim of a continuous, basin-shaped sheet 1 to 2 miles thick that is commonly known as the Sudbury nickel irruptive. The sheet was intruded along the unconformable contact between an underlying complex of sedimentary and igneous rocks and the overlying late Precambrian Whitewater series. The underlying complex includes Keewatin volcanics, sediments of the Sudbury series, pre-Huronian granite and gneiss, and Huronian sediments, diabase sills, and granite, all older than the irruptive. The overlying Whitewater series is now preserved only in the basin surrounded by the irruptive. The lowest member, formerly known as the Trout Lake conglomerate, is now regarded as an agglomerate and has been grouped with the Onaping tuff, above which lie the Onwatin slates and highest of all, the uppermost Chelmsford sandstone. After the irruptive was intruded there was evidently a further intrusion of granite, for numerous, small, dyke-shaped bodies of granite cut the irruptive.

The irruptive itself, though evidently a single intrusion, is not of uniform composition. It consists of a lower (outer) layer of dark grey norite and an upper (inner) layer of light pink, granitic rock called micropegmatite. These two layers are about equally thick and grade into one another in a thickness of 200 to 600 feet. Around the outer edge of the irruptive there are several dyke-like masses of rock of dioritic composition called basic offsets. They extend out from the irruptive into the basement complex or in one case (Frood offset) show no present connexion with the irruptive. Some material of the same kind constitutes the base of the nickel irruptive itself along parts of its rim. These offset masses have the same chemical composition as the average of the norite layer and are believed by many authorities to represent molten magma from the norite layer that was squeezed into cracks or zones of weakness in the floor of older rocks. Though they form only a minor feature of the nickel irruptive the offsets are highly important from the standpoint of the ore deposits.

Ore Deposits

The nickel-copper ore-bodies lie along or close to the outer edge of the irruptive and most of them are on the southeast side of it. They occur, mainly, in two places: at or very close to the base of the norite layer; and along the offsets. Coleman has named them marginal and offset deposits respectively. The deposits are irregular in shape, but with tendencies to be lenticular or cylindrical and for cylindrical or columnar forms along the offsets. They vary greatly in dimensions and some are very large. The outcrop of the Frood ore-body, the largest in the district, is over a mile long and in some places over 600 feet wide (*See* Figure 3). The ore is known to extend to a vertical depth of well over 3,000 feet and is not yet fully explored. The main ore-body at the Creighton is roughly lenticular but irregular, 500 to 1,000 feet long and 50 to 300 feet wide (*See* Figure 4). Some deposits, like the Levack (*See* Figure 5) are in the old basement rocks, but most of them are partly in norite and partly in

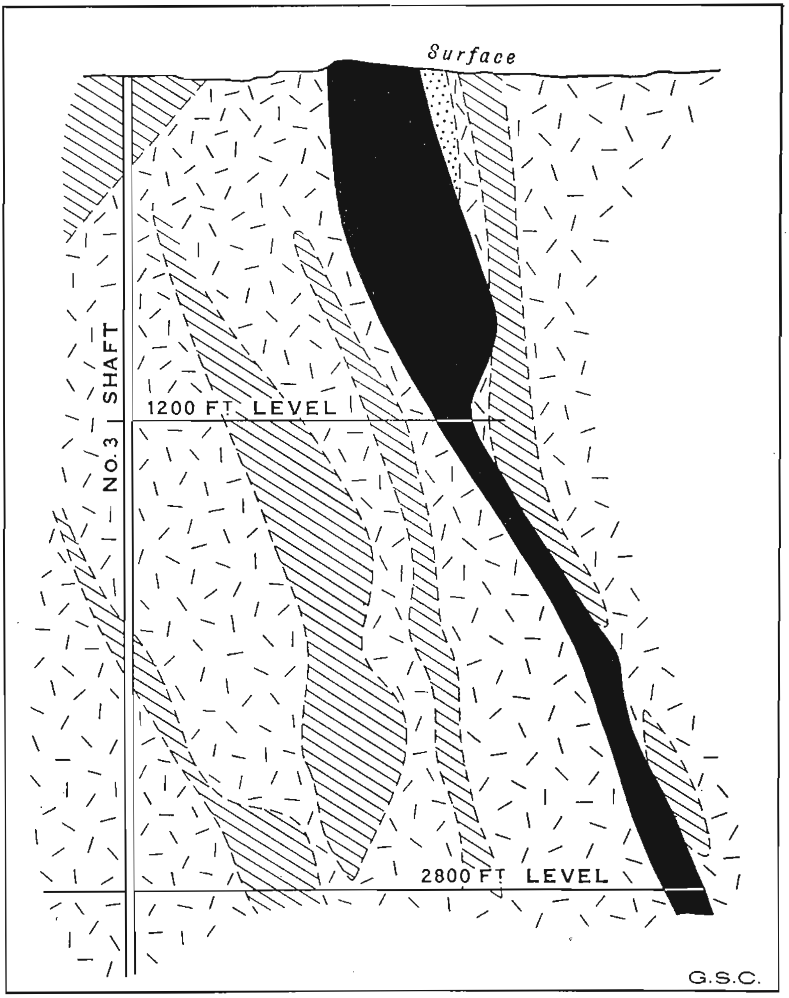

Figure 3. Cross-section through No. 3 shaft, Frood mine, Sudbury (after H. J. Mutz). Ore shown by solid black; greenstone by diagonal ruling; greywacke with some quartzite by irregular pattern of pecks; breccia by stipple.

the older rocks. Marginal deposits tend to occur at bays or bulges along the contact and never between such places. When not affected by faulting they usually dip towards the centre of the basin at 30 to 50 degrees and have a hanging-wall of norite containing more or less disseminated sulphides.

The foot-wall may consist of any of the older rocks, either partly replaced and impregnated by sulphides or little affected and then sharply defined from the ore.

The chief ore minerals are pyrrhotite, chalcopyrite, and pentlandite. Pyrite and magnetite occur in lesser amounts. A number of other minerals, including cubanite, arsenopyrite, sphalerite, and galena have been found. Sperrylite, the arsenide of platinum ($PtAs_2$) is the only platinum group mineral that has been identified. As a general rule the gangue consists of norite or any of the other country rocks in which the ore lies. In typical marginal deposits there is a conspicuous absence of the products of so-called

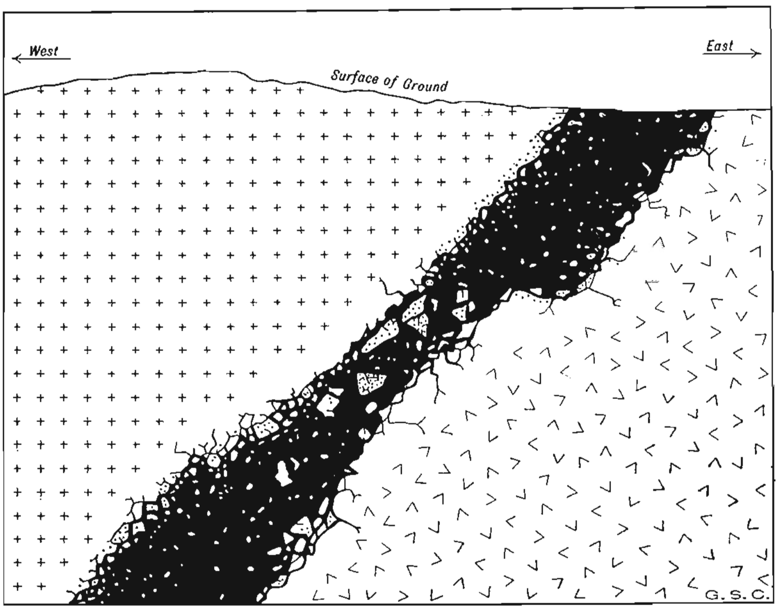

Figure 4. Ideal cross-section through Creighton ore-body from the surface to 18th level, Sudbury area (after C. W. Knight). Ore shown by solid black; norite by pattern of crosses; and granite by angle pattern.

hydrothermal action, but in offset deposits and some of the more faulted marginal ones quartz and carbonates, as well as amphibole, biotite, epidote, and other minerals are not uncommon.

All the deposits do not exhibit the same type of mineralization. Some are relatively rich in quartz, carbonates, and other minerals that are usually believed to be formed by heated solutions. In other places the sulphides are disseminated in fresh norite, and are intergrown with the original silicates of that rock. This type of generally low-grade material is very abundant along the base of the irruptive. Some deposits resemble veins to a certain extent and have quite definite walls. The Vermilion mine is an example of a deposit that was remarkably rich in gold, platinum, copper, and nickel. It contained much polydymite and was first worked as a gold mine. Later, some of the ore was so rich in copper and nickel as to equal some grades of matte. But ores of these kinds are very subordinate and have contributed little to the output of Sudbury district. The principal kind in nearly all the mines that have been worked is a massive association of pyrrhotite, chalcopyrite, and pentlandite that forms the matrix or bonding material of brecciated zones in the country rock. The proportion of rock fragments to sulphides varies greatly. Some brecciated zones, or parts of them, contain no sulphides at all, whereas in other cases, like the lower part of Frood mine, the ore is practically solid sulphides with only

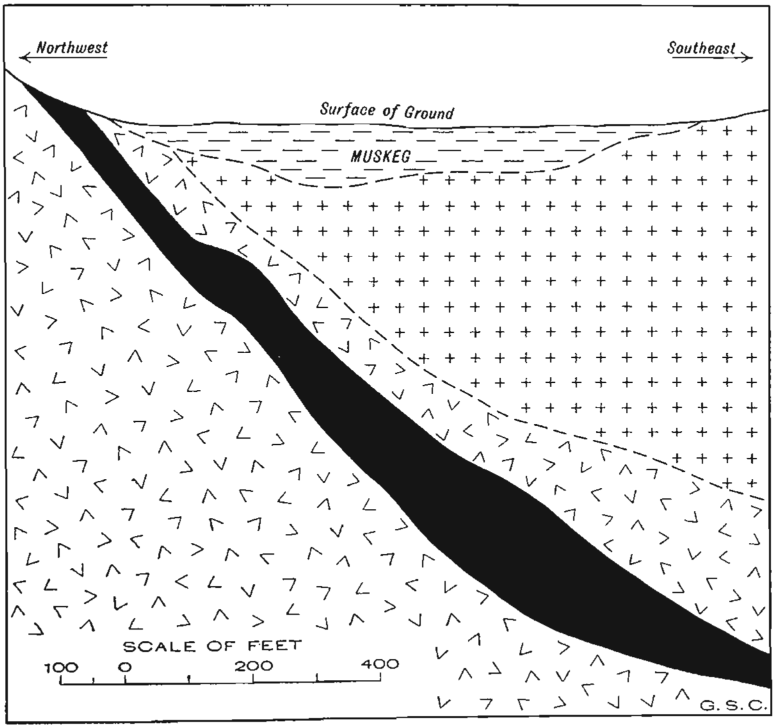

Figure 5. Cross-section through Levack ore-body, Sudbury area (after C. W. Knight). Ore-body shown by solid black; norite by pattern of crosses; and granite-gneiss by angle pattern.

a few scattered rock fragments. All gradations between these two extremes are encountered. The fragments may be of norite, granite, or any of the rocks of the basement complex and they range from sand grains to blocks several feet, or even yards, in diameter. The shapes are equally variable, from rounded forms that are very common, to shards with knife-like points and edges.

The brecciated zones are an important feature of the geology of the district, to which all too little space is devoted in the literature. Some of their features have never been properly explained. They are particularly abundant along the offsets and also occur at places along the base of the nickel irruptive. Their economic importance is indicated by the regularity with which the ores, particularly in the offset deposits, coincide with them.

Origin of the Ores

The origin of the ores has occasioned a great deal of controversy and discussion and there is as yet no complete agreement among the various authorities on the subject. The earlier, and perhaps generally best known, theory is that which states that the sulphides are derived directly from the nickel irruptive by gravitational settling. Coleman has been its chief proponent and Barlow, Adams, Kemp, Roberts and Longyear, and others, have supported it. The theory has been briefly summarized by Coleman (1929, page 10) as follows:

"It begins with a great mass of magma far below the surface which makes its way up to the plane of weakness beneath the Animikie sediments and there spreads out as a sheet a mile and a quarter thick. The underlying floor of older rocks, left without support, collapses,[1] and great faults extend in various directions, especially on the south side. Blanketed under 10,000 feet of sedimentary beds the molten mass cools very slowly, allowing time for segregation to take place, norite sinking beneath the lighter micropegmatite, and the sulphides, much heavier and more fluid than the molten rock, settling toward the bottom, where much of it was caught as small particles in the cooling norite, while the rest escaped into depressions of the floor, forming marginal deposits, or found its way under pressure into the fissures and crush breccias caused by the faults, forming offset deposits. Later, hot waters from the cooling magma penetrated these openings in the country rock depositing quartz and carbonates and somewhat modifying the offset ores. In this process rare and precious metals, silver, gold, and the platinum group, were concentrated along with copper ore in the narrower offset openings."

The arguments advanced in favour of this theory include the almost invariably close association between norite and ore, the concentration of ore along the lower edge of the irruptive, the occurrence of disseminated sulphides in the fresh silicates of the lower part of the norite layer, the fact that most of the marginal deposits occur where bays of the norite extend out into the basement rocks, and the now generally conceded conclusion that the irruptive separated into a lower, basic (norite) phase and an upper, acidic (micropegmatite) layer by differentiation in place, the heavier constituents, including the sulphides, settling to the bottom.

A second theory, supported by Dickson, Knight, Tolman and Rogers, Wandke and Hoffman, and others, suggests that the ores were formed by the circulation of heated, mineral-bearing waters. The mineralizing solutions are believed to have circulated most freely along crush zones at the base of the irruptive or along offsets and to have deposited the ores there. The theory thus explains the presence of quartz and carbonates, and the replacement of country rock, including norite, that has been observed in the ore deposits. Perhaps the greatest factor that contributed to this hydrothermal conception of origin was the manner of occurrence of the Creighton ore-body (*See* Figure 4). Knight writes (1917, page 151) that the ore lies between a granite foot-wall and the norite hanging-wall. The sulphides have penetrated and replaced the granite to a large extent and now surround many blocks of granite, particularly near the foot-wall. The hanging-wall norite also is brecciated, cemented, and replaced by the sulphides. Knight claims that the granite is younger than and intrudes the norite. If this is true, the norite was intruded, then invaded by granite,

[1] Collins is of the opinion that collapse into the present basin shape did not occur until after the irruptive had solidified, a condition of much significance as regards the arrangement of the ore-bodies.

and finally the contact zone was extensively brecciated, all before the ore was introduced. Under these conditions he rightly argues that the sulphides could not have settled out of the norite into their present position, and, considering the extensive replacement of country rock by ore, he assumes that they were deposited by circulating, heated, aqueous solutions that " possibly carried little else than sulphides," and that came from great depths. The ultimate source of the solutions is not definitely assigned; although it is admitted that they may have been connected with the reservoir whence came the irruptive itself, it is also suggested that the possibility of a genetic relation with the younger granite should not be overlooked.

A third theory, proposed by Howe (1914, page 503) is that the ores were injected as molten material that formed by differentiation in the deep-seated magma reservoir whence came the norite. The injection took place after the cooling of the norite.

Bateman (1917) adopted a theory that is really a compromise. He suggests that the pyrrhotite-norite of some marginal deposits was formed by differentiation in situ, that the greater part of the main marginal and the offset deposits was injected from below as magma overcharged with sulphides, and that later " hydrothermal " solutions, connected with the injections, rearranged the ore minerals, altered the rocks, and deposited the typically aqueous minerals that are found in some deposits.

It should be recalled, however, that in 1929 Coleman, Moore, and Walker still considered that the original, in situ, magmatic segregation theory best explains the formation of the ore deposits. They call attention particularly to the probability that large quantities of the sulphides, formed by differentiation from the irruptive, would be liquid, mobile, and under great hydrostatic pressure and that in some cases they may be regarded as having moved considerable distances.

Whatever disagreement there may be as to details of origin of different deposits, there can be but little doubt that the ores are closely related, genetically, to the norite.

Operations and Ore Reserves

Since production of nickel and copper began at Sudbury in 1887, until the end of 1932 over 30,000,000 tons of ore have been mined. The peak output was attained in 1931 with 2,115,139 tons. In 1932 the Frood mine alone contained over 135,000,000 tons of proved ore and published reserves of proved ore in the district that year totalled 206,908,973 tons. This large figure gives only a suggestion of the total possible or probable reserves in the district, for it includes none of the numerous prospects that are known and the two operating companies have been making no serious effort in the last few years to develop new supplies. Also, there appear to be considerable possibilities of additional discoveries. Up to the present prospecting has been largely confined to areas of bare or thinly drift-covered rock and to ordinary methods, chiefly search for the rusty gossan produced by oxidation of the sulphides and exploration of these places with the diamond drill. There remains much favourable but heavily drift-covered ground to be explored by geophysical methods and by drilling.

Discovery of the Falconbridge deposit in such ground is indication of the further possibilities. The good electrical conductivity of the ores and the magnetic property of the pyrrhotite are especially favourable for geophysical methods.

Sudbury district produces practically all of Canada's nickel and its importance as a world producer is shown in the following table based on the Statistical Summary of the Imperial Institute.

TABLE VIII

Production of Nickel in Canada and the World

—	1929		1930		1931	
	Long tons	Per cent	Long tons	Per cent	Long tons	Per cent
Canada	49,230	89·5	47,400	89·4	30,200	86
World	55,000	100·0	53,000	100·0	34,900	100

In addition the district supplies each year a very important amount of copper.

International Nickel Company of Canada, Limited. This company dates back to December 16, 1928, when, as a result of changes in corporate title, it emerged as the offspring of International Nickel Company, Inc., of New Jersey. It consequently includes the holdings of Canadian Copper Company and some other smaller mining corporations in Sudbury district that had previously been controlled by the New Jersey company. On January 1, 1929, by exchange of stock, Mond Nickel Company, Limited, the chief Canadian competitor, and Mond's wholly owned subsidiaries, were absorbed and since that time some further amalgamations have been effected. The annual report for 1932 lists total assets of the company and its subsidiaries as $179,924,097.25.

On December 31, 1932, ore reserves of the International Nickel Company were given, in the annual report, as 203,909,973 tons and the statement was made that " large additional tonnages may be added to ore reserves whenever it is considered expedient to incur the necessary expense." In 1929 reserves stood at 202,620,000 tons and included 91,111,000 tons of Frood mine low grade, 43,562,000 Frood high grade, 5,503,000 tons in the Creighton mine, 19,062,000 tons in Levack mine, 3,193,000 tons in Garson mine, 22,490,000 tons in Murray mine, 13,712,000 tons in the Stobie, 3,028,000 tons in Crean Hill, and 959,000 tons in other mines. Average values are difficult to obtain. Recoveries per ton of ore for the district in 1928 averaged 3·3 per cent nickel, 2·05 per cent copper, 0·0026 ounce gold, 0·15 ounce silver, and 0·016 ounce of platinum metals. In that year, however, Frood mine contributed little to the production and is now known to contain much ore that is considerably higher grade than the average of the district. On December 31, 1929, 43,562,000 tons of proved ore below the 1,400 level in the Frood averaged 2·39 per cent nickel and 3·62 per cent copper. In 1930, 6,610,000 tons of ore, averaging 3·53 per cent nickel and 4·93 per cent copper, were proved below the 2,000 level. The company's actual representative assays for the 2,800 level are 5·40 per cent copper and 2·90 per cent nickel, and for the 3,100 level, 7·9 per cent copper and 2·7 per cent nickel.[1] In 1930, the Frood mine was being equipped to produce 8,000 tons a day from the lower-level high-grade zone. In 1932 (International Nickel Company, 1932), the company was equipped to produce 90,000 tons of pure nickel, 120,000 tons of copper, 40,000 ounces of gold, 1,500,000 ounces of silver, and 300,000 ounces of platinum metals each year, using current grade of ore. Present production (1933) is far below these figures.

Platinum Metals in the Ores. Production of platinum metals during the last ten years has been as follows:

TABLE IX

Production of Platinum Metals, Sudbury District, 1923-32 (in troy ounces)

<table>
<tr><th>Year</th><th>Platinum</th><th>Palladium</th><th>Other metals of the group</th><th>Total</th></tr>
<tr><td>1923</td><td>6,810</td><td>8,511</td><td>304</td><td>15,625</td></tr>
<tr><td>1924</td><td>9,181</td><td>8,923</td><td>593</td><td>18,697</td></tr>
<tr><td>1925</td><td>8,692</td><td>7,856</td><td>432</td><td>16,980</td></tr>
<tr><td>1926</td><td>9,471</td><td>9,790</td><td>234</td><td>19,495</td></tr>
<tr><td>1927</td><td>11,217</td><td>11,247</td><td>298</td><td>22,762</td></tr>
<tr><td>1928</td><td>10,452</td><td>11,389</td><td>1,689</td><td>23,530</td></tr>
<tr><td>1929</td><td>12,474</td><td>12,231</td><td>4,910</td><td>29,615</td></tr>
<tr><td>1930</td><td>33,996</td><td>29,893</td><td>4,133</td><td>68,022</td></tr>
<tr><td>1931</td><td>44,725</td><td>39,313</td><td>7,605</td><td>91,643</td></tr>
<tr><td>1932</td><td>27,284</td><td colspan="2">37,613</td><td>64,897</td></tr>
</table>

Total value to end of 1932 is over $23,000,000.

It is generally stated that palladium is present in the ore in much greater amount than platinum, and assays appear to bear this out. Production figures, however, indicate either that the content of the two metals is about the same, or that much of the palladium is not recovered. The production by International Nickel Company for the first nine months of 1933 shows a ratio of approximately 1 part of palladium to 1·4 parts of platinum.[1]

The actual experience of the International Nickel Company does not seem to indicate that the platinum or precious metal content varies in any systematic manner with the copper content.[1]

The platinum occurs, in part at least, as the diarsenide, sperrylite, which contains also some rhodium, but no palladium. The latter metal has not been traced to any definite mineral. Possibly palladium and platinum are present in a very finely divided state as "native" elements disseminated through the ore, or it may be that they are in solid solution in the sulphides, as they are believed to be in the somewhat similar deposits in the "Merensky Horizon" in the Transvaal. In this connexion, also, it is of interest that in some polished sections of the Transvaal ore,

[1]Personal communication from Paul D. Merica, January, 1934.

a palladium compound of undetermined composition has been noted in regular intergrowth with the sulphides, as has been mentioned above in the section dealing with the mineralogy of the platinum metals.

In the ore, these precious metals are present in infinitesimal amount. From sixteen samples taken some years ago by diamond drilling through large, undeveloped ore-bodies, an average of 0·0068 ounce of platinum metals a ton was obtained. But it is extremely difficult, if not impossible, to determine the exact proportion of platinum metals in the ores, partly on account of the difficulty of sampling but mainly because the proportions vary greatly in different parts of all deposits. Nevertheless, a fair approximation of the values in ores treated during certain periods can be obtained in an indirect manner, for all the platinum metals are automatically concentrated in matte made from Sudbury ores. Canadian Copper Company reported that, as determined by assays, the average platinum metal content of the matte produced by them during the three years ending 1915 was, a ton: 0·10 ounce platinum, and 0·15 ounce palladium. It was stated in the report of the Royal Ontario Nickel Commission, 1917, page 429, that this company smelted 17 or 18 tons of ore to produce 1 ton of matte. Using the maximum of 18 tons, the average content of the ores smelted in the three years ending 1915 would have been 0·0055 ounce platinum with 0·0083 ounce of palladium, or a total for both of 0·0139 ounce a ton of ore. This makes no allowance for the possibility of losses during smelting. The same report states that "the Mond Nickel Company estimate that their ore reserves will yield not over 70 cents precious metal values per ton of ore and the British America Nickel Corporation $1." These figures include gold and silver. Although they may represent approximately the values in the older mines now controlled by the International Nickel Company they certainly do not apply to the high-grade ores that have been developed, within the last few years, in the lower part of Frood mine. Corless (1929, page 143) has stated that, with depth in this deposit, "the gold, silver, and platinoids increase somewhat beyond the proportionate increase in base metals."

The company's annual report for 1929 states that results obtained during the year showed that bessemer matte made from Frood ore mined below the 1,600 level will net a return in precious metal values of approximately $50 a ton. No statement is given to indicate the number of tons of ore required to make one ton of matte. However, the 1932 annual report says that, at the Coniston smelter, 90,606 tons of ore was smelted and 9,679 tons of matte produced. The relation is 9·4 tons of ore to one ton of matte. That year Frood mine provided 77 per cent of the total ore mined by the company. If, as seems very probable, most of the direct smelting ore came from below the 1,600-foot level of Frood mine, it may be concluded that, in round figures, precious metal values in Frood ore are about one-tenth of those in the matte produced therefrom. On the basis of this and the 1929 statement the ore would net about $5 a ton in precious metals. But the $50 a ton value was probably estimated on the basis of 1929 metal prices. As these, with the exception of gold, have fallen very considerably since that time, the $5 a ton value would have to be considerably reduced to meet existing conditions. The proportions of the different precious metals in the matte or ore have not been published, but of the total value of precious metals recovered by the company in 1931, platinum contributed 45 per cent, palladium 22 per cent, the other metals of the platinum group 12 per cent, and gold and silver the remaining 21 per cent.

Langer and Johnson (1927, page 38) have given some interesting figures. They state that the Mond Process of refining recovers practically all the precious metals in residues that represent a concentration of about 16,000 units of ore to one unit of residue. They give an analysis of the residue as follows: the second column—ounces a ton of ore—has been calculated by the present writer on the basis of 16000 to 1 concentration.

TABLE X

Analysis of Sudbury Precious Metal Residue

——	Residue, ozs. a ton	Original ore, ozs. a ton
Platinum	540	0·03375
Palladium	557	0·03481
Gold	163	0·01019
Iridium, rhodium, ruthenium	113	0·00701
Silver	4,500	0·28125
Total precious metals a ton of ore		0·36701
Total platinum metal a ton of ore		0·07557

Of course these values do not hold true for Frood high grade, that has been developed since the paper was written.

The report of the Royal Ontario Nickel Commission contains much valuable information about platinum metals in Sudbury ores; the following quotations are from Chapter X, pages 481 to 486. Remarks in brackets have been inserted by the authors of the present report.

"Although the presence of gold and silver and of metals of the platinum group in practically all nickeliferous pyrrhotites throughout the world has long been known, their importance in connexion with the Ontario nickel industry is even now practically unrecognized, except by those who recover and sell them.

"The nickel-copper ores of Sudbury are capable of producing much more palladium than the whole of the present (1917) world's supply, together with a very large proportion of platinum, iridium, and other metals of the platinum group. The quantity of palladium present is much in excess of the platinum. It may be mentioned that the assay of ores and mattes, and of other metallurgical products, for palladium, is exceedingly difficult, and that the results published are often unreliable. They are commonly too low, so that the official or private figures given by the companies, or otherwise obtained, are not likely to be too high. The recovery of palladium is also much more difficult than that of platinum or other metals of the platinum group, so that both the assay values reported and the recoveries which have been made, are undoubtedly lower than they should be......... The first metal of the platinum group to be discovered at Sudbury was platinum, found in the mineral sperrylite. Sperrylite is essentially an arsenide of platinum, and analyses of the pure, isolated mineral have shown up to over 50 per cent of platinum, and from 0·5 to 0·75 per cent of rhodium, but only a trace of palladium. It is curious that although the occurrence of sperrylite would account for the platinum and rhodium which occur in the Sudbury matte, it does not account for the palladium, albeit that metal occurs in greater quantity than any other member of the platinum group in the Sudbury ores, and, in fact, in all pyrite nickel ores throughout the world.

"The association of rhodium with platinum in sperrylite is interesting, as it is one of the platinum metals which the International Nickel Company produces, and specifically mentions as one for which it receives payment. This, no doubt, is mainly obtained from the Vermilion mine ore, which that company treats, as far as possible, separately from its other ore.

" Palladium has never been traced to any definite mineral in the case of nickel ores, but like the gold and silver, is commonly found in greater quantity in the more cupriferous varieties, and almost certainly as a nickel-palladium or nickel-copper palladium mineral. This view is confirmed by the fact that such copper ores (represented by the blister copper obtained from them) as carry the most nickel, are almost invariably the richest in palladium as well as in platinum. The amount of palladium, where much nickel is present, is especially noticeable. According to S. Pina de Rubies,[1] native platinum always shows the spectrum of nickel, and more strongly when iron is present.

"*Associations with Copper.* It is extremely difficult to determine the exact proportion of the platinum metals present in nickel ores, except in the cases of specially selected rich specimens, and it is impossible to state how much is present in the tonnage extracted from month to month or year to year, partly on account of the difficulty in sampling, but mainly because different portions of all deposits vary greatly as regards the amount of platiniferous mineral present. As a rule, silver and gold occur in greater degree in the more cupriferous parts, but although the same is also true to a great extent as regards the platinum, iridium, and rhodium, it does not appear to be definitely proved as to palladium. Such mines or portions of a deposit as yield most palladium are usually richer in copper, but this appears to be due rather to the occurrence of an unknown cupriferous palladium mineral than to a segregation of palladium in copper ores. This is the case throughout the world, including Norway, Tasmania, and South Africa.......... "

Recoveries and Costs. During smelting of the copper-nickel ores all the precious metals are automatically concentrated in the matte, so that a ton of matte may contain from about ten to over twenty times as much as was present in one ton of the original ore, depending on the number of tons of ore required to make one ton of matte. The principal loss of precious metals occurs in the manufacture of monel metal, a nickel-copper alloy of high nickel content, made direct from Creighton ore, of which the company produces a large quantity each year. Fortunately, Creighton ore carries only modest amounts of precious metals and this loss, therefore, is small.

[1] Arch. Sci. Phys. Nat., vol. 41, pp. 475-8 (1916).

During refining of the matte, by either the Mond or electrolytic method, practically all the platinum metals are concentrated, as a by-product, in the precious metals residue. This concentrate is now shipped to the company's precious metals refinery at Acton, England, where the platinum metals are separated and refined.

The recoveries of platinum metals by the company and its predecessors for the last ten years are given in the table on page 65. It is a practical impossibility, from available data, to calculate, with certainty, the recoveries per ton of ore or per ton of matte for any one year. The relation, however, to nickel production is interesting and illuminating, although calculations along this line should not be considered mathematically exact, for a year's output of platinum metals does not necessarily come entirely from the same ore as that year's output of nickel. Consideration may be confined to the last five years, in which period production of platinum metals has greatly increased, partly due to improved extractions and partly to the coming into production of the higher grade part of Frood mine. The relation to nickel is important because nickel is the mainstay of Sudbury, and production of all other metals from the ores depends upon it. The production figures for the company are as follows:

TABLE XI

International Nickel Company Production of Nickel and Platinum Metals (1928-1932)

Year	Nickel, tons	Platinum metals		Per cent of total ore that was mined from Frood
		Ounces	Ounces a ton, nickel	
1928	48,377·8	23,530	0·486	....
1929	55,138·0	29,615	0·537	10
1930	51,415·9	68,022	1·323	44
1931	30,180·55	91,643	3·036	68
1932	12,459·8	64,897	5·209[1]	77

[1] No allowance has been made for a recovery of $52,700 of precious metals by Falconbridge Nickel Mines, that presumably was included in the 64,648 ounces. An approximate correction would reduce the 1932 figure to 5·07 ounces a ton of nickel.

The table indicates the importance of Frood mine ore to increased output of the platinum metals.

It has been noted above that the company is capable of producing, at maximum capacity, 300,000 ounces of platinum metals a year. This output, however, was estimated on the basis of a nickel production of 90,000 tons, which means 3·3 ounces of platinum metals for each ton of nickel. This is much lower than the proportion that held in 1932, say 5 ounces a ton of nickel. On that basis an output of 60,000 tons of nickel, slightly higher than has yet been attained in one year, would produce 300,000 ounces of platinum metals. However, perhaps it is unlikely that an output of 60,000 tons of nickel would be obtained by using as high as 77 per cent of Frood ore. Nevertheless, the company can, under certain conditions. produce considerably more than 3·3 ounces of platinum metal a ton of nickel, and it should be remembered that the Frood mine is capable of producing 8,000 tons or more a day, giving a yearly tonnage much greater than has been attained by the company in any year between 1928 and 1932. And the high-grade Frood ore is remarkably rich in copper, though somewhat poorer in nickel, apparently, than the average of other properties. Given a need for large copper production, relative to nickel, a very high percentage of Frood ore might be used, and thus a correspondingly high recovery of platinum metals might be obtained.

All International Nickel's precious metals are refined at its plant at Acton, England. Data on this plant are given in the article "English Operations of the Mond Company", by the Mond staff, in volume 1, 1930, page 647, of the Engineering and Mining World.

"The Acton precious-metals refinery, situated in a London suburb, recovers in a refined state the precious-metal content of concentrates produced at both the Clydach and Port Colborne nickel refineries. It is now the largest platinum refinery in the world, the enlargements effected this year having raised its yearly capacity to at least 300,000 ounces of platinum-group metals. The plant is thus prepared to refine platinum from other sources on a custom basis.

"Necessarily, the process is an intricate one, as seven metals—platinum, palladium, rhodium, ruthenium, iridium, gold, and silver—are to be separated not only from one another but from a gross assortment of other substances contained in the raw material. Long and painstaking study and research have developed the process as now used to a degree of perfection that is indicated by the high purity of its products as shown in the following average analyses over many months: platinum, 99·93 per cent; palladium, 99·94; rhodium, 99·76; ruthenium, 99·72; iridium, 99·68; gold, 99·97; and silver, 99·97 per cent. These figures give point to the statement that the plant actually is a chemical laboratory on a large scale.

"Acton refinery's place in the economic structure of the platinum market is unique, for, unlike the other platinum refineries, it is dealing with concentrates which are a by-product of ores which are primarily worked for the recovery of other metals. Therefore, the mining and treatment costs up to the refining stage may be considered as having been absorbed in the cost of producing nickel and copper. The process developed at Acton is highly efficient and operates at a low cost.

"By the middle of 1930 the annual rate of production was as stated in the table, and it is steadily increasing. Further production from the Frood mine will materially increase the amounts of precious metals produced.

Production of Precious Metals

	Troy ounces
Platinum	50,000
Palladium	26,000
Rhodium	3,300
Ruthenium	700
Iridium	500
Gold	4,800
Silver	96,000

"Concentrates from Port Colborne contain from 45 to 60 per cent of platinum metals; those from Clydach about 4 per cent, with considerable lead and silver. As Clydach is now dealing with washed sulphide from Port Colborne instead of bessemer matte, its concentrate will in future contain less lead and silver and much more platinum metals."

The article from which the above is quoted contains a brief description of the Acton plant, and an outline of the processes used in separating and refining the several precious metals contained in the concentrates.

It should be noted that the company's annual report for 1932 states that the purity of the finished metal has consistently improved.

A later article, in the Industrial Chemist (Anon., 1931), states that, of a total world consumption of some 400,000 ounces of platinum metals, approximately 300,000 ounces will be produced in England from Sudbury ores. The costs of refining are said to vary with the scale of operations, but "on the present scale (1931) work out at about 10 shillings an ounce, without any appreciable increase in cost of producing the base metals, nickel, and copper".

Falconbridge Nickel Mines, Limited

This company owns a large group of claims in Falconbridge Township (*See* Figure 2) at the southeast corner of the Sudbury Nickel irruptive (Roberts and Longyear, 1918). The contact between norite and older sediments and greenstones crosses the property for a distance of 16,570 feet and stands nearly vertical. The ore-body was discovered in 1917 by diamond drilling through a deep cover of glacial drift. It is over 10,000 feet long, varies in width, where known, from under 10 feet to a maximum of about 120 feet, and lies at or very close to the norite contact. The present company acquired the property in 1928 and now operates a smelter near the mine as well as a refinery in Norway. The mine is developed to a depth of 1,000 feet and has been explored beyond that by diamond drill. Ore reserves at the end of 1932 are given, in the annual report, as 2,920,457 tons averaging 2·25 per cent nickel and 0·93 per cent copper, but only a small part of the total section known to be ore-bearing has been developed. In the same year, 159,573 tons of ore were hoisted from the mine and 5,408,373 pounds of nickel and 2,288,897 pounds of copper produced. The precious metal values in the ore are not high; the first production was made in 1932 and netted $52,700. This figure bears no relation to the annual production from the mine, for precious metal concentrates from the refinery had been saved for some time before any shipments were made. In 1929 it was stated that a precious metal recovery of about $2 a ton of sorted ore might be expected. This estimate was based on analyses of ore, but, by later experience in smelting and refining, was found to be too high. It should be borne in mind, also, that the estimate was made in 1929, when precious metal prices, with the exception of gold, were very considerably higher than they are at present.

STRATHY TOWNSHIP

The Ontario Department of Mines reports (vol. 40, pt. I, 1931, page 22) that during nickel-copper refining in 1930, 5 ounces of gold, 62 ounces of silver, 4 ounces of platinum, and 14 of palladium were recovered from ores exported from Strathy Township. No mine is mentioned. Strathy Township is 70 miles northeast of Sudbury and in it Knight (1920) states that there are some small intrusions of pre-Algoman peridotite and diabase cutting Keewatin rocks. The largest of these is oval-shaped and ¾ mile long. It is largely altered to serpentine and contains hornblende and asbestos, as well as scattered grains of chromite. A small, neck-like protrusion extends out from the main mass into the surrounding Keewatin rocks. At this place gossan has been found over an area 300 feet long, north to south, and 125 feet wide. The ore that produced the gossan consists of pyrrhotite, chalcopyrite, and pentlandite and occurs mostly in serpentine but partly in adjoining, banded, cherty Keewatin strata. Most of the ore is disseminated, but there are also a few irregular veins, less than one foot wide, cutting disseminated material. Grab samples of low-grade, disseminated ore assayed 1·0 per cent nickel and 0·52 per cent copper, whereas a high-grade vein ran 6·54 per cent nickel and 6·40 per cent copper.

Alexo Mine

The report of the Ontario Nickel Commission, 1917, states that "an assay made by Ledoux and Company on a parcel of between 5,000 and 6,000 tons of ore shipped from the Alexo mine in 1915 showed 0·03 ounce of platinum and palladium per ton of ore". The mine (Baker, 1917) is just over ½ mile south of the Timiskaming and Northern Ontario Railway and 20 miles northeast of Porcupine. On the claims Keewatin andesite and rhyolite lavas are intruded by pre-Algoman peridotite that is now highly altered to serpentine and other minerals. There is a small percentage of chromite in the serpentine. The ore minerals are pyrrhotite and pentlandite with traces of chalcopyrite and pyrite. The ore is at the contact of a large body of serpentinized peridotite with older Keewatin pillow lava and is composed of two types of material: sulphides disseminated in serpentine and massive sulphides along the contact or in either wall (*See* Figure 6). The intrusive contact strikes northeast and dips 65 to 80 degrees northwest and ore has been proved along it for about 700 feet and to a depth of over 350 feet. The width is variable, but averages 8 to 10 feet. Serpentine forms the hanging-wall and lava the foot-wall. It is held that the disseminated ore formed by magmatic segregation in situ, the sulphide settling to the bottom of the cooling peridotite mass, and that the massive ore was introduced later, by residual ore solutions from deep-seated portions of the peridotite magma. Ore was first shipped, to Sudbury, in 1912 and up to the end of 1919 the mine had produced 51,348 tons that averaged about 4·5 per cent nickel and 0·5 per cent copper. Any platinum metals that were saved would probably be included with recoveries of Mond Nickel Company.

Placers

No placers carrying platinum are known in Ontario. There is a possibility that they may occur, since there are important areas of chromite-bearing serpentines in northern Ontario, and from one of these platinum

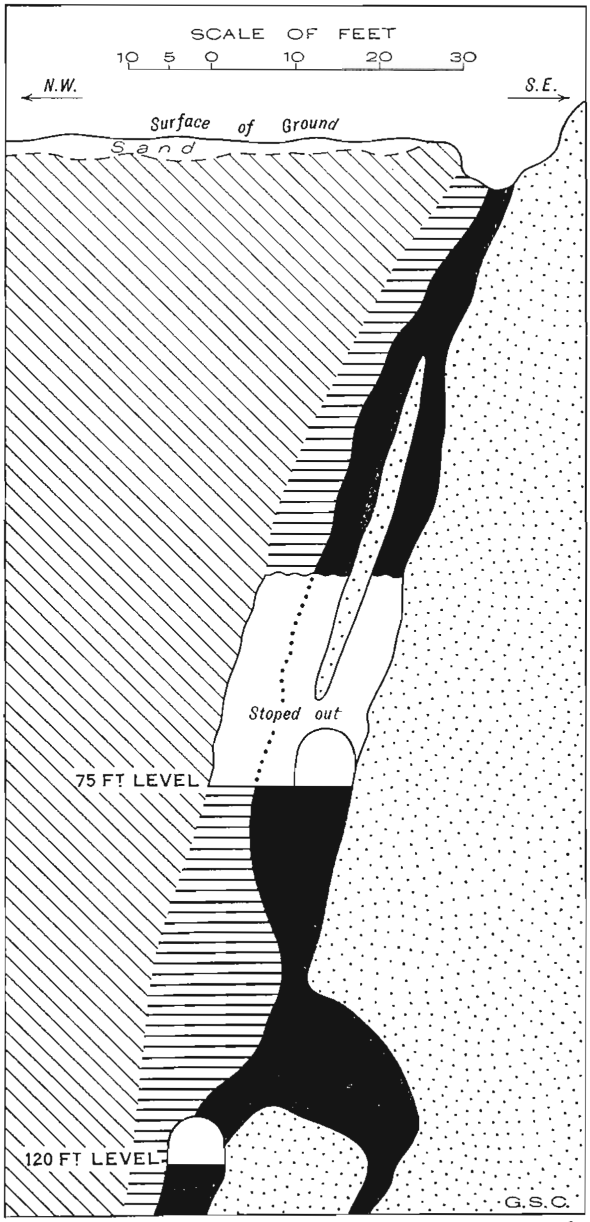

Figure 6. Cross-section through Alexo ore-body (west drift), Clergue and Dundonald Townships, Timiskaming district, Ontario (after M. B. Baker). Ore shown by solid black; serpentine by diagonal ruling; disseminated ore by heavy horizontal ruling; and pillow lava by stipple.

has been reported. The readjustment and stripping of the superficial deposits during Glacial time have destroyed most of the placer deposits then in existence. Any placers found in Ontario will occur in gravels whose peculiar situation has protected them from glacial erosion, or in those that represent a reconcentration of glacial material that contained scattered values. There has not been sufficient bedrock erosion, since Glacial time, to form valuable placers from this source alone.

MANITOBA

Lode Deposits

Platinum has been reported from three places in Manitoba. A picked sample from Star Lake district, in the southeast corner of the province, near the Ontario boundary, consisted of quartz carrying pyrite and arsenopyrite in small quantities and assayed 2·30 ounces of gold, and 0·10 ounce of platinum a ton (Marshall, 1917). Other samples from this locality gave traces of platinum.

This district was visited in 1918 by E. L. Bruce (1918) of the Geological Survey, who took twenty-one samples from the various deposits, channel-sampling those previously sampled, but the assays gave no platinum.

In Oiseau and Maskwa Rivers areas in southeastern Manitoba a number of copper-nickel sulphide replacement deposits have been prospected (Wright, 1932). The Precambrian rocks include a steeply folded series of andesitic pillow lavas and quartzose tuffs intruded by dykes and boss-shaped bodies of peridotite and gabbro and by large and small bodies of granite. Granites intrude the basic rocks. The sulphide bodies lie along sheared zones in volcanic rocks close to the edges of bodies of peridotite, gabbro, and granite, and, also, in some cases, in marginal parts of peridotite or gabbro. A small amount of development suggests that the sulphide bodies are lenticular. It seems possible that there were two periods of mineralization in the district; the first, associated with the basic intrusives, producing deposits containing both nickel and copper; the second, related to the granite, being distinguished by the presence of copper without nickel. The nickel content is due to the presence of pentlandite and nickeliferous pyrrhotite; chalcopyrite and chalmersite are the copper minerals. Gold and silver values are low, According to Wright a sample from one property, the Hititrite, assayed 0·02 per cent platinum. Other samples from the same deposit, in which sulphides occur along joint planes and schistose zones in an apparently small body of gabbro, contained from 0·27 to 3·23 per cent copper and from 0·19 to 1·68 per cent nickel.

Wright states that samples from bodies of iron sulphides in Copper and Brunne Lakes areas in northwestern Manitoba are reported to carry gold, copper, nickel, and platinum in traces.

Placers

No platinum placers are known in Manitoba.

SASKATCHEWAN

Lode Deposits

Platinum has been reported from one place in Saskatchewan. Rottenstone Lake is a small body of water in northern Saskatchewan, 80 miles north of Lac la Ronge. It lies well within the border of the Canadian Shield and the rocks are mainly various types of granite and pegmatite penetrating and enclosing small areas of gneissic rocks and masses of amphibolite, diorite, and dark schists. The gneisses are, in part at least, of sedimentary origin and locally are much interleaved with granitic and sedimentary materials.

At several localities in the vicinity of Rottenstone Lake, the gneisses and associated, dark, schistose rocks are rusty weathering along a zone or zones carrying pyrrhotite and other sulphides. One such occurrence lies close to the southeast shore of the lake and was investigated in 1928 and 1929 by the Consolidated Mining and Smelting Company. The rusty weathering rocks here form part of a low hill about 150 feet in diameter. The ground was prospected by fifteen diamond drill holes. According to information furnished by the company, the oxidized outcrop where penetrated by one drill hole carries copper and nickel in amounts ranging from a trace to 0·3 per cent and a 10-foot zone entered at a depth of 27 feet carries considerably more copper and nickel as well as platinum at the rate of $3.50 and palladium at the rate of $4.30 a ton. In a second drill hole, 100 feet from the first, a 25-foot zone commencing at a depth of about 20 feet holds platinum to the amount of $2.40 and palladium to the amount of $8.60 a ton, the copper content ranging from 0·25 to 2·7 per cent and that of nickel from 1·1 per cent to 4·1 per cent. The information supplied by the company was dated 1929 and it should be remembered that, since then, prices of platinum and palladium have fallen very considerably. Allowance for this fall should be made in considering the values given above.

Placers

No placer platinum has been reported from Saskatchewan.

ALBERTA

Platinum has not been reported from any lode deposit in Alberta.

Placers

Native platinum has been found in association with gold on the bars of North Saskatchewan River, in the neighbourhood of Edmonton. In speaking of this occurrence, Mr. Hoffmann (1893) stated: "A sample of the material from this locality, received from Mr. Wm. Pearse, consisted of minute, rounded, and flattened grains of native platinum, the largest not exceeding one-fourth of a millimetre in diameter, with intermixed, equally minute scales of native gold. Mr. Johnston found a certain proportion, about one-fourth, of the platinum to be magnetic. No evidence could be obtained of the presence of iridosmine in the particular sample examined."

Four samples of black-sand concentrates submitted by Mr. A. E. Austin, from Strathcona, Alberta, in 1918, gave the following assays:[1]

(1) Gold, 26·01 ounces a ton; platinum, 0·21 ounce a ton.
(2) Gold, 12·04 ounces a ton; platinum, 0·15 ounce a ton.
(3) Gold, 19·89 ounces a ton; platinum, 0·16 ounce a ton.
(4) Gold, 33·56 ounces a ton; platinum, 0·21 ounce a ton.

W. L. Uglow (1920) carried out a series of drill tests of the Douglas gravels, 15 miles northeast of Edmonton, for the Munitions Resources Commission in 1918, and submitted twenty-two samples of black-sand concentrates to the Dominion Assay Office, Vancouver. All but one of these samples showed some platinum, but only three ran 0·1 ounce a ton or better; half of them showed merely a trace of platinum. The highest total value in gold and platinum a cubic yard of gravel was 11·64 cents and fourteen holes averaged under 1 cent. Owing to the disappointingly low results of the assays, the work was discontinued.

BRITISH COLUMBIA

Platinum has been noted in numerous localities in British Columbia, both in solid rock or lode deposits, and in placers. There has, for many years, been a small but continuous production from placers in Similkameen district, and a more or less sporadic recovery of small amounts from placers in other parts of the province, as on Quesnel and Fraser Rivers. In recent years, some palladium and a little platinum have been recovered as by-products of refining lead-zinc ores at the Trail plant. Production from this province during 1928 was as follows:

—	Platinum	Palladium
	$	$
Finlay River, Omineca mining division	76	....
Tulameen River, Similkameen division	2,743	....
Trail plant	1,730	22,270

For convenience, the descriptions of occurrences are here arranged under the mining divisions in which they occur and progress through the province from northwest, to northeast, to central, to south-central, to southeast, and finally to southwest. Occurrences in placers on Fraser River are all described, in order not to separate them, at the end of the section on placers.

Placers

LIARD MINING DIVISION

Thibert Creek

Thibert Creek flows from the west into Dease River at the outlet of Dease Lake (Johnston, 1925; Kerr, 1925). Gold was discovered on it in 1873 and since that time much work has been done on the lower 8 miles

[1] Assays at the Dom. Assay Office, Vancouver.

of the valley. Very little gold has been found above Berry Creek and most of the production has been from an old channel on the south side of the present stream. Extensive hydraulic operations have been carried out at and below the mouths of Berry and Boulder Creeks. The richest gravels in the old channel are only a few feet thick and rest on bedrock. They are cemented in places and are probably pre-Glacial (late Tertiary) and are covered by 100 feet or more of glacial or interglacial gravels and boulder clay, in which small amounts of gold are also found. Platinum occurs in the gold-bearing gravels on Thibert Creek, but is not known elsewhere in the district.

The only recorded attempts to determine and save the platinum values were made in operations in the old stream channel immediately below the mouth of Berry Creek. At this place the old channel averaged about 400 feet in width. In 1900 the Thibert Creek Hydraulic Mining Company set undercurrents in their sluice boxes to recover the fine gold, but the recovery did not pay for installation and working. However, the black sand remaining in the sluice boxes and undercurrents was known to contain platinum and a sample was saved and later analysed by the Provincial Assayer, who reported as follows (B.C. 1902, pt. H, page 44):

"Contents from Thibert Creek, Cassiar

Platinum	=12,864·5 ounces troy per ton...	=44·1 per cent
Osmiridium	= 3,475·5 " "	=11·9 "
Total	16,340 ounces per ton	=56·0 "

"Little or none of this sand is saved, which seems a pity, considering its great value."

The water supply of about 450 inches was not considered sufficient for economical working, so in 1904, when the property was taken over by the Berry Creek Mining Company, an additional supply of water was brought in from Dease Creek. Mr. Hamfield, who continued as manager, conducted experiments to find out whether the platinum minerals were present in sufficient amount to be of importance. He reported as follows (B.C., 1905, pages 77-78):

"Experiments were made to concentrate the black sands containing minerals of the platinum group. For this purpose an undercurrent, and a series of tables covered with cocoa-matting, canvas, and burlap, were installed at the end of No. 2 sluice.

"Although it was this year largely experimental, the mechanical concentration was quite satisfactory. During the twenty-one days that the concentrating plant was in operation, it yielded 250 pounds of concentrates, and this amount could have been greatly increased by a man in attendance with some experience in concentration.

"Assays of these concentrates, made at the B.C. Government Assay Office, gave 60 ounces of platinum to the ton of concentrates and assays obtained in San Francisco gave up to 15 ounces of platinum and 7 ounces in gold per ton. These results were obtained almost entirely from top gravel, and as the bottom gravels will naturally contain more of the heavier minerals, the concentrates from the latter should be very much better than this year's output."

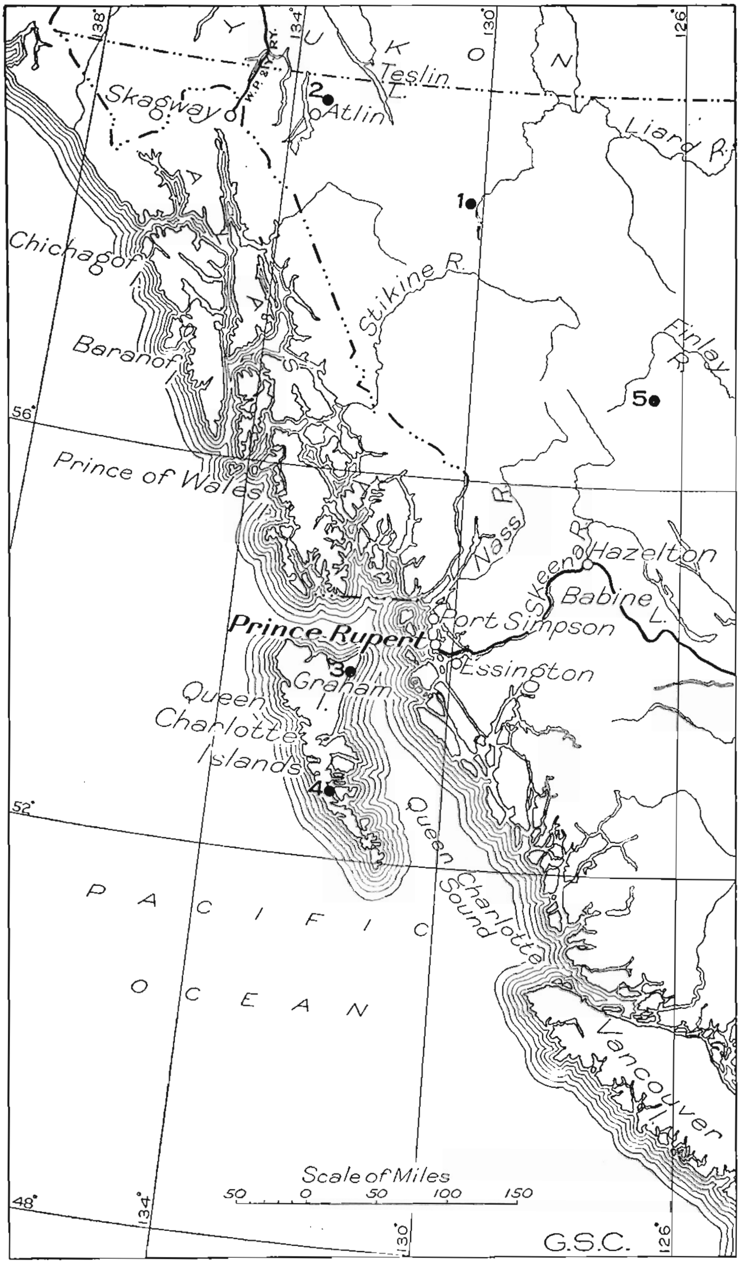

Figure 7. Index map showing location of platinum-bearing deposits in western British Columbia. 1, Thibert Creek; 2, Ruby Creek; 3, Graham Island; 4, Swede group; 5, McConnell Creek.

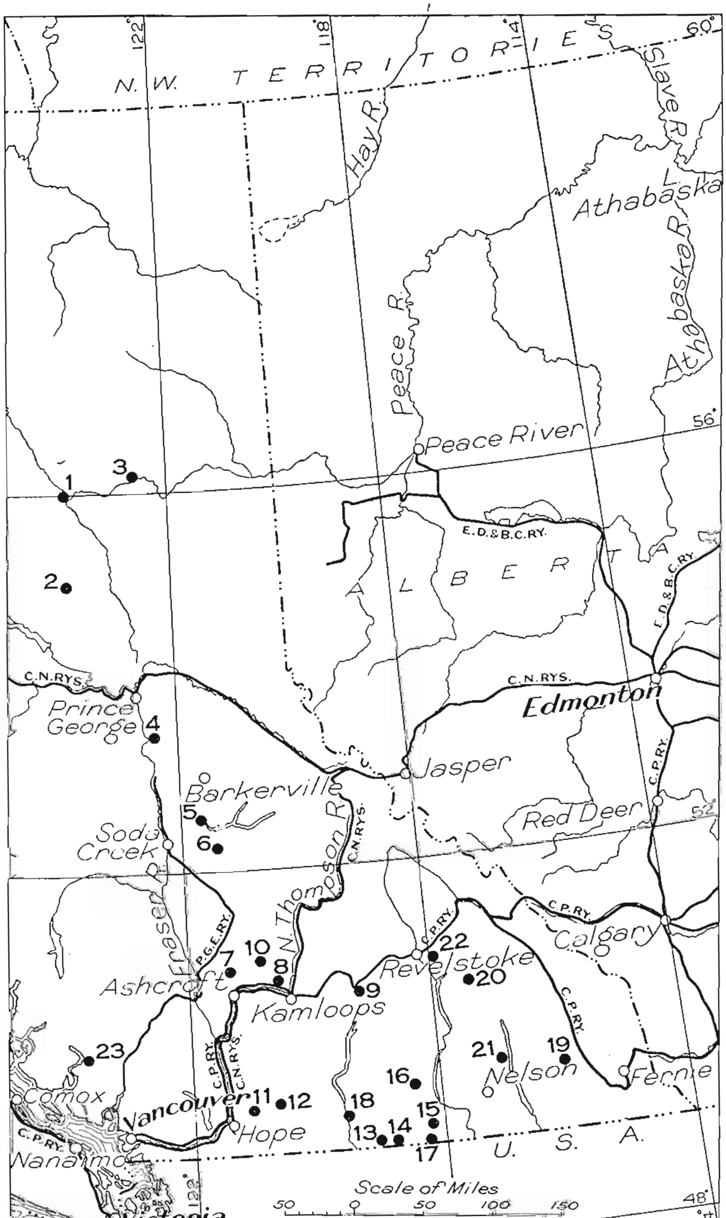

Figure 8. Index map showing location of platinum-bearing deposits in eastern British Columbia. 1, Pete Toy's Bar; 2, Rainbow Creek; 3, Peace River; 4, Government Creek; 5, Bullion Mine; 6, Horsefly River; 7, Scottie Creek; 8, Tranquille River; 9, Mount Ida; 10, Criss Creek; 11, Coquihalla Area; 12, Tulameen; 13, Rock Creek; 14, Sappho; 15, Mother Lode; 16, Franklin Mining Group; 17, Cascade; 18, Shuttleworth Creek; 19, Sullivan Mine; 20, Lardeau River; 21, Ainsworth Division; 22, Isaac Creek; 23, Potato Creek.

In 1906 Mr. D. R. Irvine, of Victoria, B.C., became manager of the property, and at the close of the season made the following estimate concerning No. 2 pit, which he had operated for 50 days (B.C., 1906, part H, page 59):

"Bottom gravel and cement	6 feet thick	25	cents per cubic yard	
Lower gravel	70 " "	14	" " "	
Upper gravel	234 " "	8	" " "	

"In places the top gravel runs much richer, as high as several dollars to the cubic yard. No. 2 pit, and the results obtained therefrom, is said to give the fairest idea of the deposit. The height of the bank in this pit is 210 feet, and the face is 400 feet from the outer edge of the new channel. The bank is all gravel, with no boulder clay on top."

The company was prepared to operate on a large scale in 1907, but a series of bad landslides covered up the sluices and plant in the pits, and a similar accident happened in 1908, so that very little profitable work could be accomplished. After lying idle for two years, the property was leased in 1911 to the Boulder Creek Mining Company, who constructed a plant to operate 1½ miles downstream from the old workings, where there was apparently less likelihood of slides. Slides did occur for a couple of years, but these were overcome and in 1915 the company moved 452,777 cubic yards of gravel in a total running time of 108 days. The work was continued each year until 1917, when a slide at the end of the season prevented the clean-up, and in 1918 the mine was not operated.

Since that time some minor operations have been attempted on Thibert Creek with no very great success, although G. Adams succeeded in saving about $14,000 in twenty-two days in 1919, by hydraulic work on the claims described above. Apparently no attempt has been made since 1905 to determine the amount of platinum in the gravels or to save any of it. Nevertheless, there undoubtedly is a considerable amount of platinum in the gravels remaining along Thibert Creek and this fact might be of importance in considering further hydraulic operations. The longest continuous stretch of gravels now preserved in the old channels extends for about 4,600 feet below the mouth of Fivemile Creek. This part is about 1,000 feet longer than the sections above Fivemile Creek that have already been hydraulicked. In order to make the work on this section pay the values in the gravels would probably have to be considerably higher than in the parts already hydraulicked and this does not seem very probable. Definite information on this point would necessitate systematic drilling. The platinum is thought to be related in origin to certain basic lavas of Triassic and? Jurrassic age that outcrop along Thibert Creek.

ATLIN MINING DIVISION

Ruby Creek

During the examination of about three pounds of black sand from placer washings on this creek, Gledhill (1921) extracted about thirty crystals and grains of iridosmine. They were examined crystallographically and the characteristic habit was found to consist commonly of three forms: the base C, the second order pyramid x, and the prism a. Some of the crystals were tin-white, others were steel-grey. The other constituents of the sand included cassiterite, wolframite, magnetite, zircon, brookite, native gold, copper, bismuth, ilmenite, rutile, chalcopyrite, pyrite, pyrope, quartz, feldspar, biotite, muscovite, and chrysolite.

QUEEN CHARLOTTE MINING DIVISION

Graham Island

From time to time it has been reported that platinum occurs with gold in beach placers on the northeast coast of Graham Island. In 1918 it was reported that important values in both gold and platinum had been found by assay of black sand concentrates from Tow Hill, on the northeast corner of Graham Island. Three samples were later forwarded to the Munition Resources Commission and were reported on by the Ore Dressing and Metallurgical Division of the Department of Mines, Ottawa, as follows:

Sample No. 1, 3 sacks, average of 10 feet deep: platinum, nil; gold, trace.

Sample No. 2, 1 sack of heads (first to seconds): platinum, nil; gold, 0·04 oz. a ton.

Sample No. 3, one package of gravel from beach: platinum, nil; gold, nil.

Samples of this nature, however, do not necessarily give the true value of such deposits. According to Carmichael (1930) wave or stream-concentrated black sand deposits may be expected in an area of several hundred square miles on the northeast part of Graham Island and are best known along the east coast, particularly south of Cape Fife. He states that the presence of gold and platinum metals in the black sands has been proved by many assays made on samples from widely separated districts. The values may be derived by reconcentration from glacial drift which covers large areas of this part of Graham Island. Black sands are known both along the present shorelines and for considerable distances inland.

A recent report (Carmichael, 1931; Mandy, 1931) mentions the presence of platinum and gold in black sands on Graham Island and states that although there does not seem to be much promise of success for large gold-saving operations, yet, where water is available, wages might be made by individuals or small syndicates.

OMINECA MINING DIVISION

Platinum has been found in several places in the gravels of Finlay River and its tributaries the Omineca and Ingenika, and on the Parsnip and its tributary Nation River. In every occurrence the platinum is present in much smaller amount than gold and in many places the quantity is practically negligible.

In 1928 Finlay River Mining Company, Limited, tested the gravels of Pete Toy's Bar, on Finlay River 3 miles above Finlay Forks. A black sand concentrate, containing some fine gold and platinum, was obtained by passing gravels from the top 8 inches of the bar over riffles with undercurrents. Nine hundred and seventy-one pounds of these concentrates were tested in Chicago by Goldsmith Bros. and contained 21·362 ounces of gold and 0·971 ounces of platinum.

Rainbow Creek

In 1931 J. D. Galloway (1931) examined Rainbow Creek, a tributary of Nation River. He notes that the creek is about 25 miles long and, except for $1\frac{1}{2}$ miles at its mouth, where it flows rapidly in a rock canyon, lies in a flat valley abounding in beaver dams and meadows. Most work had been done in the canyon, on gravels from 2 to 8 feet deep either in the bed of, or on small benches near, the stream. Only small amounts of gold had been recovered. Above the canyon test work had revealed values of 2 to 10 cents a yard in from 2 to 10 feet of top gravels overlying boulder clay, and some values in gravel in the clay. These seemed to warrant drilling operations to determine values down to bedrock. The grade of the stream above the canyon is too low to permit of ordinary hydraulic operations.

Some high platinum values obtained from black sand concentrates from workings in the canyon had been reported before Mr. Galloway's visit. He states that, by assaying about forty samples of black sand concentrates from panning, rocking, and sluicing operations, it has been determined that the platinum content of the gravels is not of major importance. Black sand, even when it occurs in considerable quantity, in the top gravels and clays, carries practically no platinum. Platinum occurs as minute flat grains with the black sand in the canyon, and tests of sluice concentrates, thoroughly cleaned, from that place indicated a value of $4.51 in platinum and $0.17 in iridium per 100 pounds of concentrate, or nearly $96 a ton. Samples from another sluicing in the canyon contained $46 in platinum a ton of concentrates. Galloway assumes that the canyon gravels so far might average 50 cents a yard in gold; on this basis they would contain a little better than 4 cents a yard in platinum. It may be assumed that his calculations were made in August, 1931, when platinum was worth $40 an ounce. Platinum was found at only one place above the canyon and then at the rate of $1\frac{1}{2}$ cent a cubic yard, but it may occur in the black sands with bedrock gravels that had not been tested at the time of examination. Both the gold and platinum in Rainbow Creek are well worn and may have travelled a long way. Galloway noted no rocks in the district that might have been a probable source of platinum, but the geology is not well known.

In 1931 a discovery of gold-bearing gravels was made on Dog Creek, which flows into Stuart River south of Fort St. James (B.C., 1931, page 80). Very little work had been done at the time the discoveries were examined, but a test made by the resident mining engineer, on $\frac{1}{10}$ cubic yard of gravel from a pit in a few feet of gravel overlying a false bedrock on an extensive bench near the creek, indicated gold to the value of $2.58 and platinum worth 1 cent a cubic yard.

McConnell Creek

McConnell Creek was reported on in 1932 (Lay, 1932). The stream, a tributary of Ingenika River, is about 7 miles long and in its upper 4½ miles meanders in a flat valley that averages not less than 2,000 feet in width, In this part indurated silt of considerable thickness forms a false bedrock below auriferous gravels that probably would not average much over 25 feet in thickness and are in many cases much thinner than that. These gravels are due to Recent stream action on glacial deposits in the valley and consist of sand and gravel mixed with small to very large boulders. Sufficient testing has not been carried out to prove whether or not large-scale operations would be profitable. Seventeen pan samples taken at widely separated points averaged $1.52 in gold and $0.12 in platinum a cubic yard, platinum being calculated at $40 an ounce. The highest return, $2.82 in gold and $0.675 in platinum a cubic yard, was obtained by panning a sample from the north end of a pit, 3 feet deep, on P. Jensen's Lease No. 457. A sample of black sand from another lease, after the gold had been removed by amalgamation, assayed $2.20 in gold and $45.20 in platinum a ton. Mr. Lay concluded that the gold and platinum are of local origin, the platinum possibly being related to basic intrusives like pyroxenite, that occur in the district.

PEACE RIVER MINING DIVISION

Gold placers near Hudson Hope, on Peace River, are reported to carry values in platinum. Assays of a ten-pound concentrate indicated values of 80 cents in gold plus platinum, per yard of original sand. These deposits were being investigated in 1918 by Mr. W. A. Aubin, who had two steam drills working on the property. It is reached from Hudson Hope by a portage of 14 miles over a good Government road, followed by a 26-mile steamer trip on Peace River. The deposits lie in benches on either side of the river. They are said to be from 40 to 50 feet in thickness, and well suited for dredging.

CARIBOO MINING DIVISION

Government Creek

Government Creek drains into Fraser River from the east, about 35 miles south of Prince George. In 1914 D. A. Cameron and associates were granted ten placer leases, about 7 miles east of Fraser River (B.C. 1914, part F, page 132). Mr. Cameron claimed values of from 15 to 40 cents a yard for about 4,000,000 cubic yards of gravels in the creek bed and on low, shallow-covered benches. The property was well suited for hydraulicking and the gold was moderately fine to coarse. Concentrates were reported, by Mr. Pooke of Prince George, to contain platinum and he furnished one certificate from the Government Assay Office, Victoria, giving 1·8 ounces gold and 2·8 ounces platinum a ton.

QUESNEL MINING DIVISION

The first mention of platinum from Quesnel district, so far as known, was a note by George M. Dawson in his Summary Report of the Geological

Survey for 1894. He there states that platinum was found in small quantities with the gold in the Horsefly Hydraulic Mining Company's mine on Horsefly River, about 6 miles south of Quesnel Lake.

In 1902 the Provincial Mineralogist secured a number of samples of black sands from various parts of Quesnel and adjacent districts with a view to tracing the platinum to its source. Particulars of the results of assays of these are given in the following table (B.C. 1902, part H, page 64).

TABLE XII

Results of Tests on Black Sands from Quesnel and Adjoining Districts, B.C.

———	Assay value in ounces a ton except as indicated			
	Gold	Silver	Platinum	Osmiridium
Head of Harvey Creek	....	....	None	....
Upper Cunningham Creek	....	....	"	....
Fraser Creek, Horsefly	....	....	"	....
Eureka Creek, Horsefly	....	....	"	....
Cottonwood Creek	....	....	"	....
Keithley Creek (Hayward claim), black sand and pyrites	5·9	2·0	"	....
Quesnel River, 82 miles above mouth	3·8	Not det.	1·0	....
" " 40 " " "	1·0	"	2·8	....
" " 40 " " "	0·06	"	0·14	....
" " 25 " from "	0·2	"	0·4	....
" " 13 " above Quesnel	4·7	"	7·8	....
[1] " " 30 " " "	....	"	6·4	....
[1]Fraser " 2 " " "	....	"	2·4	....
Quesnel " 25 " below forks	1·0	Trace	0·5	....
" " 25 " " "	2·5	"	2·5	....
Three miles above Quesnel	0·85	Not det.	0·25	3·2
[2]Quesnel mouth (concentrates)	7·1%	"	71%	3·1%
Consolidated Cariboo Hyd. Mg. Co.	....	....	70%	3·5%
[3]Horsefly River, Harper's Camp	....	....	25%	4·5%
Fraser River, 15 miles above Quesnel	121·8	Not det.	3·9	....
Cobledick dredge, Quesnel, Fraser River	913·0	"	165·7	....

[1] Mostly platinum; other metals not assayed.

[2] $\frac{7}{10}$ ounce of mineral giving: gold, 0·05 oz. troy; osmiridium, 0·022 oz. troy.

[3] Mr. Hobson says that this platinum is found in the proportion of 1 oz. platinum to 100 ozs. gold.

"From this it will be noted that platinum occurs throughout the drainage area of the Quesnel River, but that it is also found on the Fraser above Quesnel mouth, and that it follows the Fraser down to Lytton. The samples obtained do not indicate its presence in the Barkerville district, though samplings from this section may reveal it."

Since that time (1902) prospecting has confirmed the occurrence of native platinum in appreciable quantities throughout a large part of Quesnel River basin; but although some large companies have been in operation, they have made little effort to recover this metal. The platinum, and some palladium and osmiridium, are found in black sand concentrates that remain in the sluice boxes after cleaning up. Consequently, the extraction of platinum necessitates the installation of undercurrents or some other device to save the heavy concentrates, which are ordinarily lost in the tailings. The values in platinum metals thus must be sufficient to pay for the additional cost involved in their extraction and, of course, any production of these metals depends primarily on the gold content of the gravels.

Bullion Mine

The most extensive tests for platinum values have been made on gravels of the old Bullion mine, on the south fork of Quesnel River, 4 miles west of the outlet of Quesnel Lake. This property has had a checkered career, but at one time or another, principally between 1899 and 1905, has produced in the neighbourhood of a million dollars of gold. The gold is in gravels in an old channel of the south fork, the channel varying in width from a few hundred to about 1,000 feet. The richest gold-bearing gravels are probably pre-Glacial and lie on bedrock. They are in places over 300 feet thick and are overlain by barren boulder clay and other low-grade gravels, with, in some places, a second layer of boulder clay at the surface. The total thickness of these deposits would average over 400 feet. As there may be a length of 10 miles of these old channels on the property it is apparent that a tremendous yardage of gold-bearing gravel is indicated. The quantity has been estimated by Mr. Hobson, manager of operations at one time, as 500,000,000 cubic yards with an average gold tenor of 25 cents a yard (B.C., 1902, part H, page 77). Lack of adequate water supply has been one of the principal stumbling blocks to most attempts at operation. The latest endeavour was made in 1931 by B.C. Hydraulics, Limited (B.C., 1931, page 91).

The information concerning the platinum metals is well summed up in a report of Mr. Hobson, quoted in the B.C. Bureau of Mines Report for 1904, part G, page 41, as follows:

"For several years past, qualitative tests have been made from time to time for the presence of gold, platinum, and osmiridium, in the heavy concentrates that remain in the sluices after cleaning up; and while making one of these tests in May, 1903, the presence of palladium was indicated in addition to platinum and osmiridium. An analysis of a sample of concentrates, made by J. O'Sullivan, F.C.S., chemist, of Vancouver, in May, 1903, gave large percentages of gold, platinum, palladium, and osmiridium, which brought the value of the concentrates up to $3,872.76 per ton. A second sample, taken from a pan of concentrates taken from the sluices after the clean-up in September, 1904, was sent to Mr. O'Sullivan, and gave the following results:

—	—	Gross value a ton of 2,000 lbs.
		$ cts.
Gold	95 ozs. a ton	1,900 00
Silver	180 " "	90 00
Platinum	64 " "	832 00
Palladium	64·4 " "	1,769 00
Osmiridium	42 " "	1,386 00
Copper	10·5 per cent.	16 56
Total value		5,993 56

"The gold and silver values are, no doubt, included in particles of pyrite and argentiferous galena, and partly in small particles of gold covered by manganese and other metallic oxides, and cannot be recovered by the process of amalgamation. The platinum, palladium, and osmiridium are found in minute metallic grains, and enclosed in small fragments and nuggets of magnetite and chromite, which appear to make up quite a large percentage of the sluice concentrates found after cleaning up.

"What quantity of these high-grade concentrates are included in the deposits, or can be recovered therefrom, cannot be determined until after the completion of the system of undercurrents which is to be placed at the end of the sluice outside the tunnel, where everything of value will be separated from the tailings, before going over into the dump, and concentrated on the undercurrent tables. These undercurrents will probably be completed before the close of the ensuing season."

Unfortunately these undercurrents were never completed, so the above is all the information available as to the amounts of platinum, palladium, and osmiridium contained in the gravels.

Platinum has been found or reported from other placer deposits in Quesnel division, as follows:

Quesnel Hydraulic Mining Company started operations in 1911 with an extensive hydraulic plant on an enormous yardage of gravels of Twenty-mile Creek, which flows into Quesnel River about 9 miles below the forks. Values in platinum were said to have been found in the gravels and a series of undercurrents was installed to save them and the fine gold. The operation was discontinued when values obtained did not come up to expectations and samples of concentrates stored at the mine failed to give any platinum values.

Morehead Creek flows into Quesnel River from the south about 6 miles below the forks. Hydraulic operations have been attempted on deep gravels in the left bank by the Morehead Mining Company and (B.C., 1913, part K, page 64) in 1913 it was reported that a small quantity of crude platinum was recovered from riffles. No devices to save the platinum had been introduced at that time and no platinum production has been reported to date.

In the same year (Op. cit., page 62) it was reported that a material amount of crude platinum had been found in gold-bearing gravels on Quesnel River, below the forks, by the Water-tight Dipper Dredge and Mining Company, Limited. A dredge was built in 1914 but was not operated.

Horsefly River flows north into Quesnel Lake. About $500,000 in gold was won from a single hydraulic pit at Harpers Bar, where the main values were on bedrock, 50 to 60 feet and more below the level of the river (B.C., 1897, page 487). In 1903 it was reported that the gold encountered in top gravels 1,000 feet south of the old workings carried over 1 per cent platinum (B.C., 1903, part H, page 66). Presumably the meaning is that platinum is present, or is saved, in the ratio of over 1 ounce for each 100 ounces of gold.

CLINTON MINING DIVISION

Scottie Creek

This stream flows into Bonaparte River, a tributary of Thompson River. The gravels were tested in 1918 by panning and assaying (Thomlinson, 1920, page 177). Values in platinum varied from nil to 0·14 ounce a ton of panning concentrates in the case of four samples from the main stream and were 0·06 ounce a ton of concentrate in the case of two from gravels of the tributary, Chrome Creek. The pannings also contained gold.

KAMLOOPS MINING DIVISION

Tranquille River

Tranquille River enters Kamloops Lake from the north, near the east end of the lake. Gold was discovered on this river in 1858 and the placers were worked for more than thirty years. The gravels worked were those forming the banks or bed of the stream, or flats immediately adjacent to it, for a distance of 8 miles up from the mouth; the flats are in a few places extensive but shallow, and the bedrock is of Tertiary volcanics.

" Besides the gravels near the level of the present stream, an older series is exposed in banks about 100 feet high on its east side, and is interstratified towards the summit with the white silt deposit. The gravels are bedded and the stones well rounded, reaching in some cases a diameter of 6 or 8 inches. The deposit is evidently a remnant of a rough delta formed by the Tranquille River when the water of the lake was at a higher level, in times immediately succeeding the Glacial period. It should contain gold, but I could not learn that it had been found to do so in paying quantities " (Dawson, 1877-78, part B, page 155).

" Most of the gold is scaly, and mixed with it are particles of platinum, similar in shape and size to those of the gold."

Apparently very little effort was made to save the platinum, and very little work has been done at this place since the price of platinum became sufficiently high to be an inducement to go to any trouble or expense to save it. The source of this platinum is not known, but it may have come with the gold, which Dawson suggested was probably derived from the gravels of an old main stream channel through which Tranquille River cuts a few miles above its mouth (Dawson, 1894, page 320). Two samples of panning concentrates taken in 1918 from places on Tranquille River where placer operations had been conducted assayed nil and 0·02 ounce platinum (Thomlinson, 1920, page 176).

North Thompson River

On North Thompson River traces of platinum were found in five samples taken from near the mouth of Clearwater River and submitted for analysis to the Dominion Assay Office, Vancouver, by Mr. J. R. Arthur, of Vancouver. So far as known, no other attempt has been made to test the gravels of this river for platinum.

ASHCROFT MINING DIVISION

Criss Creek

A little placer mining was done near the mouth of Criss Creek, a tributary of Deadman River, but was abandoned after one season's work (Dawson, 1887-88, part R, page 135). A sample concentrated from the gravels in a pit at the junction of Criss Creek and Deadman River was submitted to the Dominion Assay Office by Mr. Charles Camsell in 1918, and assayed 12·24 ounces of gold and 0·12 ounce of platinum a ton of 2,000 pounds of concentrates.

YALE MINING DIVISION

Coquihalla Area

Placer gold and some platinum have long been known to occur in the gravels of Coquihalla River and some of its tributaries. Gold colours can be obtained by panning the gravels or sand of the Coquihalla at almost any place below Ladner, and some coarse gold and platinum nuggets have been found on bedrock. Information concerning platinum has been derived principally from placer operations on Sowaqua Creek, which drains into Coquihalla River 1½ miles below Jessica. Captain J. D. Fullbrook and associates, of New Westminster, were working on a series of low benches in 1923 and had sunk two shallow shafts. The following tests were made by the Resident Engineer in December, 1923 (B.C., 1923, page 163).

"No. 1 Test. Ground sluice on No. 3 lease (¼ yard put through rocker): riffle concentrates, 19 cents a yard in gold; blanket concentrates, 16·6 cents a yard in gold, and 1·1 cents in platinum; total value of gravel 36·7 cents a yard.

"No. 2 Test. Windlass shaft on right side of creek on bench (⅛ yard put through rocker): riffle concentrates 13·3 cents a yard in gold and 0·6 cent in platinum; blanket concentrates, 437 cents a yard in gold, 1·3 cents in silver, and 1·3 cents in platinum; total value 453·5 cents a yard.

"No. 3 Test. From 10-foot shaft near left bank of creek (¼ yard put through rocker): all concentrates together, 2·4 cents a yard in gold.

"In making the above tests it was assumed that, for every yard of material such as was handled above, half a yard exists as boulders."

Considerably higher values, reported by the owners, are given in the same report. In 1929 C. E. Cairnes (1929, page 174) reported that exploration work on the property included three or more shafts, a number of shallow pits, and some surface sluicing. These operations were reported to have yielded some $4,400 in gold and $600 in platinum. The deepest shaft had been sunk for 60 feet below the water-level of Sowaqua Creek without reaching bedrock. Values were reported to be encouraging, but sufficient testing to indicate the possibilities of the property had not been carried out, although Cairnes was of the opinion that a careful program of boring and sampling was justified. The placer gold and platinum are believed to have been derived by concentration of glacial debris that contained some values in these metals, but the original source may have been in rocks drained by

Sowaqua Creek. This stream cuts across the so-called "Serpentine Belt" of the district which includes sill-like masses of serpentinized peridotite or olivine-rich pyroxenite. This rock contains disseminated magnetite, chromite, and nickeliferous silicates, but the few tests that have been made have not revealed any platinum. Chromite may occur in segregations in it and it is possible that platinum may be present either in the rock or, if segregations of chromite do occur, in association with that mineral.

SIMILKAMEEN MINING DIVISION

Tulameen District

History

Placer gold was discovered in upper Similkameen River, near the mouth of the Tulameen, in 1860. It was soon recognized that platinum occurred with the gold, but no attempt was made to save it and no important developments took place until 1885. In August of that year coarse gold was discovered in the bed of Granite Creek and a rush ensued. Eighteen hundred and eighty-six saw great activity on the Tulameen and its tributaries and during that year $193,000 in gold and platinum was won from the gravels, the greatest production the district has ever achieved. Although some platinum was saved in these and earlier years the production of this metal was not recorded officially until 1887 when 2,000 ounces valued at $5,600 are noted, along with $118,000 of gold. Gold production waned rapidly in the following years, but platinum to amounts between 1,000 and 2,000 ounces was saved annually until 1891. Since then the productivity of the area has gradually fallen. Some work has been done every year, however, and there have been several attempts at large scale hydraulic operations, but it cannot be said that any of these were very successful.

G. M. Dawson (1877-78, part B, pages 50, 156) contributed the first geological notes on the area, but these, apparently, were not the result of personal examination. In 1888, however, he visited the Tulameen and discussed the placer deposits (1887-88, page 62). In 1900 J. F. Kemp spent three months investigating the platinum resources of the district and in 1902 published his results in Bulletin 193 of the United States Geological Survey. Camsell (1913) spent two seasons (1909 and 1910) studying the geology and mineral deposits and his report is the last complete one on the area. In 1918 bench and river gravels along Tulameen River were tested by the Munition Resources Commission, Canada (1920), under the direction of Mr. G. C. Mackenzie, and during the same year Eugene Poitevin investigated the ultrabasic intrusives of the area (1923). Additional information is contained in the Annual Reports of the British Columbia Minister of Mines.

General Character of the District

Tulameen district lies at the western border of the Interior Plateau of British Columbia and exhibits the physical features common to much of the border belt of the plateau. Immediately west, the rugged Hope Mountains rise to heights of over 7,500 feet. Within the district, plateau features are preserved, however, in the form of broadly rounded summits that, viewed from a higher peak, present an almost level, rolling skyline. The valleys, however, are deeply incised, giving a maximum relief within the area of 3,800 feet, from about 2,350 feet above sea-level in Tulameen Valley to 6,150 feet on Lodestone Mountain, the highest peak. The old plateau level rises gradually about 1,000 feet from northeast to southwest. The two main valleys, of Tulameen River and Otter Creek, are broadly U-shaped, whereas the principal tributary valleys are strongly V-shaped, or, in their upper reaches, broad and quite flat. Otter Creek is broad and drift filled and, where not occupied by lakes, has a grade of about 8 feet a mile. Tulameen River Valley, below Slate Creek, is also broad and, with a grade of about 29 feet a mile, the stream meanders in the drift-filled channel. Above Slate Creek the grade is about 100 feet to the mile and the stream flows in a canyon, cut 200 or 300 feet below the level of the still-preserved, older, broad, U-shaped valley. Most of the tributaries enter Tulameen River through narrow canyons with falls, but farther back the gradients are more gentle. The district is well wooded throughout its greater part.

General Geology

Camsell (1913) has discussed the general geology of the district in detail. According to his report, the oldest rocks are andesitic flows and breccias with interbedded limestone, argillite, and chloritic or talcose schist of the Tulameen group, referred tentatively to the Triassic. These rocks are extensively folded and dip at angles varying from 25 to 90 degrees, striking, on the average, west of north. During the Jurassic they were intruded by four successive groups of batholithic rocks, in the following order: (1) boulder granite; (2) peridotite and pyroxenite; (3) augite syenite; (4) Eagle granodiorite. Numbers 2 and 3 are believed to be closely related in time of intrusion. All these rocks tend to occur in large and small bodies that are elongated approximately north and south, or sub-parallel to the general trend of the older strata. Oligocene sediments and volcanics are capped by post-Oligocene olivine-basalt and are also intruded by post-Oligocene granite.

During the Pleistocene the whole district was covered by the continental ice-sheet that flowed west of south through the interior of British Columbia. As the ice retreated, valley glaciers formed and accentuated the U-shape of the major valleys by broadening and probably deepening them. This left many of the tributary streams of the Tulameen occupying hanging valleys.

Peridotite and Pyroxenite. Peridotite and pyroxenite occur in one principal mass that is over 7 miles long and from ½ to 2½ miles wide. In addition there are several smaller bodies. The main body crosses Tulameen River between Olivine and Grasshopper Mountains (*See* Figure 9). The general relation is a core or central mass of peridotite surrounded on all sides and in places capped by a shell of pyroxenite. The contact between peridotite and pyroxenite is transitional and there is a gradation from almost pure olivine, or dunite, in the centre, through a zone of peridotite, containing pyroxene, to pure pyroxenite on the outside. All the evidence indicates that the two types of rock are parts of one magma that have formed by differentiation in place. The dunite is partly fresh, but much of it is entirely altered to serpentine. Where fresh, olivine and minor amounts of chromite in scattered grains, or in small veins and bunches, are the only constituents. Where altered, the dunite consists of serpentine, with minor amounts of tremolite, magnesite, and mica, and scattered chromite grains. Small dykes of olivine and augite, with some magnetite and chromite, cut the dunite. Typically the pyroxenite consists of coarse crystals of augite and

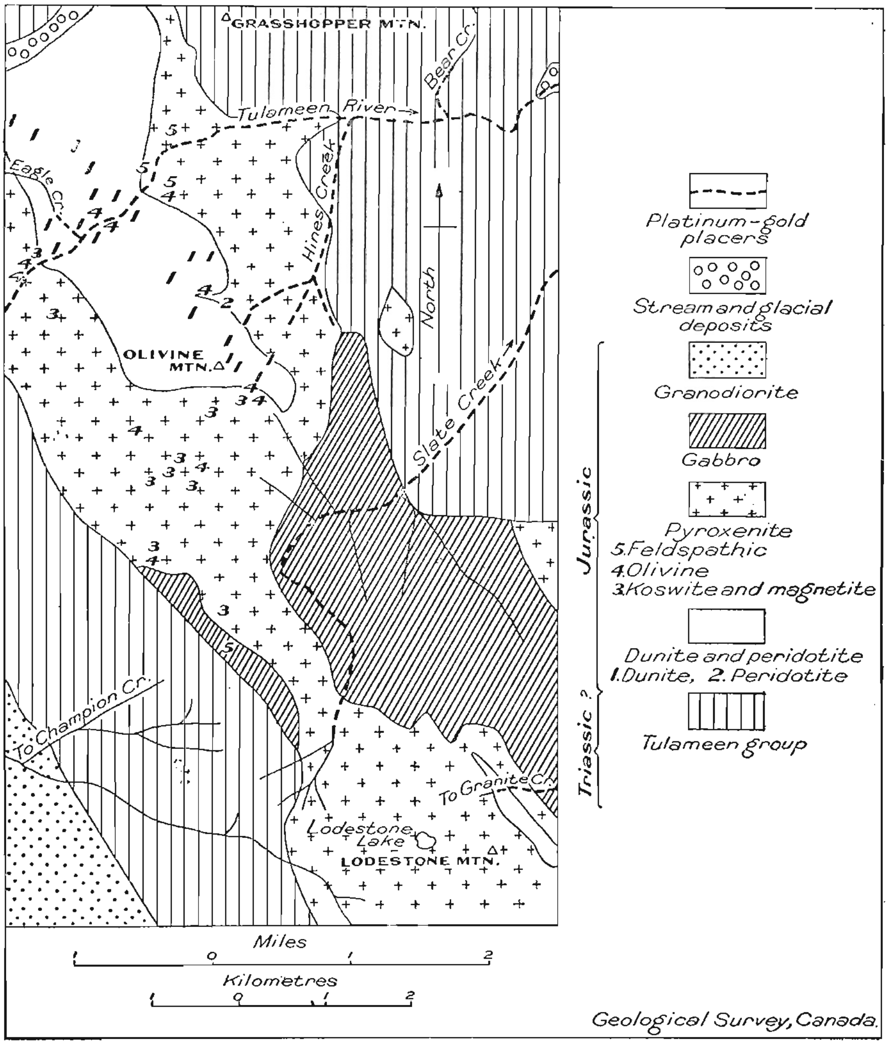

Figure 9. Part of Tulameen district, B.C. (after Poitevin).

some magnetite. The augite alters readily to hornblende and the rock is cut by coarse-grained, hornblendite dykes.

It is apparent from the above description that the main peridotite-pyroxenite body of Tulameen district is very similar in occurrence to the primary dunite-pyroxenite centres of the Ural Mountains as described by Duparc. Poitevin (1923) has made a detailed comparative chemical and mineralogical study of the rocks from the two places, which further emphasizes the similarity and leaves no doubt that the Tulameen rocks are of the Uralian type. He notes the close similarity between the dunites of the two regions and that the Tulameen pyroxenite is really a koswite, very similar to typical Uralian koswite. True pyroxenite is rare in Tulameen and occurs only as dykes or as a marginal phase of magnetite diallagite. The following table shows the composition of typical dunite and koswite from Tulameen district. The analyses are given by Camsell (1913) from specimens taken from Olivine Mountain.

TABLE XIII

Analyses of Dunite and Koswite, Tulameen District, B.C.

—	Dunite	Koswite
SiO_2	33·48	37·33
TiO_2	....	1·66
Al_2O_3	1·50	7·27
Fe_2O_3	7·27	13·41
FeO	1·36	9·24
MnO	0·06	0·07
CaO	0·02	16·50
MgO	42·02	12·27
K_2O ($+Na_2O$)	0·29	....
Na_2O	....	0·45
H_2O	13·86	1·13
	99·86	99·63

Lode Deposits

In Peridotite and Pyroxenite. In the careful investigation made by Prof. Kemp as to the general distribution of the platinum, he concluded, from a consideration of the location of the placers, the association of minerals in the platinum nuggets, and from chemical analyses of the rocks themselves, that the source of the platinum must have been the peridotite and pyroxenite.

In testing for platinum, his best results were obtained from the peridotite, or from the pyroxenite dykes in the peridotite, and particularly where alteration had taken place to serpentine, or where the rock was rich in chromite. Assays of serpentine veins in peridotite yielded platinum from a trace up to nearly 2 ounces to the ton, but it was found that the distribution of the platinum in these veins was not sufficiently uniform to justify exploitation. Masses of chromite also gave good results, which varied from nothing up to half an ounce a ton, but again the high assays were found to be too scattered to pay for mining. No platinum could be discerned in the rock itself or in concentrates obtained from it after crushing and panning, so that Kemp concluded that the platinum is in very fine scales and that large nuggets are exceedingly rare.

Camsell, however, reports (1913, page 154).

"A sample of chromite from a mineral claim owned by T. Lee, on the northwest slope of Olivine Mountain, was examined by Mr. R. A. A. Johnston, of the Survey, and found to contain . . . platinum in an amount approximating 2 ounces to the ton of rock. When examined under the microscope, the platinum was seen to be in thin, roughened scales or small sponge-like masses of silver-white colour. No crystalline form was apparent, but on the other hand the edges of the grains were very irregular and their projecting points rounded. The general appearance and form were often similar to the native silver of the Cobalt region. In this case, again, the distribution of the platinum was uneven, for no results were obtained from analyses of other parts of the same hand-specimen."

Conclusion. Because of the very uneven distribution of the platinum in the general body of the stock, it is considered improbable that any selected portion of the peridotite or pyroxenite will be found to carry enough of the metal to pay for mining. Any general test of these rocks would probably prove disappointing.

There is, of course, always the possibility that a concentration of platinum may have taken place locally under special conditions, with formation of a body of ore which could be mined profitably. It was with this in mind that Kemp particularly tested all the unusual phases of the rocks which he came across in the district; but although he obtained high platinum assays from some of these, there was never enough of the material to make profitable mining possible. Kemp secured high assays in concentrations of chromite, in pyroxenite dykes cutting the peridotite, and even in a sheer zone of the granite. If there are workable bodies of platinum ore in Tulameen district they may be expected in occurrences such as these.

Replacement and Vein Deposits (associated with chalcopyrite). There are two localities in Tulameen district from which platinum has been reported associated with chalcopyrite. The first is known as Law's Camp, and the second is on Newton Creek.

Camsell (1913, page 163) reported that the deposits in Law's Camp are replacements of limestones of the Tulameen series. They consist of pyrrhotite, chalcopyrite, pyrite, and sometimes sphalerite, usually in a gangue of calcite, and carry values in gold and silver. The deposits are genetically related to the Eagle granodiorite, which intrudes the Tulameen series to the west of the camp.

Mr. C. D. Law, manager of the St. Lawrence-St. George group in Law's Camp, reports (personal communication, 1919) that a trial carload of the ore, shipped in 1916, gave a return of $42 a ton in total gold, copper, and silver. A selected sample sent to Baker Bros., Newark, N.J., assayed: platinum, 4 ounces a ton; gold, 10 ounces a ton; silver, 96 ounces a ton; copper, 2 per cent. A second sample gave no platinum.

On Newton Creek, the property from which platinum is reported was owned by Mr. J. D. Thynn. According to Mr. C. D. Law, the mineralization is in a greenstone dyke some 60 feet in width, of which only about one foot is mineralized. Copper sulphide occurs in thin seams in the dyke, and an analysis gave one-quarter of an ounce of platinum to the ton of sulphide; but where the sulphide was absent there was no platinum, and the seams were so small and scattered that they were not considered to be economically important.

Deposits in Shear Zones in Granite. Owing to rumours that platinum had been discovered in former years in the gravels near the mouth of Siwash Creek, which enters the Tulameen about 3 miles above Eagle Creek, Kemp examined the rocks through which Siwash Creek flows, and found that the bedrock is everywhere granite, or, more properly, granodiorite, according to Camsell. This rock is traversed in several places by shear zones, and here it is considerably decomposed.

Samples of the sheared and altered rock gave assays from a trace up to 0·125 ounce of platinum a ton of rock. The granodiorite is stained green by chlorite, but there are no metallic minerals in the shear zones, so far as observed.

Kemp did not have analyses made of the unaltered granodiorite, so he was not sure whether the platinum was an original constituent of the rock or had been introduced at the time of, or later than, the shearing.

General Conclusion

From the foregoing account of the modes of occurrence of platinum in situ in Tulameen district, it would appear that this metal accompanied the three different intrusions that followed the Boulder granite during the Jurassic period. As regards the platinum disseminated in the parent rock, it has been pointed out that there is no great probability of workable deposits of this type being found, except perhaps in dykes; but there are chances of finding concentrations of the platinum, either in contact metamorphic deposits near the borders of these intrusives, or in veins or replacements in the intrusives, or, and more probably, in the older Tulameen series. Such deposits would be likely to be accompanied by sulphides, particularly of copper.

Placers

Tulameen River is the north fork of Similkameen River and flows east, making a broad bow to the north (*See* Figure 9). At the town of Princeton, 10 miles southeast of Tulameen Village, it unites with the South Fork that heads across the border in Washington and flows almost due north. Platinum has been found on both those branches and in Similkameen River, below the forks. Below Princeton it has been found in small particles with scaly or fine gold, but the production from this source has been very small. Nevertheless, a test made by Canada Copper Corporation on a bench about 15 feet above the river, just below Princeton, is reported to have yielded 30 cents in platinum and 90 cents in gold a cubic yard of gravels (1918 prices).

On the South Fork, above Princeton, fairly coarse gold has been washed from the gravels for a distance of over 30 miles. Patinum occurs with the gold and has been noted principally at workings 3½ miles above the forks (Dawson, 1877-78, page 156), and on Whipsaw Creek, a tributary from the west (Dawson 1887-88, page 62), which rises near the head of Granite Creek. A considerable amount of gravel, which will no doubt be worked at some future time for its content of gold and platinum, remains in this district. Up to date, no serious effort has been made to work the gravels on the large scale they demand if they are to return a reasonable profit.

Tulameen River, with its tributaries, was at one time the chief source of placer platinum in North America and is still the most important source in Canada. The official production is shown in the following table (Camsell, 1913, page 143), but it is generally conceded that, for the years covered and including preceding years when no official record was kept, total production of platinum for the district more nearly approaches 20,000 ounces than 10,000.

TABLE XIV

Platinum Production (official) Tulameen District, B.C., 1885-1909

Year	Gold	Platinum	
	Value	Value	Ounces
	$	$	
1885	114,000		
1886	193,000		
1887	118,000	5,600	2,000
1888	89,000	6,000	1,500
1889	31,800	3,500	1,000
1890	17,700	4,500	1,100
1891	17,800	10,000	2,000
1892	16,750	3,500	500
1893	9,550	1,800	257
1894	5,630	950	160
1895	41,650	3,800	633
1896	9,000	750	125
1897	23,500	1,600	266
1898	7,560	1,500	100
1899	6,600	825	137
1900	4,800	....	....
1901	4,680	457	22
1902	2,700	190	10
1903	2,000	....	....
1904	2,500	420	20
1905	1,140	500	30
1906	2,500	....	....
1907	1,000	....	....
1908	1,000	....	....
1909	1,000	....	....
Totals	724,860	45,892	9,860

Since 1918 the production of platinum has been as follows, according to the Annual Reports of the British Columbia Minister of Mines.

TABLE XV

Platinum Production, Tulameen District, B.C., 1919-1932

	$		$
1919	About 1,500	1926	4,258
1920	400	1927	960
1921	About 100	1928	2,743
1922	About 100	1929	1,699
1923	100	1930	771
1924	2,100	1931	1,783
1925	1,000	1932	2,332

Platinum has been found in gravels in Tulameen River at intervals from Princeton to Champion Creek, a distance of about 25 miles as the stream flows, but mining has been carried on at only three places: near Princeton, about 2 miles below the mouth of Granite Creek, and between Slate and Champion Creeks. The reason that the intermediate stretches have not been productive is, probably, that the miners could only handle shallow gravels and so those places where bedrock was deeply buried were not touched. Most of the coarse platinum was found between the mouths of Slate and Eagle Creeks. In addition, practically all the tributaries between and including Granite Creek and Champion Creek produced gold and platinum, but Granite Creek and Slate Creek were most important and contained much of the coarse platinum.

Above Slate Creek, the Tulameen flows in a narrow, post-glacial, rock-walled canyon about 300 feet deep and for over 3 miles has cut its bed in peridotite and pyroxenite. The productive gravels lie either in the stream bed or on benches either in or above the level of the canyon. They are not of great extent but rest directly on bedrock and constitute some of the best-paying ground in the whole district. They carry both gold and platinum. The proportion of platinum to gold is greater than in other localities and increases upstream; below the mouth of Eagle Creek it was found in greater quantity than gold.

Below Slate Creek the Tulameen flows in a broad, gravel-filled valley. Above Tulameen Village, for about 3 miles, to Slate Creek, the valley averages about 700 feet in width and the gravels on low benches and in the river-bed are from 10 to 100 feet deep. It has been estimated that there are about 14,000,000 cubic yards of gravels in this stretch, and drilling carried out by the Munition Resources Commission (Mackenzie, 1920, page 154) in 1918 gave promising results, but unfortunately was stopped before the systematic test planned could be carried to a satisfactory conclusion. Large areas of similar low-lying gravels occur down to Princeton and they undoubtedly also contain some gold and platinum, but have never been systematically tested. All the alluvial deposits from Slate Creek to Princeton are considered suitable for dredging operations.

Granite Creek flows in a narrow canyon most of the way. The compact, clayey gravels, resting on bedrock, from the mouth to Newton Creek, have yielded considerable gold and platinum, in a ratio varying from 4 of gold to 1 of platinum to equal parts of each. Above Newton Creek the gravels are more deeply buried and have not been exploited to any important extent.

In Slate Creek the most productive gravels were above the falls near the mouth. They lay in the stream bed and yielded well in the early years.

In recent years a number of attempts have been made to develop large-scale operations on Tulameen or Similkameen Rivers, but none has yet been commercially successful. What small production there is comes principally from the workings of individuals or other small operations. Occasionally small, rich pockets are still encountered in the present stream beds.

Character and Distribution of the Platinum. Camsell (1913, page 136) states that the platinum is in small grains or pellets that vary in diameter from 1 to 4 millimetres, more rarely in small nuggets that do not exceed one-half ounce in weight. The grains are generally rounded and not flattened or angular like the associated gold. The surface is usually pitted with rounded cavities that are in many cases lined with chromite or other foreign matter. Kemp found olivine and one piece of pyroxene adhering to placer platinum. Gold occurs with it, in some cases apparently alloyed, in others merely welded upon it. The heavy minerals associated with platinum in concentrates are magnetite, chromite, and native copper.

All the platinum can be separated into magnetic and non-magnetic parts, the non-magnetic being more abundant. According to Camsell the magnetic part was found to consist of grains of platinum loosely covered with small particles of a black, metallic mineral, probably magnetite. A sample from Granite Creek was analysed by G. C. Hoffmann (1886). It contained 17·894 grains of platinum with a specific gravity of 16·686. The platinum was separated into a magnetic portion and a non-magnetic portion, the former constituting 37·88 per cent of the whole. These two parts were analysed and the composition of the whole calculated from them as follows:

TABLE XVI

Analysis of Platinum from Tulameen River

—	Magnetic	Non-magnetic	Total
Platinum	78·43	68·19	72·07
Palladium	0·09	0·26	0·19
Rhodium	1·70	3·10	2·57
Iridium	1·04	1·21	1·14
Copper	3·89	3·09	3·39
Iron	9·78	7·87	8·59
Iridosmine	3·77	14·62	10·51
Embedded chromite	1·27	1·95	1·69
	99·97	100·29	100·15

Non-magnetic, sp. gr. 17·017; magnetic, sp. gr. 16·095.

Hoffmann noted the presence of minute, thin, shining, steel-grey plates of osmiridium in each portion and that some of the platinum grains consisted in part of chromite. It is to be noted, however, that the percentage of chromite was higher in the non-magnetic than in the magnetic portion. Since the percentage of iron was higher in the magnetic, it might be inferred that there was some magnetite contained in the grains as well as chromite. It has been noted by Kemp that the iron in platinum tends to decrease regularly with the increase in percentage of platinum, but in the analysis cited the opposite is the case, which fact would also point to some of the iron being present in some form other than as an alloy with platinum.

In 1930, 13·43 ounces of platinum concentrate obtained from a lease on Tulameen River below Coalmont was shipped to Johnson, Matthey, and Company, Limited, 73-82 Hatton Garden, London, E.C. 1, England; the following assay returns are taken from the Annual Report, Minister of Mines, B.C., 1930, page 212.

—	Per cent	Quantity, ozs.	Value
		$	$
Gold	0·58	0·078 at 19 40	1.51
Palladium	0·31	0·041 " 16 97	0.68
Platinum	68·74	9·231 " 35 16	324.58
Iridium	2·22	0·298 " 194 00	57.81
Rhodium	0·48	0·064 " 43 65	2.79
Insoluble platinum metals (osmiridium, etc.)	8·10	1·088 " 97 00	105.53
Total	80·43	10·800	492.90

Skagit River

One other river in the Similkameen has been reported to carry platinum, associated with gold, in its gravels. This is Skagit River, which rises near the head of Tulameen River, and whose tributary, Ninemile Creek, rises near the head of Granite Creek. Ninemile Creek is said to carry more or less platinum in association with coarse gold; so far as is known no production of platinum has been made from this creek, nor from the main river, but there is very little available information on the subject (Dawson, 1887-88, part R, page 127).

GREENWOOD MINING DIVISION

Rock Creek

Rock Creek lies east of Osoyoos Lake, in Greenwood mining division. It flows south and east, and enters Kettle River from the west at the town of Rock Creek.

Gold was discovered on the creek in 1859 or 1860, and the gravels in the narrow valley, and on some of the benches, paid very good wages. In 1861 there were three hundred miners at work on the creek, and mining continued to be more or less active for more than thirty years.

At the mouth of the creek, a large quantity of gravel has been deposited where the valley widens, and this was all thoroughly worked over, chiefly by Chinese. Desultory work among large boulders, which obstruct the channel, was carried on for many miles up the creek in the early years, and there was much activity about 10 miles upstream, near Camp McKinney.

A sample of heavy, black sand taken from the riffles of sluice boxes at Camp McKinney was examined in 1893 by R. A. A. Johnston, of the Geological Survey, and was found to have the following composition:

	Per cent
Native platinum	44·7
Gold	1·8
Magnetite	47·4
Quartzose sand	6·1
	100·0

"The platinum was in the form of exceedingly minute to moderately coarse, irregular-shaped grains, the largest of which measured 4 millimetres in diameter. Of the above 44·7 per cent platinum found in this material, 5·4 per cent was strongly magnetic, 15·7 per cent but feebly magnetic, and the remaining 23·6 per cent non-magnetic. No free osmiridium was observed; on dissolving a portion of the platinum, however, there remained numerous, minute, thin, shining, steel-grey coloured scales of this alloy. The gold occurred in small, very irregular-shaped grains, the largest not exceeding 2 to 2½ millimetres in diameter. The associated sand consisted of very fine grains of ash-grey coloured quartz, with a few intermixed grains of light reddish coloured garnet, and an occasional grain of pyrite. A little chromite was detected in one of the pellets of platinum, and on another occasion very small quantities of a white, feldspathic rock was observed under similar conditions" (Hoffmann, 1892-93).

Pannings of the placer sands on Rock Creek were made by Wm. Thomlinson for the Munitions Resources Commission in 1918, at the following places:

(1) Jas. Copland's placer ground on the south fork of Rock Creek.
(2) Old placer workings above the irrigation dam, about one mile from the mouth of the creek.
(3) Old placer workings below the irrigation dam, about 500 yards from the mouth of the creek.

The Dominion Assay Office reported that these pannings contained no platinum.

GRAND FORKS MINING DIVISION

When it was demonstrated that platinum occurs in several of the lode deposits in Franklin district, Mr. Wm. Thomlinson took pannings of the gravels near the mouth of Franklin Creek, from McDonald Creek, a branch of the Franklin, and from the north fork of Kettle River. These pannings were assayed with the following results:

—	Gold, oz. a ton	Platinum, oz. a ton
From near mouth of Franklin Creek	0·32	0·03
From McDonald Creek	Nil	0·09
From west branch of north fork of Kettle River	Trace	0·06

There is no information available as to the amount of gravel, or the possibility of better values in the gravels, in this district.

OSOYOOS MINING DIVISION

Shuttleworth Creek

Camsell reported on this locality as follows (1918, page 30):

"In November a trip was made to Shuttleworth Creek, which enters Okanagan Valley at Okanagan Falls, where the geology suggests the possibility of platinum occurring in the gravels. The rocks are Precambrian gneisses associated with bodies of amphibolite and serpentine.

"J. Hislop and G. Maynard have done some prospecting of the gravels of the creek and have obtained some evidence of the presence of platinum, but not as yet in commercial quantities."

LARDEAU MINING DIVISION

The gravels of Lardeau River have long been known to contain small amounts of platinum. In 1918 they were tested by Wm. Thomlinson (1920, pages 170-173). Material panned from five points, about one mile apart, in the main river above the North Fork assayed from 0·24 to 0·44 ounce gold and from 0·01 to 0·16 ounce platinum a ton. Panning concentrates from two points in the North Fork ran 0·36 to 2·80 ounces gold and 0·11 and 0·03 ounce platinum a ton; 0·29 ounce of gold and 0·17 ounce of platinum a ton were obtained from pannings of gravel near the mouth of the canyon just above Trout Lake City. Fivemile Creek on Trout Lake, and Canyon Creek at Gerrard, were similarly tested, the assays in platinum a ton of pannings being 0·09 and 0·02 respectively. Two samples of pannings from near an old dredge at Gold Hill, on Lardeau River below Poplar Creek, assayed 0·27 and 0·08 ounce gold and 0·04 and 0·02 ounce platinum a ton.

REVELSTOKE MINING DIVISION

Isaac Creek

Wm. Thomlinson (1920, page 174) examined the gravels of this creek for about 2 miles above the falls. Three samples of panning concentrates assayed 0·04, 0·02, and nil ounce of platinum a ton. The stream flows from the east into Columbia River about 12 miles north of Arrowhead.

VANCOUVER MINING DIVISION

Potato Creek, Jervis Inlet

Placer claims on this stream were tested for platinum by panning in 1918 (Thomlinson, 1920, pages 180-182). Twenty samples of panning concentrates, principally from gravel bars along the main channel of the stream but including some from pits in benches or old channels, were assayed. Sixteen contained a trace, or no platinum, and four varied between 0·02 and 0·17 ounce a ton of concentrates.

CLAYOQUOT MINING DIVISION

Wreck Bay

Two samples of auriferous black sand taken by V. Dolmage, in 1919, from the sea beach at this locality on the west coast of Vancouver Island assayed 0·05 and 0·03 ounce of metals of the platinum group per ton of sand.

FRASER RIVER PLACERS

Platinum is known to occur in the gravels of Fraser River from 15 miles above the mouth of Quesnel River all the way down to Hope, a distance of over 270 miles; but there has not been any reported production from this source. Black sand concentrates from various places along the river have been assayed with results as follows. Figures are in ounces per ton except for the first sample, from Quesnel mouth, which is given in percentages.

TABLE XVII

Assays of Black Sand Concentrates from Fraser River

Locality	Gold	Silver	Platinum	Osmiridium
Quesnel mouth[1] (Q.M.)	7·1%	....	71·0%	3·1%
15 miles above Quesnel mouth[1]	121·8	....	3·9	....
3 miles above Quesnel mouth[1]	0·85	....	0·25	3·2
2 miles above Quesnel mouth[1]	....	....	2·4	....
Lytton[1] (Cobledick dredge)	913·0	....	165·7	....
Opposite Saddle Rock Station,[2] near Yale	2·30	....	0·14	....
Near Yale[3], average of 6 samples of 5 assay tons each	1·92	0·34%	0·40	....

[1]B.C. Bureau of Mines, Ann. Rept., 1902, pt. H, p. 64.
[2]Received at Dom. Assay Office, Vancouver, 1918.
[3]Report by R. D. McLellan.

In addition to the above, there are other places from which platinum has been reported, although specific analyses of the sands are not given. Among these are the following:

A few miles below Quesnel mouth.
Above and below Lillooet.
At Boston Bar, North Bend, etc.
Near Hope.

In connexion with platinum on the Fraser, mention should be made of the platinum placers on its tributaries, which have received separate notice; these are on Government Creek, and on Quesnel River with its tributaries.

Except for the above analyses and location of occurrences, very little is known of the extent or value of the platinum placers of Fraser River. Dredging operations for gold have been undertaken at several points, and any platinum obtained was regarded more as a curiosity than as a mineral of value; so much was this the case that during the summer of 1917 more than half an ounce ($53 worth) of platinum was obtained from cleaning up the concentrating tables of the old dredge at Lillooet, which had lain idle there for some years. The locality is 4 to 5 miles below Lillooet on the east side of the river. The platinum was in fair-sized flakes, and Dawson (1887-88, part R, page 156) reports the occurrence of the metal in very fine scales, with gold, about 10 miles below Lillooet.

Near Lytton, where Thompson River flows into the Fraser, a dredge was in operation for a number of years, first for the Cobledick Company, and later for the Fraser River Gold Dredging Company. A good account of the design of this dredge, and of the work accomplished by it, is given by the Provincial Mineralogist for British Columbia in his annual report for 1902, part H, page 104. Although good values in gold were reported by the Cobledick Company from the gravels being dredged, recoveries were very poor. They are stated not to have been more than about 10 per cent of the gold in the gravels handled.

Another dredge was operated for three years at Boston Bar, about 28·5 miles below Lytton, under the management of Mr. L. R. Symes. A little platinum was recovered from the concentrates, but no special effort was made to save this metal. One of the owners, Mr. A. O. Beatty of Welland, Ontario, stated that the dredge paid well the first year because the water was very low in the river, but that during the next two years the dredge could not get deep enough to reach the good pay-gravels.

In 1918 the Cariboo Gold Platinum Extracting Company was organized to engage in the extraction of gold and platinum values from the black sand occurring in placer gravels of Quesnel district. The company intended to treat sand from its own leases on Quesnel and Fraser Rivers and sands from other operations on a custom basis. Some equipment was purchased and a certain amount of experimenting done, partly in a small plant erected at Quesnel, but in 1926 lack of funds forced the company to dissolve.

Lode Deposits

QUEEN CHARLOTTE MINING DIVISION

Moresby Island

It is reported (B.C., 1921, page 39; 1923, page 43) that an immense deposit of low-grade copper ore, consisting of small veinlets and disseminations of chalcopyrite and bornite in diabase on the Swede group, outside Lockeport Harbour on Moresby Island, carries low platinum values in the bornite. A sample of bornite is said to have assayed 3·1 per cent copper and 0·01 ounce platinum, a trace of palladium, 20 cents in gold, and 1 ounce silver a ton.

CLINTON MINING DIVISION

Scottie Creek

Two samples of chromite ore taken from dumps on the chromite deposit on Chrome Creek in 1918 assayed 0·10 and 0·02 ounce of platinum a ton (Thomlinson, 1920, page 177). These deposits have been described by Reinecke (1920, pages 86-91). The chromite occurs disseminated or as nodules, lenses, and tabular sheets in serpentine that outcrops on the claims over an area of about 50 acres. Magnetite is present. The chromite is believed to have formed by segregation in the original basic intrusive that is now altered to serpentine. In 1929 the property was bonded by Consolidated Mining and Smelting Company and 126 tons of ore was shipped to Trail for testing. Development continued in 1930 and 1931 (B.C., 1929, 1930, 1931). The final results of the exploration have not as yet been published and no mention of platinum is made in the recent reports.

KAMLOOPS MINING DIVISION

The Fortuna mining claim, situated on Louis Creek, and belonging to the Fraser River Mining Company, has several times been reported to contain platiniferous ore. High assays in platinum have been claimed and have been given considerable publicity; the Worsey Mining Company, of Republic, Wash., was said to have taken an option on 100,000 tons of the ore.

A sample (weighing 2½ pounds) of the ore was sent by the manager of the property to the Mines Branch, Ottawa, in 1918, and an assay of this gave neither gold nor platinum.

A personal communication from the Worsey Mining Company, in answer to a request for information concerning their results with ore from this property, stated that their results were unfavourable and that they could detect no platinum in the ore shipped to them.

Certain deposits on Mount Ida, about 3 miles southeast of Salmon Arm, were tested for platinum in 1918 (Ferrier, 1920). Two samples were taken from a quartz vein, mineralized sparingly with sphalerite, galena, and pyrite, exposed in a short drift. One sample, taken for 10 feet along the tunnel wall, assayed 0·03 ounce platinum a ton and the second, of sulphides, contained no platinum. Samples of similar material from the Mountain View claim, across widths of 8·5 and 2·5 feet, respectively, assayed 0·20 and 0·02 ounce platinum. Two other samples from a wide shear zone mineralized with quartz stringers carrying sphalerite, galena, chalcopyrite, and pyrite assayed 0·02 and 0·03 ounce of platinum a ton. All the samples contained gold, in amounts varying from 0·08 to 0·38 ounce a ton.

SIMILKAMEEN MINING DIVISION

Occurrences of platinum in lode deposits in Tulameen district are described on pages 89 to 94.

Copper Mountain

Jules Catharinet (1905) mentions reports of platinum assays from Copper Mountain and claims to have identified sperrylite in a pegmatite on the Copper Cliff claim. Minute crystals and grains are said to have been observed in biotite in a thin section and in bornite and chalcopyrite microscopically. The pegmatite contained bornite and chalcopyrite as well as orthoclase, oligoclase, tourmaline, fluorite, and other minerals, and carried some native gold. Dolmage, however, who has studied Copper Mountain in considerable detail reports (personal communication, 1933) that he has seen no sperrylite.

OSOYOOS MINING DIVISION

Nickel Plate Mine, Hedley

Camsell (1910, page 137) states that he was informed that in a monthly clean up at the Nickel Plate stamp mill an unusual deposit was noticed on one of the plates, close to the lip of the mortar. A sample of it, about one pound in weight, was analysed and reported to yield about 0·5 per cent platinum. It was suspected that the platinum occurred as sperrylite.

GREENWOOD MINING DIVISION

Sappho Property

This property is close to the International Boundary about 2½ miles east of Midway. It was worked from 1916 to 1918 and 112 tons of ore, shipped to the Greenwood smelter, carried 197 ounces of silver and 13,580 pounds of copper. The bead gave distinct indication of the presence of platinum, but no quantitative assay was made. In 1927 (B.C., 1927, page 234; 1928, page 250) a crosscut adit was started towards the bottom of the old workings and in 1928 it was completed and about 10 tons of ore was extracted. The above report states that the rock formations consist chiefly of argillites intruded by diorite, pyroxenite, and later alkali-syenite-porphyry dykes and that a sample of chalcopyrite ore from near the pyroxenite assayed 3·2 per cent copper and 0·03 ounce of platinum a ton.

GRAND FORKS MINING DIVISION

Mother Lode Claim

In a preliminary report on Boundary Creek district, B.C., R. W. Brock (1906, pages 131-132) considered that the chances of finding platinum in this and neighbouring districts were very good. His reasons included the widespread occurrence of basic eruptive rocks, largely altered to serpentine, and the similarity in geologic conditions there and in Similkameen district. He recorded that samples of a gold-bearing quartz vein from the Mother Lode claim, in Burnt Basin, were assayed by Baker and Company of Newark, New Jersey, and yielded from traces to 0·25 ounce of platinum a ton. Assays varying from traces to 0·1 ounce a ton were obtained by the Geological Survey, from other samples of the ore. The quartz carried free gold, near the surface at least, chalcopyrite, pyrite, galena, zinc blende, and molybdenite, and occurred in a dark schistose rock, probably altered porphyrite, cut by syenite porphyry dykes and a basic syenite or gabbroic rock.

The Annual Report of the B.C. Department of Mines for 1917, page 201, states that the veins vary in width from 1 foot to 2 feet 2 inches and that tests of the ore showed platinum values that varied from nil to 0·75 ounce a ton.

Samples taken for the Canadian Munitions Resources Commission gave no trace of platinum, so it is quite evident that the distribution is not uniform in the vein. It is suggested that the platinum is closely associated with one particular sulphide and that its presence or absence depends on the presence or absence of that particular associate; for example, the platinum in the Maple Leaf claim at Franklin Camp is closely associated with chalcopyrite.

FRANKLIN MINING CAMP

In 1915, a shipment of 23 tons of copper ore from the Maple Leaf property to the Grand Forks smelter was found to assay 0·26 ounce of platinum to the ton, and a further shipment of 17 tons in 1916 assayed 0·20 ounce platinum a ton. These relatively high values immediately drew attention to the property, and several engineers examined it. The highest assay obtained as the result of this work was 0·40 ounce of platinum to the ton of ore. The general tenor of the ore may be seen from the assays of the two shipments referred to above:

—	March, 1915 23 tons	October, 1916 17 tons
Platinum	0·26 oz. a ton	0·20 oz. a ton
Gold	0·02 "	0·13 "
Silver	6·7 "	2·6 "
Copper	9·6 per cent	5·6 per cent
Iron	9·5 "	6·8 "
Lime	0·7 "	0·4 "
Sulphur	7·7 "	4·8 "
Insoluble	66·0 "	74·6 "

In 1918, this property was visited by the writer and it was finally concluded that the platinum was associated closely with the chalcopyrite. Very little development has been done on the property and practically all the high-grade ore opened up so far has been mined and shipped.

According to Drysdale (1915, page 174) this deposit is of the contact-metamorphic type, and occurs in impure quartzite and greenstone near their contact with an intrusive of augite syenite; the marginal facies of this syenite is a shonkinite-pyroxenite, a coarsely crystalline, dark-coloured rock locally known as the " black lead."

There are several other mining claims located on the borders of the " black lead " in this district. The ore is chalcopyrite, pyrite, and a little bornite, and Drysdale considered them to be magmatic segregations in the shonkinite-pyroxenite. From assays made by the Dominion Assay Office, Vancouver, of samples collected by Wm. Thomlinson, it appears that practically all of these deposits carry appreciable values in platinum. The following are results of some of the assays: (Thomlinson, 1920, pages 161-166).

Mining claim and location of sample	Gold, oz. a ton	Platinum metals, oz. a ton
Lucky Jack, from tunnel at west end	Trace	0·08
Lucky Jack, lens in shaft above tunnel	0·04	0·04
Lucky Jack, open-cut near east end of claim	0·04	0·06
Mountain Lion, solid ore from open-cuts	Trace	0·09
Mountain Lion, oxidized ore from small shaft	0·02	0·02
Golden Age, oxidized ore from small shaft, south end	Trace	0·06
Averill group, tunnel near cabin	Trace	0·09
Averill group, upper shaft	Trace	0·09
Buffalo, old shaft near and below trail	Trace	0·19
Buffalo, open-cut in small ravine below trail	Trace	0·08
Ottawa, open-cut above cabin	Trace	0·06
Columbia, tunnels north of cabin	Nil	0·04

All the properties in the above list are in the prospect stage. The only property of those mentioned above about which information is available is the Buffalo. At the smelter at Grand Forks it was learned that a series of eight samples had been taken from the Buffalo property and that three of the eight showed copper and the one highest in copper gave values in platinum. The result of this assay was: copper, 2·2 per cent; gold, trace; platinum, 0·14 ounce a ton.

In the 1922 Annual Report of the B.C. Minister of Mines it is reported on page 169 that ore carrying values in copper, gold, and platinum occurs in small segregations throughout pyroxenite on the Don claim.

Granby River Section

There are large areas of highly altered talcose rocks in this section that may be derived from an original basic rock (B.C., 1923, page 180). Mineralization includes copper ore and occasional specks and lenses of chromite in serpentine; platinum is reported to be present in some cases.

Near Cascade

A number of properties near Cascade have been taken up for chromite, and a sampling of these shows that the ore on most of them contains traces of platinum, one assay showing as much as 0·15 ounce of platinum a ton of ore.

From what little is known of these deposits it would appear that they are located in small intrusives of serpentinized dunite, which Daly (1912, page 334) mentions as cutting through the Rossland volcanic formation just east of Cascade.

Samples of the ore taken by Wm. Thomlinson (1920, page 166) for the Munition Resources Commission in 1918, and assayed at the Dominion Assay Office at Vancouver, gave the following results, in ounces a ton.

Mastodon Group

Soft vein matter with serpentine showing some chromite. General sample from several open-cuts gave: Au, 0·01; Pt, trace. Soft altered rock from line of open-cuts where chromite was being mined for shipment: Au, 0·05; Pt, trace.

Cerargyrite M.C.

Serpentine rock-matter from chromite deposit: Au, trace; Pt, trace.

Midnight M.C.

General sample of chromite in fine green serpentine; north showing, open-cut: Au, trace; Pt, 0·15.

Blacktail M.C.

General sample of chromite from main open-cut: Au, 0·02; Pt, 0·02.

Blacktail Fr. M.C.

Soft, oxidized matter and serpentine from the north open-cut: Au, trace; Pt, trace.

The Mastodon group is the only one of the above properties that has shipped, so far as known. It was under lease to the Stewart-Calvert Company, of Oroville, Wash., and to the end of 1918 had produced 800 tons of ore carrying 30 to 45 per cent chromic oxide. "The ore-bodies, lying in small lenses, made development work difficult and expensive" (B.C. Bull. No. 1, 1919, page 40).

The Midnight claim is owned by H. W. Phillips, of Cascade, and has been developed by a few open-cuts.

Fife Mines

This property is about 3 miles from Cascade; no particulars are available. A general sample of the shipping ore, which is said to be copper-gold ore, was taken by Mr. Thomlinson, and gave: gold, 0·12 ounce a ton; platinum, trace.

FORT STEELE MINING DIVISION

Palladium, with a little platinum, is one of the metals recovered as by-products of refining at the Trail plant of the Consolidated Mining and Smelting Company of Canada, Limited, so these metals are presumably present in very minute amount in the lead-zinc ore of the Sullivan mine. Recoveries during 1928 were: palladium, $22,270; platinum, $1,730; 1929: palladium, $6,836; platinum, $1,129; 1930: palladium, $1,356; platinum, $318; 1931: nil; 1932: nil.

AINSWORTH MINING DIVISION

Cable Mining Claim

The ore on this mining claim, situated at the head of Woodbury Creek, is said to carry some platinum. This claim has been practically idle for the last twenty years, although a little development work was done on it in 1906.

The deposit is said to be in a quartz vein in granodiorite or granite, and the mineralization to consist of pyrite carrying a trace of gold, about 6 ounces of silver to the ton, and some platinum. A sample assayed at the Mines Branch, Department of Mines, in 1896, gave: gold, trace; silver, 6·008 ounces a ton.

A sample sent to the Dominion Assay office, Vancouver, in 1918, gave: gold, trace; platinum, 0·07 ounce a ton.

There is no other information available as to the extent or character of the mineralization at this place.

Nome Claim

Samples sent to the Dominion Assay office in Vancouver in 1918 by A. J. Curle of Kaslo and said to come from this claim on the south fork of Kaslo River yielded traces of platinum. Later in the same year Mr. Thomlinson (1920, page 169) was taken by Mr. Curle to visit the occurrence from which the above samples were taken. He was guided to a slide on the south fork of Kaslo River, 1 mile below the Index mine, and nearly 2 miles from the Nome claim. There he took two samples of fragments, in the slide, of a feldspathic white to pink rock resembling quartzite. This rock contained specks and small masses of a hard, dark-coloured mineral. The samples assayed 0·04 and 0·06 ounce gold and 0·08 and 0·05 ounce platinum.

Mineral Dyke Property

In 1929 it was reported (B.C., 1929, page 325; 1930, page 254) that surface showings of pyrite and chalcopyrite in a decomposed dyke or sill on this property southeast of Walker Landing on Kootenay Lake contained appreciable values in platinum and palladium. Consolidated Mining and Smelting Company acquired an option but dropped it in 1930.

YUKON[1]

Platinum has been reported from Yukon a number of times and the localities where the discoveries were made are widely separated. The earliest record (Dawson, 1887-88, part R, page 156) states that platinum was found on the Yukon in small scales with river bar gold and on nearly all the important tributaries that had been worked; but there is no record of any production. In the same report Stewart River is mentioned as one of the localities where platinum had been found. Placer operations in the river between 1885 and 1887 produced about $100,000 in gold, but no mention is made of platinum recovery.

In 1903 (B.C., 1903, pt. H, page 23) it was reported that a small sample of gold from near Dawson was tested by the British Columbia Assay office and yielded 390 milligrams of osmiridium an ounce of gold, and 1905 (B.C., 1905, part J, page 30) experiments at the same office showed that "A number of samples of gold from different localities in the Yukon and Cassiar have been refined in this laboratory, and in almost every case platinum and allied metals have been separated to an amount which has a commercial significance. This platinum appears to be directly combined with the gold and is not visible as a separate mineral in the gold dust, and for this reason, in the ordinary melting down and refining of such gold dust at the mint, is apt to have been overlooked."

Platinum has been reported a number of times from Teslin (Hootalinqua) River, but definite figures as to the content of the gravels are hard to obtain. In 1906 (Anon., 1906) it was stated that black sand from the Teslin was treated by the U.S. Geological Survey's plant at the Portland Exhibition in 1905, the opinion being that the platinum, although exceedingly fine, was capable of recovery by Wilfley, Pinder, or Christiansen tables. Dr. Day saved platinum worth 60 cents from about 10 ounces of black sand taken at random from a gold wash and a later test, on 15 ounces of black sand, recovered from 200 pounds of original gravel, yielded 0·7 gramme platinum and 0·023 gramme of osmiridium.

In 1907, however, G. L. Holmes (1907) challenged the statements made in this article, claiming that, after thoroughly prospecting the Teslin up to 90 miles from its mouth, his results showed the greatest amount of black sand to be recovered from 500 pounds of gravel to be 15 ounces. He had competent assayers examine his black sand and they could find no trace of platinum, iridium, osmium, or kindred metals. Nevertheless, the fact that platinum does occur on the Teslin was reaffirmed by Sime (Territorial Assay office, personal communication to W. E. Cockfield, 1918) who states, however, that the mineral occurs in an extremely fine state and is difficult to save.

During the years 1916 and 1917 a small amount of platinum was recovered from Ferguson Creek, a tributary of Kaskawulsh (O'Connor) River, but it cannot be stated if it is present in economic quantities.

In 1918, W. E. Cockfield examined Burwash Creek, in Kluane mining district, for platinum, and the remaining paragraphs of this section are taken from an unpublished manuscript he prepared the following winter.

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[1] Most of the information in this section was supplied by W. E. Cockfield in 1918.

" Burwash is a typical St. Elias stream, which heads in two small glaciers on the inner slopes of that range and empties into Kluane River about 6 miles below Kluane Lake. The length of the stream, measured along the valley, is 18 miles, and for the greater part of its course it crosses a high platform of glacial origin which fronts the St. Elias range. The creek is typical of the swift mountain streams, having a grade of 125 feet a mile in the central part of its course, and like other glacial streams the volume of water varies greatly from day to day.

" Into this high, upland tract, Burwash Creek has cut for itself a deep depression, which lies for the most part along the extreme edge of the plain, the creek being bordered on the left (looking downstream) by a mountain wall rising from 500 to 2,000 feet above its bed, and on the right by more gentle slopes, which rise gradually to unite with the plain. At some points the stream has become superimposed upon rock spurs projecting from the mountain to the left, and, as a result, canyons have been cut. There are two such canyons, one at the point where the stream breaks through into Kluane Valley and the other about 4 miles upstream from this.

" In the process of deepening its valley the channel of Burwash Creek has undergone many changes, as the creek has shifted continuously to the left, with the result that, along the right side of the valley, are a series of rock-cut channels containing stream gravels, which become gradually lower in elevation as the present stream is approached. These are most commonly covered with glacial and other superficial detrital accumulations, masking them and making them difficult to find; but they are nevertheless important from an economic standpoint, for in them the earlier concentrations of gold and platinum were accomplished, and such deposits as are found in the present stream are largely reconcentrates from these older channels. Several of these have been discovered and opened up, and important amounts of gold recovered from them.

" Tatamagouche Creek is the largest and most important tributary to Burwash Creek, joining it in the vicinity of claim No. 60 above discovery. This stream follows a fairly straight break in the mountains that border Burwash Creek on the left, and in the upper part of its course occupies a wide, open valley. Closer to Burwash, however, evidently as a result of the deepening of the valley of that creek, it forces its way through a narrow canyon, with rocky, precipitous walls.

" *Gravels.* The creek gravels on Burwash and Tatamagouche Creeks are generally quite coarse and usually only of relatively slight depth. They remain for the most part unfrozen, even in winter, as the frost zone does not generally extend to bedrock, thus making prospecting exceedingly difficult. The bench gravels are generally less coarse and vary greatly in depth. They are frozen at some localities and thawed at others.

" Burwash Creek, from a mining standpoint, is the most important of the whole Kluane district, producing more gold than all the others combined. Coarse gold has been found from about the mouth of the lower canyon upstream for a distance of about 8 miles, and the creek has been more or less thoroughly prospected as far up as claim No. 66 above discovery. Associated with the gold in the gravels are platinum, native silver, and native copper. Both the gold and platinum are well-worn and smooth, and usually flat. A large percentage of nuggets is obtained. The coarsest pieces of platinum obtained were about the size of duck shot, and from this there is every gradation in size down to the most minute colours. The native silver presents a pitted surface and is of a slightly different colour from the platinum and can usually be distinguished from it at a glance.

"At the time of the writer's visit, work had been largely suspended for the season and some of the miners had left the creek, so that it was impossible to obtain full and accurate data as to the content of all the gravels. Only three men were still on the creek and from them much information was obtained.

"On claims Nos. 27 and 29, Sam May was working. The depth to bedrock at this point varies from 6 to 9 feet, and the gravel is peculiar in being very fine. The paystreak averages about 150 feet wide and has an average content of about $3 a cubic yard in gold, taking the recovery over a season as the basis of this figure. The amount of platinum obtained by the writer was about 0·005 ounce an ounce of gold or about 0·001 ounce a cubic yard of gravel.

"On Tatamagouche Creek, J. O. Erickson is working in the canyon one-quarter mile above the mouth of the creek. The ground at this point is shallow, the depth ranging from 2 to 6 feet to bedrock, and the gravel is very coarse. The paystreak is very narrow and the distribution of the gold is pockety, but the content would probably average about $3.50 per cubic yard. From 2½ ounces of fine gold, platinum to the amount of 0·0025 ounce an ounce was separated by hand. The platinum content thus amounts to about 0·0005 ounce a cubic yard.

"On the bench situated on the right side of Burwash Creek an old channel has been tapped. Erickson has done a considerable amount of work here. Although no accurate figures as to the content of platinum can be given, it is stated that there is at least as much as appeared in the gold from claims Nos. 27 and 29.

"On Elevated Gulch, S. Frank is working the creek gravels. This gulch enters Burwash Creek in the vicinity of claim No. 120 above discovery. The gold obtained differs from that recovered lower down on Burwash in being quite rough and unworn. With the gold here is native silver, argentite, ruby silver, and pyrite, but no platinum.

Summary and Conclusions

"The gold on Burwash Creek is very irregularly distributed and appears to be largely a reconcentrate from the older rock-cut channels on the right limit of the creek. Prospecting work on the creek gravels above claim 66 will undoubtedly reveal pockets of auriferous gravels which will pay for mining; below claim 66, the content of the creek gravels is fairly well known. The older channels on the hillsides, however, carry pay which is much more uniformly distributed, as they represent relatively longer concentrations than do the creek gravels, and where opened up they have usually been mined with success.

"The platinum appears to be restricted to the central part of Burwash Creek, and although full data are not available to warrant a definite conclusion, it appears to be derived from a mass of serpentinized dunite outcropping some distance above the mouth of Tatamagouche Creek, as it has not been demonstrated that the creek contains platinum above this outcrop.

"The amount of platinum is small, and no great production is looked for; and, under the conditions obtaining at present, the production cannot exceed 1 or possibly 2 ounces a man in a season. Nevertheless it makes a valuable by-product from the gold mining. The coarser platinum can be separated by hand from the coarser gold dust, and the finer platinum can be saved during the amalgamation of the black sand, as it collects with the amalgam though not uniting with it. The black sand can then be disposed of by panning, and the amalgam containing the gold poured off, leaving the platinum as a residue.

"In conclusion it may be pointed out that the St. Elias Range, containing large areas of basic and ultra-basic rocks,[1] offers possibilities to the prospector in search of platinum. This mineral has been reported from Ferguson Creek, another St. Elias stream, and the report has been verified, but no data as to quantity can be given. The physical conditions of the region are, however, distinctly discouraging, as it forms a rugged, mountainous belt where climatic conditions are severe, and where the extent of placer deposits is always uncertain, owing to intense glaciation."

NORTHWEST TERRITORIES

RANKIN INLET, HUDSON BAY

The only authentic occurrence of platinum metals in Northwest Territories is on the south shore of Johnston Bay, an inlet on the north shore of Rankin Inlet on the east side of Hudson Bay. The deposit has been described by Drybrough (1931) and by Weeks (1931). Platinum and palladium are contained in sulphides disseminated in a sill of basic rock, possibly pyroxenite, 200 to 300 feet thick, that is intrusive between Precambrian sediments and volcanics and dips about 50 degrees to the south. Granite and gabbro intrusions are also present in the vicinity. The sulphides consist of pyrrhotite with minor amounts of chalcopyrite, pyrite, and pentlandite. The pyroxenite(?) is largely altered to serpentine and carbonate and contains some magnetite. Six diamond drill holes were made by drillers for the Cyril Knight Prospecting Company, Limited, in 1930. They indicated a lens of massive sulphide in the sill at or quite close to the foot-wall, overlain by a finely disseminated sulphide zone. The length of the lens is about 250 feet and the width, 8 feet of massive, plus about 18 feet of disseminated, ore, but the body has not been completely explored. A second disseminated sulphide zone, of lower grade than the above, was found some 40 feet to the south. Drybrough estimates that the block of the main lens developed by drill holes and surface work contains the following tonnage of possible ore.

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[1] For a description of topography and geology *See* McConnell, R. G.: Geol. Surv., Canada, Ann. Rept., vol. XVI, pt. A, pp. 1-10 (1905). Cairnes, D.D.: Geol. Surv., Canada, Sum. Rept. 1914, pp. 14-15. Geol. Surv., Canada, Mem. 67 (1914).

—	Tons	Cu, per cent	Ni, per cent	Pt, oz.
Massive sulphide	30,000	1·28	9·25	0·20
Disseminated sulphide	90,000	1·19	3·10	0·08
	120,000	1·22	4·62	0·11

The greatest depth at which ore was cut by drilling was about 200 feet vertically beneath the surface.

Drybrough notes that the evidence was insufficient to suggest a relationship of platinum, or palladium which is present in smaller amount than platinum, with either copper or nickel. Weeks in speaking of the altered pyroxenite? states that every thin section shows blebs of sulphides which apparently increase in number with proximity to the bottom of the body.

Platinum is reported from one other place in Northwest Territories. F. G. Wait (1910, page 147) found no gold and 0·11 ounce of platinum a ton in " an association in varying proportions of iron pyrites and quartz. The main vein has a width of 40 feet and has been traced for several miles." The specimens were collected by Captain Bernier during the cruise of the Arctic in 1910-11, and were stated to come from Strathcona Sound, an arm of Admiralty Inlet near the north end of Baffin Island.

CHAPTER IV

OCCURRENCES OF PLATINUM METALS IN FOREIGN COUNTRIES

In this chapter brief descriptions are given of occurrences of platinum metals in countries other than Canada. Where deposits have already been discussed in Chapter II the descriptions given here are merely supplementary. Apart from the important alluvial or lode deposits of Russia, Colombia, and South Africa there are small productions from several countries, such as Abyssinia, United States, Tasmania, Sierra Leone, and a few others. The majority of the occurrences mentioned, however, are of interest principally because they indicate the widespread distribution of platinum metals and, by adding to our knowledge of their mode of occurrence, are of value not only to the scientist but to those engaged in the search for or development of deposits containing these precious metals.

EUROPE

British Isles

Very small amounts of platinum have been noted in sands of Wicklow, Ireland, on the Island of Jersey, and at the mouth of River Urr, Kirkcudbrightshire (Kemp, 1902, page 67). Minute quantities have been found in black sand from alluvial deposits derived from dunite-serpentine of the Lizard Plateau, in Cornwall (McPherson and Lamb, 1921).

France

Scales of platinum in very small amounts have been reported from Morbihan, Brittany, in the tin-bearing sands along the coast. The metal has been noted also in Gard.

There is a very interesting occurrence of platiniferous tetrahedrite in metamorphic limestone on Mount Chapeau, above Chatelard, in the Vallée du Drac, Hautes Alpes. The tetrahedrite contains silver up to 12 per cent, and, in addition, antimony, lead, zinc, iron, and sulphur; the gangue is dolomite, quartz, and barite. The distribution of the platinum is by no means uniform, and the deposits are not of economic importance.

Platinum has also been recorded in slightly argentiferous tetrahedrite and malachite near Presles, in Savoy; in a peculiar copper carbonate in dolomite and magnesian limestone in the Plain des Cavales, Oisans, Isère; in bournonite, in dolomite and altered limestone at St. Arey, near La Mure, Isère; and associated with pyrite and limonite in the Department of Charost and Deux-Sèvres. None of the deposits contains sufficient platinum to justify mining (Kemp, 1902, page 65).

Spain

Platinum was discovered in 1915 in the peridotites of Ronda Mountains, Province of Malaga, by Don Domingo de Orueta, a Government geologist, who made a series of spectrum tests on the rocks for that purpose (Herior, 1918). There are about 550 square miles of such rocks in these mountains, and the Spanish Government undertook a comprehensive examination of the placers in the principal rivers that drain this area. The work was carried on during 1914, 1915, 1916, and 1917, principally along Verde and Guadaiza Rivers, in the region about midway between Malaga and Gibraltar. One hundred and seventy-five holes were drilled (Dreyfuss, 1917) and the results of the tests are said to have been quite satisfactory. The largest nugget found measured over 5 mm. (0·196 inch) and it is reported that one-third of the material from the holes assayed 0·05 to 0·07 troy ounce a cubic yard of alluvium; another one-third assayed 0·006 to 0·052 ounce. There were found to be rich and poor zones, the values not being uniformly distributed. Later work indicated that some of the deposits would be of commercial grade, but no production is recorded.

According to Duparc and Grosset (1916) and Duparc and Tikonowitch (1920) the source of the platinum is a number of peridotite intrusions that cut gneiss and metamorphosed sediments. The largest massif is about 40 by 15 kilometres. In some places, principally near the margin, the peridotite is almost completely altered to serpentine. When less altered, the typical rock is a peridotite, carrying rhombic pyroxene, of the harzburgite family, but lherzolite and dunite also occur. Opaque chromite and dark brown spinels are present in all varieties. Dunite is rather rare and forms small bodies in peridotite. The typical concentric structure of dunite, pyroxenite, and gabbro of the Ural centres is lacking. The placers, also, are very different from those in Russia. The valleys in Spain are youthful, and the gravels show no sharply defined pay beds. Values, as a rule, increase gradually from surface to bedrock.

Platinum occurs also in the gold and tin-bearing alluvials of a number of rivers in Northern Spain.

Kemp (1902, page 81) records the presence of platinum in a suite of ores from a silver mine at Guadalcanal, north of Seville, The ore resembled tetrahedrite, with a gangue of calcite, barite, and quartz, and contained from a trace to 10 per cent platinum as well as some copper, lead, antimony, iron, sulphur, silver, and, in some cases, arsenic.

Germany

There has been no production of platinum from Germany, but the metal has been recorded as occurring in fragmental rocks at a number of localities in Westphalia. These rocks are principally slates and greywackes, probably of Silurian and Devonian age. The platinum is very finely disseminated, and is associated with chromium, nickel, arsenic, antimony, iron, copper, lead, zinc, silver, and gold. Krusch (1914) investigated the deposits in 1914 and concluded that the original source of the platinum was peridotite, or related basic rock. He obtained values of from a trace to 1 ounce troy platinum a ton. It was stated in 1918 that a plant to treat these ores had been erected at Wenden.

Allopalladium was noted many years ago in gold in quartz-calcite-dolomite lodes carrying selenides of lead and mercury in or alongside diabase at Tilkerode, in the Harz Mountains (Kemp, 1902, page 66).

Czechoslovakia

A few scales of platinum have been found in the gold-bearing sands of Ollálipian, Siebenbürgen (Kemp, 1902, page 65).

Norway

The presence of platinum metals in the magmatic nickel-copper deposits of Norway has been noted in Chapter II, page 35.

Finland

Platinum occurs associated with chromite and diamonds in alluvial deposits on Ivalo River in northern Finland. It is believed to be derived from serpentine rock, of which the neighbouring country is largely composed (Lumb, 1920, page 41).

Platinum has been found in the south of Finland in a lode-formation containing quartz, siderite, calcite, and dolomite. Gold and carbonate of copper are also present in small quantities (Lumb, 1920, page 41).

Russia

Platinum was discovered in alluvial deposits in the Urals in 1823, and production commenced the following year. Russia immediately became, and has remained, the chief source of the world's platinum. According to official statistics, the output of crude platinum to the end of 1912 amounted to 7,202,790 ounces troy (on the basis 1 pood=526·6632 ounces troy), but this is believed to be considerably below the actual production, it being estimated that from one-third to one-fourth of the output was annually stolen by miners or surreptitiously removed from the country by certain of the smaller producers to avoid payment of taxes. J. L. Howe (1918) estimated production to the end of 1916 as between 7,115,482 and 10,128,308 ounces troy. The largest production officially recorded in any one year is 203,257 ounces in 1901. From 1910 to 1914 the annual production varied between 187,000 and 157,000 ounces troy. The war and, later, the revolution, disorganized the industry so that in 1919 the output had fallen to about 39,000 ounces. Since then the production of crude platinum, according to the Statistical Summary of the Imperial Institute, has been as follows:

TABLE XVIII

Production of Platinum, Russia, 1920-1927

Year	Ounces troy
1920	11,060
1921	6,582
1922	22,383
1923	31,862
1924	40,000
1925	94,778
1926	92,668
1927 estimated	100,000

Exact production for 1927 and succeeding years is not available; however, it is generally estimated that an output of about 100,000 ounces of crude platinum has been maintained in each of these years. It should be noted that the figures given by different authorities for the years tabulated above do not generally correspond exactly.

The Russian platinum fields lie along the axis of the Ural Mountains in Perm Government. The primary deposits are discussed in Chapter II of this volume, and it will be recalled that the platinum occurs in dunite, and less abundantly in pyroxenite bodies that are the ultrabasic differentiates of larger, north-south trending belts of intrusive rocks. The dunite-pyroxenite centres outcrop at different places along the axis of the range for over 300 miles, between latitudes 56 and 61 degrees north. The majority, however, lie within a stretch about 200 miles long beginning some 65 miles north-northwest of Sverdlovsk (Ekaterinburg). In the northern sections the alluvial deposits lie on streams or rivers on the eastern watershed of the Urals, but farther south they are on the western watershed. Prior to 1900 the greater part of the platinum came from the Nizhne Tagilsk (Taguil) district in the south, but more recently much of it has been obtained from the Goroblagodat and Bisersk districts, over 100 miles to the north.

PLACERS

The alluvial platinum deposits have been described by J. F. Kemp in Bulletin 193 of the United States Geological Survey, and more recently by Duparc and Tikonowitch (1920). The following brief summary is extracted largely from the latter report.

The region has been deeply eroded, in parts almost to a peneplain, and is one of mature topography. Most of the rivers meander in broad, silt-filled valleys in low, flat, or rolling country, or, near the axis of the mountain range, between moderately low, rounded mountains. The elevations of the primary dunite centres vary from 350 to 1,040 metres above sea-level and most of the peaks in the Urals range from 400 to 700 metres. A few rise to 1,600 metres or more. The region is heavily timbered below timber-line which varies from about 700 to 900 metres in the districts under discussion. The platinum fields have not been glaciated, the southern limit of the continental ice-sheet being at about 61 degrees north latitude. There are many marshes and bogs.

Origin of the Platinum

The platinum in the placers is directly due, in almost all cases, to erosion of platiniferous dunite or pyroxenite, particularly dunite, and Duparc lists nine centres as being of economic importance in this respect. Each primary centre gives rise to a series of more or less important streams that drain it and that are all platiniferous. To each centre there corresponds a certain number of miles of platiniferous alluvial deposits of varying richness, and the extent and richness of these deposits are generally directly related to the richness and size of the primary centre and also to the extent and depth to which it has been eroded. Tests were made on residual dunite material and it was found that, although a certain concentration of platinum had been effected by weathering, it was not sufficient to form commercial deposits. The highest average value obtained was 0·041 grain a cubic metre (0·026 dwts.) in Omoutnaïa centre, south of Sverdlovsk.

Types of Deposits

Duparc and Tikonowitch have divided the alluvial deposits into three groups that have quite different characteristics, as follows:

(1) " Lojok " alluvials
(2) River alluvials
(3) Bench or terrace alluvials (Alluvions des ouwals).

(1) " Les alluvions des lojoks " lie in small depressions in dunite or pyroxenite of primary centres. They combine the characteristics of alluvial and eluvial deposits. The depression, which may or may not be occupied by running water, is filled with erosional debris of the primary centre—dunite, pyroxenite, or dykes that cut these rocks. The larger blocks are generally pyroxenite, may be up to ½ cubic metre in volume, are angular, and show little effect of transportation. Dunite breaks down more readily into smaller particles. At the upper end of these deposits the material is entirely unsorted and platinum is distributed throughout the whole mass of loose material, although somewhat concentrated toward the bottom. Farther down the little valley or gulch, however, a layer of platiniferous, clayey sand, containing small pebbles of fresh or serpentinized dunite, often occurs on top of the altered bedrock and is yellowish or brownish in colour. This sand then contains relatively high values in platinum, although the unsorted, detrital material above it is also platiniferous. A typical section through one of these deposits is given below.

(*a*) Top—a layer of decomposed, earthy vegetable matter—0·15 to 3 metres thick.
(*b*) Brown clay with particles of dunite and pyroxenite—0·2 to 16 metres thick.
(*c*) Platiniferous sand—called " peskis "—0·20 to 3 metres thick.
(*d*) Decomposed bedrock.

The thickness of layer (*b*) generally varies from 4 to 6 metres and it contains chromite or magnetite pebbles, depending on whether the primary source was dunite or pyroxenite. The " peskis " is generally very clayey and from 0·4 to 0·75 metre thick. The bedrock is usually highly decomposed and platinum values sink into this loose material below the sands, so that up to nearly two feet must be removed for efficient recovery. In some cases the bedrock is relatively fresh but considerably fractured and jointed, and platinum finds its way into the open crevices. Again, the platiniferous sands lie between large blocks of dunite or pyroxenite, on bedrock, and are difficult to extract. In Taguil district a bed of hard conglomerate, carrying platinum and some gold, is found in the "peskis". In some places the lojok deposits are in heavily timbered, shallow depressions with no watercourse and would be easily neglected. Depending on the depth of detrital material they are worked by surface or underground methods. Occasionally, as in the basin of Martian River in Taguil Centre, several "lojoks" unite at their lower ends to form a small alluvial plain in which the platiniferous sands are particularly rich. The lojok deposits are always richer than the river or bench alluvials.

(2) The river alluvials are in the beds of large streams and rivers. The valley bottoms, covered with alluvial material, vary greatly in width, but are generally wide and sinuous; widths of 150 to 200 metres and more are not uncommon. A typical vertical section through these alluvial deposits is about as follows:

(*a*) Top-earthy vegetable matter—0·35 to 1 metre thick.
(*b*) Brown or greyish clay—0·5 to 1·5 metres thick.
(*c*) Porous gravels or sands, grey-green or yellow—0·3 to 4 metres thick. This is called "retschnikis".
(*d*) Platiniferous sands, generally clayey—0·25 to 1·5 metres thick. Called "peskis".
(*e*) Bedrock, more or less profoundly altered.

Layer (*c*), the "retschnikis," is variable in different deposits and is generally considered barren. This, however, is not strictly correct, as it does contain some values, particularly in its lower part, but it is always much poorer than the underlying "peskis." At times it contains boulders up to 1 metre in diameter.

Layer (*d*), the "peskis," is much more clayey than the overlying sands and the constituent pebbles are more altered, and are often smaller. Much of the material is quite hard and consolidated and the colour is greyish or greenish. The average thickness is a little over 2 feet, but deposits up to 10 feet thick are known. Occasionally there are two such beds in a deposit, the upper lying above the "retschnikis." In some rivers the "peskis" is entirely lacking in certain places and the overlying, barren gravels and sands rest directly on bedrock. The bedrock is always much decomposed and its nature is of considerable importance. Hard bands sticking up above surrounding softer material, or any irregularity due to the nature of the rocks, or to fracturing and jointing, form natural riffles that catch and hold the platinum. In limestone or dolomite, fractures and joints are particularly important in this respect, and hold much platinum. To obtain good extraction it is always necessary to remove the upper part of bedrock.

(3) Terrace alluvials (alluvions des ouwals) are bench deposits alongside the present streams. They are at times covered by high water and vary in width up to about 200 metres. The platiniferous sands are gener-

ally, but not always, directly covered by clay which is from 10 to over 30 feet thick, in some exceptional cases over 130 feet. They generally contain more clay than those in the river alluvials but are otherwise similar. Occasionally, as for example on the Iss River, there are two horizons of platiniferous sand separated by a considerable thickness of clay.

Remains of *Elephas primigenius* are abundant in the " peskis," but are rarely found in the overlying gravels and clays.

Platinum Values

The richness of the platiniferous sands of the river and bench deposits is inversely proportional to their distance from the primary centre, making allowance, of course, for local factors like platiniferous tributary streams, irregularities in bedrock that cause accumulations of the precious metals, variable widths of valleys, etc.

In Taguil district, the richest, the platiniferous sands at the headwaters of Martian, Syssim, Wyssim, and Tschauch Rivers and other smaller streams were at first extremely rich and in some places yielded over 10 troy ounces of crude platinum a cubic yard. As time passed there was a gradual fall in values until, between 1900 and 1914, the average recovery was between about 0·01 and 0·085 troy ounce a cubic yard, or, taking the platinum at $40 an ounce, from about 40 cents to $3.40 a cubic yard.

The same applies to the Iss River, which drains the dunite centres of Swetli-Bor and Weressowy-Ouwal, although the values there were lower than at Taguil. Several " lojok " deposits in this district averaged 2 or 3 ounces a cubic yard when first worked about 100 years ago, but the average at that time was from about 0·065 to 0·65 ounce a yard. By the early part of this century, however, the tenors had fallen as low as 0·0067 to 0·009 troy ounce a cubic yard, and even lower.

The other fields have experienced the same drastic drop in values. The richer placers were worked first and the poorer ones later. Indeed, Duparc reports that in some cases the original platiniferous sands have been washed and rewashed, sometimes five or six times. In a general way the alluvials in or from pyroxenite were poorer than those from dunite, although they did provide some very rich " lojok " deposits. For example, in a tributary of Goussewka River, values may have run well over 1·5 ounces a cubic yard and thievery took place on a large scale in spite of all precautions.

The river alluvials, away from the primary centres, were poorer than the lojok deposits discussed above, but even there the better paystreaks in some of the main buried channels were very rich. On rivers draining Taguil Centre the original values were usually between 0·065 and 0·13 ounce a cubic yard. On the Iss the river gravels in some cases yielded as much as 1 ounce a yard, but the average was from 0·04 to 0·13 ounce. On Toura River there was a considerable quantity of gold in the placers which, however, were generally of rather low grade.

The tenor of the platiniferous sands of the bench deposits on the Iss, Wyja, and some of the rivers draining Taguil Centre was frequently higher than that of the river gravels, but the values were very irregularly distributed.

All the values given above apply to the "peskis." The "retschnikis" gravels, sands, and clays overlying the "peskis" or paystreaks were generally assumed to be too low grade for working and were stripped off and discarded. Duparc and his associates tested some of these deposits with interesting results. On Severney-Kitlin River the thickness of the "retschnikis" was 19 to 40 feet and of the underlying "peskis" 14 to 56 inches. The former averaged from 0·0019 to 0·0058 ounce of platinum a cubic yard and the "peskis" from 0·013 to 0·034 ounce. Other tests showed results of the same order. The inference was that, for large-scale dredging operations at least, the values in the "retschnikis" should not be disregarded.

Nature and Distribution of the Platinum

The coarsest platinum is found in placers near or in the primary centre, particularly in dunite, and more particularly in the "lojok" deposits. In these, nuggets of large size were abundant; the largest ever found came from a tributary of Martian River, on Mount Solovief, and weighed 23 funts, 43½ zolotniks (21·18 avoirdupois pounds). Large nuggets were more abundant in Taguil district than elsewhere and the largest probably came from concentrations in dunite, not from chromite segregations. On the Iss and its tributaries nuggets were more rare; two from Weressowy-Ouwal Centre weighed 5 and 4·31 avoirdupois pounds and the two largest weighed 18·52 and 8·59 pounds. As a general rule the platinum becomes finer the farther it travels from the primary centre, until very minute grains predominate.

Very rarely is dunite found attached to nuggets—the olivine weathers out of the platinum readily, leaving a yellow or brown ochre in the cavity. Nuggets with chromite are more common and in many cases the platinum is entirely encased in this mineral or appears only as small points or spots between the chromite grains. Nuggets from pyroxenite centres are extremely irregular and cavernous, depending on the form in which the pyroxene crystallized, and many contain crystals of diopside or diallage. Magnetite is found with this platinum and in some cases forms the bulk of the black, shiny platiniferous nugget, but is rarely coarsely crystalline like chromite. An interesting point is that, in some cases, the platinum apparently undergoes a change in composition during water transportation, for the platinum of some "lojok" deposits is richer in osmium than that of the large rivers which are fed by the "lojok" deposits.

Placers Not Derived Directly from Primary Centres

Although most of the placer deposits can be traced directly to a source in dunite or pyroxenite, some cannot. As an example Duparc cites the little Koswa River, of Koswinsky-Kamen centre, that drains only rocks that are known to be barren of platinum. Yet for its length of about 11 kilometres the stream carries good values, in the form of small, rounded grains of uniform size. The source of the platinum is not proved but Duparc considers that, in a previous period, the river was longer and drained platiniferous rocks to the north, either those that are at present exposed there or possibly other bodies that have since been completely removed by erosion. As the head of the river moved south the actual connexion with the primary centre may have been lost, but the platiniferous gravels still remain.

Tertiary placers are believed to have formed along the main Koswa River, for its tributaries on both sides between Tilaï and Tépil Rivers are platiniferous for some distance back from their mouths. It is believed that the platinum in the present tributaries is due to reconcentration of values in Tertiary alluvials that were deposited by the Koswa when it flowed at a level some 50 or 60 feet higher than at present; and that, during Tertiary time, the main values were caught in the fractured dolomite which forms the bedrock on either side of the Koswa, the tributaries now eroding the upper part of this rock and re-collecting the platinum in their own channels. The main river is now deeply entrenched in solid rock, 50 to 60 feet below its Tertiary level. Duparc suggested that placers due to the reworking of Tertiary alluvials were probably much more prevalent than is generally imagined.

There are also some platiniferous gravels, on the Oulair, Oupouda, and Bérézowka Rivers, for example, that are not due to erosion of any visible primary centre but have in all probability derived their platinum from marine conglomerates of permo-Carboniferous age that contain many pebbles of basic igneous rocks.

Extent of the Placers

It was stated above that to each primary dunite or pyroxenite centre there corresponds a number of miles of exploitable gravels of varying richness. The following figures serve to show this relation. The adjoining Swetli-Bor and Weressowy-Ouwal Centres have a combined area of outcrops of 7·7 square miles. The gravels of streams and rivers draining the centres, principally the Iss and Toura Rivers, have been worked for a total length of about 136 miles. Wyssotsky estimated that the total length of exploitable gravels derived from Taguil Centre was 63 miles. The area of outcrop there is 10·9 square miles. This was the richest major platinum field in the Urals.

Sosnowsky-Ouwal Centre, with an area of 4·4 square miles, has produced between 9 and 18 miles of exploitable placers; some had not been worked at the time Duparc wrote. Kammenoe-Koswinsky Centre, with an area of outcrop of only 1·05 square miles produced, in Kitlin and Lobwa Rivers, at least 10 miles of commercial deposits, and if the gravels of the little Koswa River be added, at least 16 miles. Kamenouchky Centre, with an area of 2·9 square miles, probably contributed about 25 miles of gravels.

Present Status

At present the bulk of the platinum is extracted by modern electrically equipped dredges, although a large quantity is still obtained from small operations by peasants working on tribute. The whole output is refined at the State refinery at Sverdlovsk (Ekaterinburg). Even in 1914 twenty-five large dredges were in operation (Hutchins, 1914, page 857).

It is difficult to obtain figures on reserves, but it should be remembered that a notable quantity of platinum is now being extracted from primary deposits (Chapter II, page 25). The figures given above indicate clearly the tremendous drop in values that has occurred since the early days and Hutchins (Op. cit.) stated, in 1914, that most of the easily worked ground was becoming exhausted. I. I. Rogovin (1918, page 368) stated, in 1917, that the real cause of the fall in platinum production was the exhaustion of the mines and considered it unlikely that there would be any increase in production after the war. His statement would seem to have been borne out if the estimated productions of about 100,000 ounces annually in recent years are correct; it should be remembered that for at least six years after 1918 the output was far below normal. Early in 1916, L. Duparc stated (U.S.G.S. Min. Res. 1917, page 12) that the known Russian deposits (placers) could last only twelve years if mined at pre-war rate. One may perhaps assume that he considered about 175,000 ounces a year reported production a fair pre-war rate. Twelve years at that rate would give 2,100,000 ounces of platinum. Available production figures, in part as given on page 116, and assuming an annual production of 100,000 ounces for 1927 and succeeding years, gives a total Russian production since 1916 of about 1,100,000 ounces. Arguing on this basis there would still be about an even million ounces left out of Duparc's 1916 estimate. This means about ten years' life at the present estimated rate. Wagner (1929, page 292), however, stated in 1929 that the known Russian deposits are officially estimated to contain 7,000,000 ounces of platinum, but that reports of independent engineers who have visited the Urals placed the reserves at a very much lower figure. The possibility of the new discoveries must be allowed for, and also the effect of the price of platinum, at present very much lower than in 1929.

OTHER RUSSIAN DEPOSITS

Very little information is available, recently, on occurrences of platinum elsewhere in Russia or in Siberia. Vogt (1927, page 339) has noted the presence of platinum, some of it native, in nickeliferous pyrrhotite ores in large, flat-lying sills of coarse-grained diabase in the Norylsk district, Siberia. According to the Moscow Pravda rich deposits of platinum ore have been discovered seven kilometres west of Lake Imandra, in Kola Peninsula (Mineral Industry, 1931, page 441).

Albania

It was stated in 1922 that platinum had been discovered recently in Albania by Professor Sederholm.

ASIA

India

BURMA

Platinum, associated with gold, occurs in the gravels of Irrawaddy River, in Burma, and there has been a small production, by the Burma Gold Dredging Company, from deposits at Myitkyina. This company went into liquidation in 1918, and since that time there has apparently been no production of platinum metals in India. The output was not important, as the following figures will show (Hayden, 1919).

TABLE XIX

Production of Platinum, India, 1911-1918

Year	Ozs. troy	Year	Ozs. troy
1911	38	1915	17·7
1912	57	1916	9·25
1913	57·68	1917	3·79
1914	36·69	1918	0·31

Gravels of rivers draining the Patkai Ranges, both on the Assam and Burma sides, have been observed to contain some platinum and iridosmine (Hayden, 1915).

The Geological Survey of India has reported the occurrence of small amounts of platinum with the alluvial gold of Uru River (The Mineral Industry, 1928).

Armenia

Platinum, in association with gold, is reported to occur in the districts of Batum and Sassun, on Charokh River (Mineral Industry, vol. 23, 1914, page 610).

Borneo

It has been known since 1831 that platinum occurs in gold- and diamond-bearing gravels in Borneo, especially in the southeastern part of the island. The best known deposits are in certain streams in Tanah-laut and Martapura regions, and especially at Gunong-lawak, where the gold concentrates contain about 10 per cent platinum. In the diamondiferous deposits, platinum and gold are present in about equal amount. The streams in which the precious metals occur rise in Bobaris Mountains, composed of schists and gneisses intruded by serpentine, gabbro, and diorite dykes, and olivine and chromite are found in the gravels. The basic intrusives are doubtless the source of the platinum, but the metal has not been observed in the rock in situ. Osmiridium is associated with the platinum, and it is also of interest that the very rare ruthenium sulphide, laurite (RuS_2), was discovered in these deposits. In some of the placers, the platinum scales contain from 3·8 to 4·5 per cent of copper. J. L. Howe (1918, page 607) estimated that, up to the end of 1916, Borneo had produced between 175,000 and 200,000 ounces of crude platinum. For more detailed production figures, see under Sumatra below.

Java

Platinum has been found in minute quantities in auriferous black sands along the seashore near Tjilatjap (Banjaemas), but the economic value of these deposits has not yet been determined.

Sumatra

A somewhat rare type of occurrence of platinum in western Sumatra has been described by L. Hundeshagen (1904). It is near the high-road, at Singenggoe River, west of the village of Moeara Sipongi (Tapanuli), about

35 miles from the coast. The platinum, together with gold, occurs in a contact metamorphic deposit, consisting of grossular garnet and wollastonite with some bornite, which is regarded as having resulted from the metamorphism of a limestone lens by an intrusion of granodiorite. Assays indicate that the platinum is associated with the wollastonite, one sample of the latter giving about 3·5 dwt. platinum, 2·4 dwt. gold, and 1·1 dwt. silver a short ton. The garnet appears to contain no platinum. The river gravels adjacent to the outcrop give colours in platinum and gold.

PRODUCTION FROM BORNEO AND SUMATRA

Details of production of crude platinum from the Dutch East Indies are very meagre. The combined Borneo and Sumatra output for 1909 has been estimated at 500 ounces troy, and for 1910 at 200 ounces, with the same in 1912. None is reported during 1911. Since that time, the only recorded production, so far as can be ascertained, was in 1913 and 1917, with, respectively, 183 ounces and 64 ounces.

Phillipine Islands

There is a little platinum in placer deposits on the Island of Mindanao (Mineral Industry, 1922). A few ounces have been produced from the islands in recent years.

China

Platinum and iridium are reported to have been found in appreciable quantities, associated with gold, in auriferous placers that have been worked on a fairly extensive scale, in the Uryauchai district of Mongolia. Extensive outcrops of olivine rocks have been found in the vicinity (Lumb, 1920, page 43; Hautpick, 1913).

Japan

Information on the platinum metals in Japan is very meagre. The empire imports large quantities of metal each year and the Mineral Industry, 1930, gives the annual production of fine platinum as varying from 1,459 to 8,014 ounces between 1918 and 1928. Most of this, however, must be of foreign origin, for Hill (U.S.G.S. Min. Res., 1922, page 133) states that the Japanese production comes from placers on Hokushu Island. The output of crude placer platinum is given as from 47 to 258 ounces annually between 1916 and 1930. According to Hill (Op. cit.) osmiridium and platinum are associated with magnetite, chromite, and cinnabar in the gravels of Yubarigawa, Pechan, and Usotanni Rivers on Hokushu Island. Osmiridium forms up to 65 per cent of the precious metal content and is well crystallized. An analysis of osmiridium from Kitami province is given as iridium 49·80 per cent, osmium 37·30 per cent, ruthenium 7·69 per cent, rhodium 3·92 per cent, platinum 0·15 per cent, gold 0·02 per cent, aluminium 0·03 per cent, ferric oxide 0·76 per cent. The precious metals are found in the present river channels and partly in beaches and the source is not definitely known. Platinum is also found in placers at Tsuyo, Daigo, and Keda on Honshiu Island, with gold on Shikoku, and it is reported from gold placers on Sado Island.

AUSTRALASIA

Commonwealth of Australia

QUEENSLAND

The platiniferous beach-sand deposits occurring at Ballina and other points in the extreme northeast of New South Wales extend northwards across the state boundary into Queensland.

Platinum with alluvial gold was first found in Queensland in 1869, at Brickfield Gully, Gympie goldfield. The metal also occurs there in the Lucknow and Alma "reefs"; where it is present in quartz lodes with native gold and arsenopyrite, the associated rocks being slates alternating with volcanic tuffs and conglomerates.

Alluvial platinum has also been recorded from Coopooroo and Wairamba Creeks in the Russell goldfield, near Innisfail; and at the head of Don River in central Queensland.

NEW SOUTH WALES

Platinum was first noted in New South Wales in 1851, in alluvial deposits near Orange, in Wellington County, about 30 miles northwest of Bathurst. Since 1878, small amounts have been recovered from beach sands on the northeastern coast, notably at Ballina and Evans Head. Practically all the production, however, has come from placers at Fifield and Platina, in the Fifield division, in the east-central part of the state (Morrison, 1928). The rocks in the vicinity of the deposits are chiefly Silurian slates, intruded in places by dioritic dykes, but the original source of the platinum is not known. In addition to platinum, the gravels carry some osmiridium and gold, with platinum and gold in a ratio ranging from 3:1 to 6:1. An analysis of the platinum by J. C. H. Mingaye gave:

TABLE XX

Analysis of Platinum from New South Wales

—	Per cent	—	Per cent
Platinum	75·90	Osmiridium	9·30
Iridium	1·30	Iron	10·15
Rhodium	1·30	Copper	0·41
Palladium	Trace	Silica	1·12

These deposits were discovered in 1887 and have been worked continually since 1893. They have contributed practically all the platinum production of the state, which to the end of 1932 amounted to 19,702 ounces. In 1932 The New South Wales Department of Mines estimated the production at 336 ounces.

The peculiar lode deposits at Mulga Springs, Little Darling Creek, and elsewhere in Broken Hill district have never proved commercial. They consist, according to Andrews (1922, page 260), of narrow veins, mainly of hematite and limonite, at or near the contact of serpentine with altered shales and sandstones. The veins have no regular wall but are bordered by a leached zone with sporadic silicification and occasional patches of common opal.

Platinum is present in amount varying from 1 dwt. to over 2 ounces a ton and is accompanied by palladium and iridium, in some places in greater amount than platinum. Copper and nickel are present in important amount, and some gold and silver. The manner of occurrence of the platinum is not known, due to very fine division of the precious metals in the ore, but J. C. H. Mingaye thought sperrylite might be present. Jaquet (1892) thought the deposits had been formed by springs, but Andrews (1922, page 191) favoured deposition in veins by solutions or emanations from the intrusive basic rocks with which they are closely associated.

VICTORIA

Platinum, as well as gold and silver, is present in chalcopyrite ore in the Walhalla mine, Gippsland district. The ore occurs in a hornblende matrix in diorite. In 1911, 1,116 tons of copper ore and 18 tons of auriferous quartz yielded 184 ounces of platinum and in 1913, 1,291 tons of ore gave 127 ounces of platinum. No subsequent production has been reported. Iridosmine has been found near Foster and at Waratah Range, south Gippsland.

Kemp (1902, page 35) records the presence of platinum metals in coal from Australia, to the extent of 3·6 per cent in ash which formed 1·7 per cent of the coal. The ash also contained 25·1 per cent vanadium. The indicated platinum metal content is so high—20⅔ ounces a long ton of coal—that it would be good business to burn the coal to save these precious metals. As there is no record of any attempt in this direction, the record may be viewed with suspicion.

TASMANIA

Although platinum appears to be rare in Tasmania, this country has been until the last decade by far the most important source of the world's supplies of osmiridium, or iridosmine. The nevyanskite variety, with iridium above 40 per cent, is much more abundant than the siserskite variety, in which iridium is below 30 per cent. The production has all come from placer deposits, in which the mineral occurs either alone or in association with gold; platinum is present only very rarely.

The principal occurrences have been described by A. M. Reid (1921). The productive areas are confined almost exclusively to the western sections of the island and extend about 30 miles northwest from South Dundas, but adjoining districts are not fully explored. Reid divides the placer deposits into three groups:

(1) Detrital accumulations, in weathered serpentine. They are neither deep nor extensive but they are easily worked and some very rich pay-streaks are found in them. (2) Alluvial concentrations, along numerous streams. These contribute the greatest part of the osmiridium production. (3) Buried detrital and alluvial deposits. Some rich deposits are covered by late Tertiary basaltic flows. One such occurrence has been worked in Nineteenmile Creek area, Heazlewood district.

The productive streams drain a belt of serpentine and associated basic rocks from 1 to 5 miles in width. The primary osmiridium occurs in those portions of the belt that consist wholly or partly of olivine and bronzite (peridotite) or of serpentine derived from rocks composed of these minerals. Serpentines derived from gabbros and pyroxenites are barren. Further, the primary deposits of osmiridium, from which the placers have been derived, are almost exclusively confined to streaks and schlieren distributed irregularly along structural planes, in the serpentine. Chromite is an important associate, as also is gold, either free or alloyed with osmiridium. Other interesting features are the presence of chrome spinel in the serpentines and the high percentages of alumina in bronzite.

Bald Hill, in Heazlewood district, is regarded as the most important source of the osmiridium in the placers and the possibility of finding primary deposits of commercial grade, especially on the northwestern slope of the hill, is considered favourable. This is important, as many of the rich placer concentrations on Savage, Wilson, and other rivers are now seriously depleted or exhausted.

In 1925 osmiridium was discovered in placers on Adam River, in southwestern Tasmania. The deposits have been described by P. B. Nye (1929). As in Heazlewood district and elsewhere, Silurian sediments are intruded by Devonian plutonics that include a large, dyke-like mass of serpentine, from which the osmiridium is believed to be derived. No primary deposits have been found, but the placer osmiridium is associated with gold and chromite and one specimen from a placer showed grains of chromite and osmiridium in serpentine. The field had produced 7,666 ounces of osmiridium by the end of August, 1928—that is, in about three and a half years.

Osmiridium was discovered in the gravels of Savage River in 1881, but there was no official record of the occurrence until 1894. For many years there was no market for the material, and although some was produced, there was no official record of output until 1910. Production since then has been as follows:

TABLE XXI

Production of Osmiridium, Tasmania, 1910-1932

Year	Ounces troy	Average value per ounce	Year	Ounces troy	Average value per ounce
		£ s. d.			£ s. d.
1910	120·00	....	1922	1,174	30 6 0
1911	271·88	....	1923	673	29 4 0
1912	778·77	....	1924	365	29 2 0
1913	1,261·65	....	1925	3,666	30 15 0
1914	1,018·83	....	1926	3,172	19 10 0
1915	247·05	6 8 0	1927	633	....
1916	222·15	8 10 0	1928	1,627	26 2 0
1917	332·08	14 15 0	1929	1,360	22 6 0
1918	1,606·74	27 18 0	1930	953	17 1 0
1919	1,669·72	23 14 0	1931	1,280	14 2 0
1920	2,009·20	38 8 0	1932	785	11 11 0
1921	1,751·00	24 10 0			

Deposits of nickeliferous pyrrhotite occur, near the town of Zeehan, in slate near its contact with serpentine. A few thousand tons of the ore have been mined, but the deposits are not large. The average grade of the ore is said to be approximately: Ni, 9·61 per cent; Cu, 4·7 per cent, and, according to an assay by D. C. Griffith and Company, of London, the ore contains 2·2 ounces silver and 0·06 ounce platinum a ton (White, 1915).

PAPUA (NEW GUINEA)

Osmiridium, with associated gold, has been found in alluvial deposits in a number of localities in Papua. The mineral has been derived from the denudation of serpentines, representing peridotite and other basic igneous rocks, which are widespread in certain areas, as along Yodda and Gira Rivers. According to C. Brown (1918) the osmiridium is all of the nevyanskite variety.

The deposits have been described by E. R. Stanley, the government geologist (1919-20). The annual production has never been large; prior to 1918 it never exceeded 10 ounces; in 1920, 360 ounces were reported, but 1929, 1930, and 1931 saw contributions of only 29, 11, and 20 ounces respectively.

New Zealand

Platinum is of widespread occurrence in New Zealand, particularly in South Island. For many years a small production, averaging less than 20 ounces a year, has been won from auriferous gravels in the Orepuki and Waiau districts of Southland, Centre Island. Osmiridium is also reported from a number of localities. A complete list of occurrences is given in Bulletin 32, 1927, Geological Survey, New Zealand, by P. G. Morgan.

In South Island, platinum has been reported from the Queen of Beauty quartz reef at Thames, and also from an occurrence of massive pyrite at Coromandel (Bell, 1906). Pyritic quartz veins, in close proximity to intrusive sheets of serpentine, near Teremakau River, carry platinum and silver, in the ratio of 1 to 7, 0·17 ounce of platinum a ton being about an average value.

New Caledonia

Platinum has been noted in the gold-bearing sands of Andam Creek, below Boude.

The great deposits of garnierite, a hydrous silicate of nickel, which are mined in New Caledonia, contain a minute percentage of platinum, not of economic importance.

AFRICA

Union of South Africa

TRANSVAAL

Although it has long been known that platinum metals occur at a number of localities in the Transvaal, it is only since 1921 that there has been any production. In that year, recovery of osmiridium from gold mines on the Rand commenced, and at about the same time the platinum lode deposits of Waterberg district were discovered. Then came the important discoveries, late in 1924 and in the following year, in Lydenburg, Potgietersrust, and Rustenburg districts, these being lode deposits in the norite zone of the Bushveld Complex, which, Wagner states, " probably contains in the aggregate more platinum than all the rest of the earth's crust accessible to man." There then followed other discoveries in northern Transvaal and in Southern Rhodesia. All these deposits are very fully described by the late Dr. Percy A. Wagner in his book, " The Platinum Deposits and Mines of South Africa," published in 1929. This has been freely used in compiling the data relating to South Africa included in this report, both here and in Chapter II.

The geological setting, nature of occurrence, and origin of the principal South African platinum deposits have been discussed at some length in Chapter II. It is sufficient to recall here that they include dunite and hortonolite-dunite deposits, chromitite bodies, and the very extensive and important deposits of the Merensky Horizon where the platinum metals are contained in sulphides, as well as contact metamorphic bodies, quartz veins or lodes, and pegmatitic deposits, all in or closely associated with the Bushveld Igneous Complex in Transvaal. In addition there are some deposits of the Sudbury type, although not of great commercial importance, and " osmiridium " is saved from the Rand gold deposits. Three other deposits in Transvaal have not been mentioned previously. Four miles west of Messina, northern Transvaal, a sill of norite, of unknown age, containing appreciable amounts of platinum metals, was encountered in a shaft of the Northern Transvaal (Messina) Copper Exploration Company. Fifteen miles south of Marabastad small amounts of platinum have been found in a quartz-specularite vein cutting Precambrian granite. At Preezburg, Central Transvaal, platinum occurs in a rather coarse-grained quartz-gabbro of unknown age.

It has already been pointed out that no very important platiniferous placers are known in Transvaal, although some hope has been entertained for certain deposits in the Lydenburg district. The eluvial deposits at the Onverwacht mine and elsewhere in the Lydenburg district have been mentioned.

Operations and Production

Wagner's book was published in 1929. It contains concise statements of the status and production of the principal producing, or potential producing, companies engaged in the exploitation of platinum metals at that time. The reserves of the three dunite deposits, Onverwacht, Mooihoek, and Driekop, were comparatively small, although he estimated that the latter two could maintain their output of 600 or 700 ounces a month for at least four or five years. The Onverwacht mine produced continuously from January 1926 to July 1930, contributing 6,836 ounces of platinum metals in 1928 and 4,672 ounces in 1930. The ore-body pinched out at a depth of 975 feet and no new ore was encountered down to 1,100 feet, so, when reserves were exhausted, the operation was discontinued. The other two dunite deposits were operated by Lydenburg Platinum Areas, Limited, until November 30, 1930, yielding over 8,000 ounces a year, but were then closed down on account of the low price of platinum.

The reserves of platinum metals in ores of Merensky Horizon are conceded to be enormous, and more than adequate to meet any demand that may arise for many years, provided the price of platinum is sufficiently high to justify operation. To this must be added the very considerable reserves of the big, irregular deposits of Potgietersrust district.

During the boom of 1925 over fifty companies were incorporated to work the platinum deposits of the Bushveld Complex and Waterberg district. For one reason or another many of these soon passed out of existence or merged with other companies. In 1929 Wagner listed ten important actual and potential producers, including the Onverwacht Company and Lydenburg Platinum Areas, Limited, mentioned above.

Potgietersrust Platinums, Limited, had the largest holdings of any of the South African companies, having properties or rights in the Lydenburg, Rustenburg, and Potgietersrust districts. Operations were centred at the Zwartfontein Central mine in Potgietersrust district in 1929 and a plant designed to produce 28,000 ounces of platinum metals annually was erected at the Kroondal-Klipfontein mine in Rustenburg district. The Potgietersrust plant was producing about 4,000 ounces annually. In the year ending September 30, 1930, the Potgietersrust and Rustenburg plants produced 5,215 and 12,364 ounces of platinum metals respectively, but the Potgietersrust section was dismantled that year. The Waterval (Rustenburg) Platinum Mining Company, operating a mine at Waterval in Rustenburg district, started production in July, 1929, and by June 30, 1930, had produced 16,636 ounces of platinum metals. Both these companies continued production until September, 1931, but from August the scale of production was dropped 50 per cent, to a basis of 28,000 ounces of platinum metals a year. On September 1, 1931, the two companies merged to form the Rustenburg Platinum Mines, Limited, and the Waterval mine was closed. After September 1, 1931, this was the only platinum company operating in South Africa and, early in 1932, it was announced that their plant would shut down temporarily, due to decreased sales and an accumulation of platinum on hand.

Production of platinum group metals from deposits of the Bushveld Complex has been as follows, in troy ounces: (Min. Ind., 1931, p. 442).

TABLE XXII

Production of Platinum Metals, Bushveld Complex Deposits, 1926-1932

Year	Crude (content)	Concentrate (content)	Total content
1926	8,723	1,822	10,545
1927	12,941	6,629	19,570
1928	14,656	9,000	23,656
1929	24,084	5,730	29,814
1930	49,375	5,967	55,342
1931	41,220	5,943	47,163
1932	7,766	1,480	9,246

The annual sales have averaged considerably less than the production. The 47,021 ounces of platinum metals that were marketed in 1930 had the following composition:

TABLE XXIII

Composition of Platinum Metals from Bushveld Complex Deposits

Metal	Dunite	Norite	Average	Fine ounces
	Per cent	Per cent	Per cent	
Platinum	93·65	76·98	80·96	38,068
Palladium	1·97	15·81	12·51	5,880
Iridium	0·85	0·05	0·24	112
Osmium	....	0·59	0·45	213
Rhodium	2·12	0·17	0·64	300
Ruthenium	1·27	0·22	0·47	222
Gold	0·14	6·18	4·73	2,226
Totals	100	100	100	47,021

Witwatersrand

In 1892, William Bettel showed that iridosmine (or osmiridium) and platinum are present in the banket of the New Rietfontein mine, and later they were found in ore and concentrates from other mines on the Witwatersrand. It was, however, only in 1922, when amalgamation was abandoned in favour of preliminary concentration on corduroy and blankets, that the recovery of these metals on a large scale became practicable. Since that time "osmiridium," a concentrate containing several distinct minerals of the platinum group, has become a valuable by-product of the Witwatersrand mines, and the production has been as follows:

TABLE XXIV

Production of "Osmiridium" by Witwatersrand Mines, 1922-1932

Year	Ounces troy	Year	Ounces troy
1922	761	1927	5,473
1923	1,784	1928	5,671
1924	5,763	1929	5,810
1925	5,490	1930	5,732
1926	6,228	1931	6,306
		1932	6,523

The 5,653·18 ounces of "osmiridium" that were sold in 1927 contained:

TABLE XXV

Composition of "Osmiridium" from Witwatersrand Mines

—	Ounces troy	—	Ounces troy
Osmium	1,724·902	Gold	147·902
Iridium	1,601·031	Balance—undetermined	808·487
Ruthenium and rhodium	763·879		
Platinum	606·939	Total	5,653·180

The occurrence and origin of the osmiridium are discussed in Chapter II, page 49. The major portion of the production is obtained from mines in the Main Reef Leader conglomerate of the Witwatersrand system in the Far East Rand, but notable amounts are also obtained from the Battery Reef on the West Rand. "Osmiridium" is also known to occur with gold in the Black Reef conglomerate at the base of the Transvaal system and in conglomerates of the Elsburg series.

CAPE PROVINCE

Griqualand (East)

The occurrence of platinum and palladium at Insizwa and Tabaukulu are discussed in Chapter II, page 35.

Kimberley

Small amounts of platinum metals have been found in all the more important South African diamond pipes. In every instance observed, they are associated with the chromite of the kimberlite.

Southern Rhodesia

THE GREAT DYKE

Platinum has been discovered at three widely separated localities along the Great Dyke in southern Rhodesia. The occurrences are discussed in Chapter II, page 34, and it will be recalled that the platinum metals are in a layer of pyroxenite that lies 20 to 60 feet below the base of feldspar-rich norite that forms the central and upper part of the great lopolithic intrusion. The three areas in which the norite indicator occurs are: (1) between Hunyani and Ngesi Rivers, including the Makwira platinum field; (2) Selundi Hills, east of Selukwe, where platinum is known to occur; and (3) from near Umgezi River to Umchinwe River in Belingwe district, including the Wedza platinum field. The Wedza occurrences are the most important and the "reef" is, there, from 8 to 10 feet thick, although only the upper 3 or 4 feet carry notable values, about 3 dwts. a ton. The Makwira deposit is similar and a considerable amount of work has been done in both areas, but no production is recorded (Lightfoot, 1926).

Small amounts of platinum metals have been found, also, in the diamond-bearing conglomerate gravels near Gwelo (Maufe, 1919) and in 1918 samples of serpentinized dunite from 6 miles northeast of Indwa siding, in the same district, were found to contain platinum, but not in sufficient quantity to warrant exploitation.

Belgian Congo

Platinum and palladium are said to occur in the Ruive gold deposit, in the Katanga, southeastern Belgian Congo (Ball and Shaler, 1914). The ore-body consists of a single, indurated, banded sandstone. The values are patchy but are said to average $17 a ton in gold, silver, platinum, and palladium, across widths of from 3 to 20 feet. Bullion from the vein is said to consist, by weight, of: gold 32·77 per cent, silver 25·05 per cent, platinum 36·11 per cent, and palladium 6·06 per cent. The precious metals are very finely divided and are associated with lead and copper vanadates, pyromorphite, and malachite. Iron, cobalt, and nickel are also present.

Gold Coast Colony

Sir Albert E. Kitson, director of the Gold Coast Geological Survey, has reported the presence of platinum in a large mineralized dyke of hornblendic rock near Mamkwadi. Assays gave 3·6 to 6 grains platinum a ton, with a trace of gold and silver, and fractions of 1 per cent of copper and nickel. Samples from another similar dyke gave 2·4 grains platinum a ton. He reports the presence of a great number of basic and ultrabasic dykes in the country, and states also that, along the new Huni Valley-Kade railway, W. G. G. Cooper found platinum values in a metasomatically altered rock containing tourmaline, feldspar, and quartz, and mineralized with sulphides. Assays of this gave 4 grains a ton of gold plus platinum (Kitson, 1927).

Sierra Leone

In 1926 geological investigations in Sierra Leone under the direction of N. R. Junner resulted in the discovery of important deposits of hematite, chromite, and alluvial gold and platinum. The platinum placers are near the coast, on Sierra Leone Peninsula principally in the vicinity of York and Toke, on tributaries of Whale River, but other occurrences are known. The deposits and their geological setting have been described by V. R. Junner (1930, A and B) and L. D. Pollett (1931). The platinum occurs in the gravels as small grains and nuggets, delicate dendritic intergrowths, and dust, the largest nugget recovered weighing 12½ dwts. Platinum is accompanied by much ilmenite and magnetite and some chromite. Apparently the platinum, a considerable part of which has travelled no great distance, has been derived from intrusions of anorthosite that form part of the highly differentiated igneous complex of the peninsula, but no primary platinum deposits have as yet been discovered. Pollett states that small particles of ilmenite are found adhering to platinum in the placers and that a characteristic feature of the anorthosite is the occurrence of blebs of ilmenite in it. Further, non-waterworn platinum is found in eluvium on steep anorthosite slopes. An analysis of crude placer platinum showed 87 per cent platinum, 1·3 per cent osmiridium, 2 per cent palladium, and 9·9 per cent iron. Towards the end of 1929 placer operations were commenced on the rich alluvial deposits of Big Water River, near York Pass and the ground is said to have averaged between 10 and 15 shillings a cubic yard (Bull. Imp. Inst., vol. 28, No. 2, page 218, 1930). Ilmenite concentrate is saved as a by-product. The rocky nature of the ground, and the presence of large boulders in the wash, have necessitated reliance on hand methods of working the richer parts of the deposits. Production has been as follows: 1929, 26 ounces; 1930, 542 ounces; 1931, 594 ounces; 1932, 531 ounces.

Algeria

Platinum has been noted in a deposit of galena near Algiers, but no details of the occurrence are available (Aime, 1838).

Egypt

Mr. F. W. Moore, in a preliminary geological report on St. John Island (Red Sea), has reported the occurrence there of nickel ore (garnierite) carrying values in platinum metals. An assay gave: Ni, 4·86 per cent; Fe, 12·25 per cent; Cu, 0·25 per cent; platinum metals, 14·50 grains a ton; gold, 3·00 grains a ton; and silver, 4·00 dwts. a ton; with insoluble residue, 37·59 per cent. The locality is some 800 kilometres southeast of Port Tewfik (Suez) (Min. Ind., 1923).

Abyssinia

Platinum has been known to occur with placer gold in a number of rivers in Abyssinia for many years, but only recently has any attempt been made at commercial exploitation. Data on the occurrences are meagre. Apparently the principal deposits are in the western part of the country and they are all alluvial. Important deposits were found on Didessa River, a tributary of the Blue Nile, in 1926, and created considerable interest (U.S.G.S. Mineral Resources, 1928, page 15). Later, a concession of 500 square kilometres was granted to a French syndicate and work was commenced at once, machinery being shipped up the Nile. Other concessions have also been granted. Some of the deposits are reported to be extraordinarily rich and nuggets up to 15 grammes in weight have been found. Platinum is also reported in Wallego province. Duparc and Molly (1928) have studied deposits on Birbir River, a tributary of Baro River, which, via the Soba, flows into the White Nile. They found occurrences of dunite, pyroxenite, and gabbroic rocks similar, in many ways, to those of the Ural Mountains, and they believe that the dunite is the source of the platinum, although no metal has been found in situ. Some, however, is found in lateritic decomposition products of dunite and associated birbirites. No evidence to indicate the presence of platiniferous chromite segregations was found. An analysis of crude platinum from laterite is given as follows:

TABLE XXVI

Analysis of Crude Platinum from Abyssinia

—	Per cent	—	Per cent
Osmiridium	1·41	Palladium	0·49
Platinum	79·48	Gold	0·49
Iridium	0·82	Iron	16·50
Rhodium	0·75		

The Minerals Yearbook gives the following production for Abyssinia, but Imperial Institute figures are lower.

TABLE XXVII

Production of Platinum, Abyssinia, 1926-1932

Year	Ounces troy	Year	Ounces troy
1926	640	1930	8,038
1927	1,200	1931	6,430
1928	3,247	1932	4,823
1929	7,716		

Madagascar

There has for some years been a small recovery of platinum from alluvial deposits on the east coast of Madagascar. The platinum is associated with gold, and in some cases is coated with oxide of iron.

These deposits, which have been described by A. Lacroix (1918), occur: (1) to the northeast of Fenerive; (2) to the south-southwest of Vatomandry, west of Marosiky; and (3) in the Isongo, an affluent of the Manambihi. It was in the last-named region that platinum was first found in Madagascar, in 1904.

NORTH AMERICA

Newfoundland

Chromite derived from the serpentinized area in the region of Mount Cormack, situated in the central part of the island, has been found to contain small quantities of platinum (Howley, 1907).

United States

There is a small annual production of placer platinum in the United States, obtained mainly in California, at the base of the Sierra Nevada, and from placers in Alaska. Some has come from southwestern Oregon, and a few ounces from Washington and Utah. Some platinum has also been obtained from a gold-platinum-palladium lode deposit in Nevada, from a copper mine in Wyoming, and from a palladium-copper lode in Alaska. The largest amount of new platinum metals is generally saved as a by-product of gold and copper refining.

J. L. Howe (1918) estimates that the total, crude platinum production of the United States up to the end of 1916 amounted to between 10,000 and 12,000 ounces. The annual placer production since 1920, as given in the annual reports on mineral resources, is as follows:

TABLE XXVIII

Production of Crude Platinum from Placers, U.S.A., 1921-1923

Year	Ounces troy	Year	Ounces troy
1921	977	1927	153
1922	1,008	1928	528
1923	609	1929	797
1924	335	1930	527
1925	343	1931	885
1926	286	1932	1,074

According to the United States Mineral Resources the crude platinum, when refined, will average: platinum 85·5, palladium 0·6, iridium 1·1, osmium 1·3, and rhodium, ruthenium, etc., 1·0 per cent.

The total of new platinum metals recovered by United States refiners from ores of domestic origin is given as follows, for years since 1920, in troy ounces:

TABLE XXIX

New Platinum Metals of Domestic Origin Recovered by United States Refiners, 1921-1932

——	1932	1931	1930	1929	1928	1927	1926	1925	1924	1923	1922	1921
Platimum	1,912	5,595	5,348	5,620	4,631	4,449	4,923	4,325	3,523	2,114	1,998	2,899
Palladium	1,148	2,597	3,656	5,058	4,762	3,637	6,187	6,794	3,668	1,187	777	1,660
Iridium	78	78	128	44	85	46	26	36	53	75	75	110
Osmiridium	46	35	57	54	43	30	13	51	32	91	512	119
Others	8	88	119	110	69	11	16	3	4	5	11	12
Total	3,192	8,393	9,308	10,886	9,590	8,173	11,165	11,209	7,280	3,472	3,373	4,800

Except for the few hundred ounces contributed each year by placers and occasional shipments of platinum-rich ores, the whole amount is obtained as by-product from the refining of copper and gold ores. Placers contribute all the osmiridium, but very little palladium.

In addition, United States refiners purchase each year a large amount of foreign crude platinum. The United States Mineral Resources gives the following figures for the total amount of new platinum metals, from all sources, recovered by American refiners:

TABLE XXX

New Platinum Metals Recovered by United States Refineries

Year	Platinum, ounces troy	Iridium, ounces troy	Osmiridium, ounces troy	Palladium, ounces troy	Others, ounces troy	Total, ounces troy
1918	54,399	465	539	4,024	326	59,753
1919	40,220	401	402	3,807	279	45,109
1920	36,015	418	409	4,309	393	41,544
1921	51,791	286	581	2,686	1,026	56,370
1922	54,142	210	1,301	1,943	122	57,718
1923	46,780	280	787	1,934	16	49,797
1924	57,827	680	1,261	6,065	174	66,007
1925	41,300	283	648	7,358	54	49,643
1926	76,154	234	2,113	6,437	43	84,981
1927	41,121	256	631	3,879	163	46,050
1928	51,427	1,658	458	5,148	348	59,039
1929	41,760	302	364	5,295	256	47,977
1930	37,780	1,468	334	3,801	119	43,502
1931	31,274	1,732	272	2,742	185	36,205
1932	14,666	1,362	328	1,252	8	17,616

In the eastern United States there is no important deposit of platinum known, although the metal has been reported from Georgia, North Carolina, and Pennsylvania. In Macon County, North Carolina, sperrylite was found in gravels, and later in a rock consisting of rhodolite (garnet), biotite, and abundant iron sulphides. In Pennsylvania, platinum was detected with chalcopyrite and galena in a clay slate from Lancaster County; in a black slate from near Boyertown; and in a pyritous, dioritic gneiss from the Archæan areas, which gave assays of from half an ounce to over 2 ounces platinum to the ton (Kemp, 1902, page 59).

In the western states, platinum has been noted in a shaly rock from near Williams, Arizona; in placers in California, Oregon, Washington, and Utah; with pyrrhotite in a black hornfels in Colorado; in gold-bearing sands of Snake River, Idaho; and near Miles City, Montana. It has also been found in important amount in situ on properties in Nevada, and in Wyoming.

CALIFORNIA AND OREGON

There are two types of placers in the western United States; those along streams and those along beaches. The principal production comes from dredging operations on auriferous stream placers in California, particularly in the central and northern part of the state. The proportion of platinum to gold in many of the placers is said to be about 1 to 20, but a complete recovery is difficult as much of the platinum is very fine and it is saved along with the black sands in the dredges. Most of the Californian production has come from dredging operations in Butte, Calaveras, Stanislaus, Humboldt, Trinity, Shasta, and Sacramento Counties and osmiridium has been won from Belgium Creek on the Shasta-Tehama County line. Small amounts of platinum have been recovered elsewhere. The metals are believed to have originated in peridotite and serpentine of the Sierra Nevada and other ranges.

Platinum also occurs in beach placers along the coasts of northern California and southern Oregon. These deposits were reported upon by R. R. Horner (1918). He found that small, favourable areas showed some precious metal content, possibly sufficient for small operations, but generally the deposits are small and erratic in occurrence and content. Magnetite, chromite, and ilmenite occur with the precious metals. From 1887 to 1912, annual production in California averaged 275 ounces, according to the State Mining Bureau. Since then it has been as follows.

TABLE XXXI

Platinum Production, California, 1913-1932

Year	Ounces crude	Year	Ounces crude	Year	Ounces crude
1913	368	1919	418	1925	312
1914	463	1920	?	1926	269
1915	667	1921	500	1927	189
1916	886	1922	360	1928	299
1917	610	1923	578	1929	246
1918	571	1924	285	1930	129
				1931	354
				1932	280

In Oregon the platinum has been obtained from beach deposits near Bullards and Marshfield and from placers, rich in chromite, in the southwestern section of the state, particularly the Waldo district. The annual production has averaged about 50 ounces and since 1922 has been as follows:

TABLE XXXII

Platinum Production, Oregon, 1923-1932

Year	Ounces crude	Year	Ounces crude
1923	24	1928	66
1924	20	1929	23
1925	19	1930	13
1926	7	1931	25
1927	37	1932	74

Platinum (0·32 ounce a ton) has also been reported in ore from the 100-foot level of the Highland gold mine, 12 miles south of Gold Hill, Oregon (Mineral Industry, 1921).

WASHINGTON

Platinum is known to occur in small amount in the auriferous black sand placers on the coast of Washington immediately south of Cape Flattery and is reported from other localities as far south as the mouth of Columbia River. It is also found or reported in stream placers on Okanagan River and one or two smaller tributaries of the Columbia, and in auriferous placers on the south fork of Lewis River, northeast of Portland. Small amounts have been found in chromite segregations in serpentine on Cypress Island, north of Puget Sound. The total production of the state up to 1928 is reported as $7\frac{1}{2}$ ounces (Pardee, 1929).

NEVADA

Platinum to the extent of $\frac{1}{3}$ ounce a ton of ore assaying 4 per cent copper and 2·5 per cent nickel has been reported from a diabase dyke cutting schists in Bunkerville district, Lincoln County, Nevada (Anon., 1907).

The metal is also reported in disseminated copper-nickel ores in peridotite (enstatite-mica-picrite) dykes cutting granitic gneiss in Clarke County (Bancroft, 1909). The ore consists of magnetite, pyrite, chalcopyrite, and pyrrhotite that is probably nickeliferous; but the deposits seemed of doubtful commercial value. An assay by Ledoux and Company showed 0·15 ounce of platinum a ton of ore.

The most important platiniferous deposit in Nevada is the Boss mine, in Yellow Pine mining district (Knopf, 1915; Kennedy, 1915; Crampton, 1916). The deposit is discussed in Chapter II, page 41, of this report. It contains more palladium than platinum. Shipments reported have been as follows: 1906, 295 tons of ore produced; 1907, 443 tons yielded 107 ounces of platinum and 400 ounces of palladium; 1918, 90 tons netted $6,040; 1919, 3 cars yielded $22,365. The ore was stated to average 7 per cent copper, 4 per cent bismuth, 1 ounce platinum plus palladium, 0·75 ounce gold, and 3 ounces of silver a ton. The mine has not been operated in recent years.

Platinum metals are also present in small quantity in the ore of the Oro Anigo mine, between 1 and 2 miles southeast of Boss mine.

IDAHO

Small quantities of finely divided platinum occur in gravels of Snake River, associated with fine gold (Hite, 1933).

UTAH

Platinum and gold, both very finely divided, have been recorded in places in Green River, east of Veonal, and in Colorado River, near Hite, below the mouth of Green River.

WYOMING

Sperrylite occurs with covellite in decomposed diorite in the Rambler mine, about 45 miles southwest of Laramie, Albany County (Emmons, 1903). Taft (1918) states that gneiss occurs at the mine, but that rock from the lower levels is peridotite; that as far as is known the deposit is a kidney of diorite charged with copper and iron. The ore is decomposed diorite mineralized with grey copper (tetrahedrite) and pyrite, and much oxidized, and covellite is a secondary enrichment product. Sperrylite was isolated from covellite, but is not abundant. According to the United

States Bureau of Mines (Min. Ind., 1923) the ore is said to average 12·55 per cent copper and 0·32 ounce gold, 2·56 ounces silver, 0·211 ounce platinum, and 0·246 ounce palladium a ton. About 3 tons of ore was being shipped daily late in 1921, but no information as to recovery of platinum was available. Hess (1926), however, states that payment was received for platinum and palladium to the extent of several ounces a ton of ore. He also certified the presence of platinum and palladium in two deposits on Centennial Ridge, northeast of Rambler mine; one, the Empire No. 1 claim, contained a very small pocket of pyrite in schist, the pyrite and decomposed rusty schist both carrying platinum, palladium, and iridium.

Finch (1925) found small amounts of platinum and palladium in a small schisted dyke in Precambrian limestone in the Encampment district, but not a sufficient quantity of these metals to encourage development.

COLORADO

Platinum has been reported from black sands in Clear Creek and in auriferous gravels of the Iron Hill placer at Como, in composite grains with magnetite. It is also reported in considerable quantity in copper-gold ore from a vein near Villa Grove (Min. Ind., 1916, page 592).

NEW YORK

Traces of platinum occur in alluvials of the Adirondack region, but the deposits are not of economic importance (Min. Ind., 1917, page 542).

ALASKA

Platinum has been found in many widely separated districts in Alaska and there has been a small but continuous production from gold placers for the last fifteen years (Smith, 1933). Dime Creek, in the southeastern part of Seward Peninsula, has been one of the steadiest producers, yielding, however, only a few ounces each year from auriferous placers. Platinum is also recovered from stream gravels on Slate Creek, a tributary of Chistochina River (Martin, 1919) and has evidently been derived from Tertiary, possibly Eocene, conglomerate which is known to be platiniferous and auriferous.

Production since 1927 has been increased by important contributions from gold placers in creeks of the Goodnews Bay region, south of the mouth of Kuskokwim River. In addition to occurrences in river gravels, some platinum is found in beach placers on Kodiak Island, southwestern Alaska.

The annual production of crude platinum from Alaskan placers from 1916 to 1926 varied from 6 to about 80 ounces. Since then it has been: 1927, 20; 1928, 150; 1929, 528; 1930, 385; 1931, 506; 1932, 720 ounces.

The Salt Chuck mine at the head of Kasaan Bay, Prince of Wales Island, Ketchikan district, is the only lode deposit in Alaska that has produced platinum metals. The occurrence is described in Chapter II, page 36. Bornite is the principal ore mineral, but the deposit contains, also, palladium, platinum, gold, and silver. Average ore was said to carry 1·43 per cent copper with 1·26 dwts. gold, 0·22 ounce silver, and 0·253 ounce platinum metals a ton, with the palladium-platinum ratio variable, but of the order of 50 to 1. Shipments of concentrates commenced in 1918 and the mine was closed in 1926. During the years of operation, recoveries appear to have ranged annually from about 1,500 to 3,000 ounces palladium, with some platinum and other metals of the group. The 1923 recovery of 2,257 ounces of platinum metals from 49,000 tons of ore was at the rate of 0·046 ounce a ton, considerably lower than the average value given above.

Mexico

Mexico is not known to contain any important deposits of the platinum metals. Sandberger stated he detected platinum in pseudomorphs of limonite after pyrite from an unrecorded locality (Kemp, 1902, page 31) and the metal is present in very finely divided state in certain lateritic clays of the states of Guerrero and Hidalgo (Lumb, 1920, page 45). It is also reported that platinum is present in alluvial deposits on both sides of the Sierra Madre (Nicholl, 1925).

SOUTH AMERICA

Colombia

It was in Colombia that platinum was first discovered, and investigation of material reaching Europe from there in 1735 proved it to be a new metal. The platinum occurs in auriferous placers, some of which were known by Europeans as early as 1537, but it was not until 1778 that any of them were worked for platinum. From then until the discovery of the Ural deposits in 1823, Colombia was the source of all the world's platinum supply. There has been continuous production since that time, and although the output has been small as compared with that from the Urals, Colombia has remained until recently the second largest producer of platinum. J. L. Howe (1918, page 607) has estimated that the total output to the end of 1916 was between 700,000 and 735,000 ounces. In recent years, production of crude platinum has been as follows.

TABLE XXXIII

Platinum Production, Colombia, 1912-1932

Year	Ozs. troy	Year	Ozs. troy	Year	Ozs. troy
1912	27,021(d)	1919	32,236(d)	1926	46,714(d)
1913	17,635(d)	1920	33,500(c)	1927	45,830(d)
1914	16,264(d)	1921	34,000(c)	1928	53,531(d)
1915	18,749(d)	1922	43,574(d)	1929	45,577(d)
1916	25,592(d)	1923	40,676(d)	1930	42,382(d)
1917	26,421(d)	1924	46,533(d)	1931	44,311(d)
1918	34,266(d)	1925	38,291(d)	1932	45,075

(c) Estimated by Hill, J. M.: U.S. Geol. Surv.
(d) Exports.

Most of the production comes from the Choco district near the western frontier of the republic. The deposits (Kunz, 1918) are all alluvial, the principal sources being the San Juan and Upper Atrato Rivers and their tributaries. Dr. Tulio Ospino of the Colombian School of Mines has estimated that alluvial deposits extend over an area of over 5,000 square miles in the region lying west of the central ridge of the Colombian Andes.

According to Kunz the platinum and associated gold are found chiefly in the gravels of present streams that have eroded platiniferous Tertiary conglomerates, and are, therefore, reconcentrates of these older gravels. The conglomerate contains rounded boulders of basic rocks such as diabase, peridotite, and dunite. Streams that have not eroded the conglomerate are not platiniferous. In the San Juan River and its tributaries gold and platinum are present in about equal proportions; in the less productive Atrato the ratio is about 85 gold to 15 platinum. In 1916 there were estimated to be about 68,000,000 cubic yards of gravel that could be regarded as certainly profitable for working, and a total reserve of possible productive ground of 336,000,000 cubic yards. At present a large part of the production is won by dredges of the South American Gold and Platinum Company, but a very considerable amount is still obtained by native workers using hand methods. The British Platinum and Gold Corporation, Limited, a previous large operator, suspended operations in 1927, largely because of legal difficulties. Crude platinum from Colombia contains about 85 per cent platinum and small percentages of other metals of the group, principally iridium and osmium. The following average assay, of crude platinum for conversion purposes, is given: platinum 86·69, palladium 0·54 per cent, iridium 0·85 per cent (U.S. Mineral Resources, page 97, 1931).

According to Lumb (1920, page 57) platinum is found in Choco district in serpentine and also in quartz veins that traverse granite and contain palladium, iridium, osmium, and rhodium.

The result of the production allotment under Consolidated Platinums, Limited (*See* page 152), whereby Colombia was allowed only 9 per cent of the total sales controlled by this company, resulted in a decrease in Colombian output. Indeed, imports into the United States for the first six months of 1932 were only 7,824 ounces as compared with 43,155 ounces for the year 1931 (Min. Ind., 1931, page 440).

According to Codazzi (1929, pages 199-204) the only workable gravels in Colombia are in Barbacoas region, Department of Narino, and Choco district. No primary deposits have as yet been found, but small, rounded pieces of greenstone containing platinum in the gravels suggest a source in ultrabasic rocks that are known at the headwaters of the Atrato and San Juan Rivers. In the platiniferous gravels are found, also, iridosmine, osmiridium, native palladium, and, in some parts, small scales of native copper, gold, and a natural alloy of gold and silver. Native palladium is generally present and always contains a small quantity of platinum. The iridosmine is of two varieties; one contains 20 to 50 per cent osmium and the other 70 to 75 per cent. The following analysis is given: iridium 72·90, osmium 24·50, and iron 2·60 per cent. Codazzi states that recent explorations indicated that the richest gravels are in the extensive region drained by Pato and Andaqueda Rivers, tributaries of the Atrato, and the Iro, Condoto, and Tamana flowing into the San Juan, particularly the upper parts of the Condoto and Opogodo Rivers. The author gives the following analysis, by Berzelius, of platinum from the Condoto: platinum 84·30, rhodium 3·46, palladium 1·06, iridium 1·46, osmium 1·03, iron 5·31, and copper 0·74 per cent; total 97·36 per cent.

Duparc and Tikonowitch (1920, pages 478-483) discuss the Colombian deposits at some length. They contend that the primary source of the platinum of Choco district is a belt of ultrabasic rocks, including dunite and pyroxenite, west of Cerro Irro. Only those streams that drain this belt carry platinum in their gravels. Some of the alluvial deposits near the sources of the streams are said to have been very rich, and to have yielded coarse, angular platinum, at times encased in chromite.

Ecuador

Platinum, with gold, occurs in stream gravels in Ecuador in the area covered by the Rivers Boyota, Cachabi, Uimbi, Santiago, and Cayapas, but it has not yet been found in sufficient quantities to be of economic importance (Lumb, 1920, page 58).

Chile

Platinum and gold are present in the black sands, which contain olivine among other siilcates, on the west coast of the island Chiloe, off the coast of Chile. The deposits are believed to have been derived from the erosion of the basic rocks of the mainland Cordillera and to have been transported to their present location at a time when the island was still attached to the mainland. The richest deposit is at the Lavaderos beach, near the extreme southwestern point of the island, and it was reported that an attempt was to be made to exploit this deposit with a steam-operated drag-line scraper (Mella, 1921).

Brazil

Platinum was first noted in Brazil in 1801 by Jose Vieira do Couto, in the sands of Lages River, near Conceiçao, Minas Geraes, and it has since been recorded from numerous places, particularly in the basin of the Rio das Velhas, in the southern part of the state. According to E. Hussak (1916), the platinum in this region occurs only in rivers having their source on the eastern slope of the Serra do Espinhaço. He believes that the primary source of the platinum was an olivine rock, or gabbro, but since the metal occurs in mammillary form, and often in thin, foliated crusts with radiated structure, he is of opinion that it is secondary, having most probably been deposited from solutions resulting from the decomposition of platiniferous pyrite or of sperrylite. In some of the deposits the platinum is very rich in palladium, one analysis, by G. Florence, showing: Pt, 73·99; Pd, 21·77; Ir, 0·08; undetermined (Rh and Os), 3·14; Fe, 0·10; insoluble residue, 0·92 per cent.

In the Rio Abaeté, Minas Geraes, the platinum, believed to be derived from olivine rocks, contains only a trace of palladium, and closely resembles that from the Urals.

Platinum also occurs in alluvial auriferous deposits in the states of Matto Grosso and Bahia.

Palladium and platinum are found in several localities as disseminations in the crumbly, gold-bearing "jacutinga" intercalations of the itabirites; at the Congo Seco mine, Minas Geraes, palladium-gold has been mined from zones of lime silicates produced by contact metamorphism, the intrusive being granite with associated pegmatites.

Both in the alluvial deposits and in the jacutinga reefs, gold and palladium are in some cases present in the natural alloy known as porpezite, which received its name from its occurrence at Porpez, Brazil.

Although it is evident that the platinum metals are widely distributed in Brazil, no important production has ever been attained.

British Guiana

Potarite, the amalgam or mercuride of palladium, PdHg, occurs as white grains and small nuggets in gold and diamond washings on Potari River, British Guiana (Spencer, 1924).

French Guiana

"An announcement was made to the French Academy, in 1861, by Damour, that a very curious nugget had reached him from Aicoupai, on Hamelin Creek, in the basin of the Appronaguel. It weighed 0·85 gramme. Its specific gravity was 13·65. It was malleable, silvery white, and less fusible than gold. On analysis it yielded:

	Per cent
Platinum	41·96
Gold	18·18
Silver	18·39
Copper	20·56
Total	99·09

"It dissolved so easily in nitric acid that it was believed to be clearly a mechanical mixture, and not an alloy—that is, the copper and silver were easily removed, and a brown sponge of gold with white scales of platinum remained" (Kemp, 1902, page 62; *See also* Kunz, 1919).

Argentine

Platinum occurs in small amounts in serpentine of Alta Gracia and there are gold-platinum alluvial deposits in Tierra del Fuego, at Paramo, near Cape San Sebastian (Ann. Bibliog. Econ. Geol. 1930, vol. III, No. 1, 404).

CHAPTER V

STATISTICS OF PRODUCTION

In spite of the fact that the world's supplies of platinum metals are derived from comparatively few sources, and that most of the platinum has come from a single country—Russia—there are no reliable statistics giving the production over a period of years or for any single year. Thus, taking at random the year 1914, the Russian production, in troy ounces, is variously given as follows:

	Ozs. troy
Officially reported, crude	157,182
Estimated by J. M. Hill, U.S. Bureau of Mines, fine	202,000
Estimated (Imp. Inst. Bull., "The Platinum Metals," 1920), crude	240,000
Queensland Geol. Surv. Bull., "Platinum," 1920	241,200

The discrepancies arise from two causes. They are in part due to the fact that the returns in some cases refer to " crude " platinum, and in others to " fine " platinum. Where the metal is recovered as a by-product in some metallurgical process, as from the Sudbury ores, the production naturally is given as fine platinum; but where placers are concerned, it is more usual to state the production in ounces of crude material. Some authorities give, instead, figures representing the estimated amount of pure metals in the crude; that is to say, based on the average composition of the crude platinum from the district or country concerned, a deduction is made for the iron and any other base metal that may be present. Moreover, in statistical tables giving the production of " fine " platinum, the other metals of the group are necessarily excluded, or should be. The difference between the estimated Russian production for 1914, quoted above, of 240,000 ounces " crude " and 202,000 ounces " fine " is thus explained, the Russian crude platinum having a " fineness " of over 80 per cent.

The difference between the " officially reported " and " estimated " crude production is to be ascribed to the frailty of human nature. It is believed, and in fact it may be said to be definitely established, that from one-third to one-quarter of the Russian production is (or at least has been in the past) never reported to the Government, but has been regularly stolen by individual miners and by some of the smaller producers, and smuggled out of the country; in the case of the latter, to escape payment of registration charges and taxes. In estimating the Russian production, therefore, it is customary to add from 20 to 30 per cent, or even more, to the officially recorded output. To a lesser extent, a similar correction should probably be made in all cases where the platinum is obtained from placer deposits.

For these reasons, any statistics of platinum production must be regarded as merely approximate. J. L. Howe (1918, page 607) has estimated that the world's total production of crude platinum up to the end of 1916 falls within the following limits:

TABLE XXXIV

Estimate of World Production of Crude Platinum to the end of 1916

Country	Ounces troy	
	Minimum	Maximum
Russia	7,115,482	10,128,308
Colombia	700,000	735,000
Borneo	175,000	200,000
United States	10,000	12,000
Canada	9,000	10,000
Miscellaneous	9,000	10,000
Total	8,018,482	11,095,308

Although the total production probably does fall within the limits given, more nearly approaching the maximum than the minimum figure, the output of the different countries is open to some question. Kunz (Min. Ind., 1917) felt that the minimum Russian figure was probably too small and that both Colombia and Borneo had been rather generously treated. That the minimum figure for Russian production is too low is shown by the fact that the official statistics of the Russian Government show that: "The total yield of crude platinum from 1824 to 1915, inclusive, amounted to 7,630,761 troy ounces. This aggregate yield, however, should be increased to approximately 9,500,000 ounces, for the official data fail to give the total production" (Merz, 1918).

The amount credited to Canada, however, 9,000 to 10,000 ounces, is certainly very considerably below the actual production, and if the output from Tulameen placers alone is taken into account, the maximum given by Howe should probably be doubled. Camsell, in his report on Tulameen district, published in 1913, states that "the platinum recovered from the gravels of this district has been variously estimated at 10,000 to 20,000 ounces." Poitevin (1923, page 90) states that although the platinum production of Tulameen is officially given as 10,000 ounces, it is generally conceded that the output of the placers was more likely to have been 20,000 ounces. In addition to this there has been the presumably much larger amount recovered as a by-product in refining the nickel-copper matte from Sudbury district. No complete figures for the production of platinum metals from this source prior to 1920 are available, but sufficient is known to prove that the output was really important and, if added to the Tulameen production, would swell Canada's total output of the platinum metals far beyond the maximum figures given by Mr. Howe. Thus, to the end of 1916, the total production of platinum metals from Canadian ores, exclusive of placer platinum, as given in the Mineral Production of Canada, 1928, was 27,843 fine ounces, made up of 10,063 ounces of platinum, 16,759 ounces of palladium, and 1,021 ounces of rhodium; the platinum and palladium included some amount of the other metals of the group, and the rhodium production included some ruthenium, osmium, and iridium. However, this production probably includes only the output of the International Nickel Company's plant at Orford in New Jersey, and certainly only that from 1907 to 1916 inclusive. The matte produced by the Mond Nickel Company at Sudbury during the years under discussion was sent to their refinery at Clydach, Wales, and, prior to 1920, no record of the production of platinum metals there was reported. This production, however, was certainly important, for by the Mond process recovery of all the precious metals in matte is practically complete, whereas the Orford process used by International Nickel recovered only a small percentage. In all probability the Mond recoveries considerably exceeded those by International Nickel, and the few figures that are available support this belief. According to Lumb (1920, page 25), Mond Nickel Company used to dispose of their precious metal residues, from Canadian matte, to Johnson, Matthey and Company, Limited, for refining, and during the years 1915 to 1918 the residues thus disposed of were estimated to contain the following amounts of platinum metals.

—	1915	1916	1917	1918
	Ozs. troy	Ozs. troy	Ozs. troy	Ozs. troy
Platinum	3,078	3,782	4,913	4,465
Palladium	5,474	....	....	....
Iridium and rhodium	973	....	....	....

Lumb gives the following figures, supplied by Johnson, Matthey and Company, of platinum extraction from these residues, in ounces troy: 1916, 3,722; 1917, 4,719; 1918, 4,958. Apparently none of the English recovery for these or preceding years has been credited to Canada in official production statistics. It is, therefore, very apparent that up to 1920 Canada has been credited with only a small part of the metals of the platinum group that have been derived from Canadian sources.

From what has been said above, it is evident that no complete, accurate figures for production of platinum metals from Canadian sources prior to 1920 can be given, although it is certain that official statistics for that period are much too low. In 1920, however, and since then, the Annual Report of the Ontario Department of Mines contains apparently complete figures of production for Ontario, including recoveries by the Mond Nickel Company in England. From 1924 to date the figures given in the Mineral Production of Canada, Dominion Bureau of Statistics, are also, apparently, complete, although for four years before that they evidently do not include recoveries made in England. By combining figures obtained from these two reliable sources, the following table of production from 1920 to 1932 has been constructed. It represents the most accurate figures that are available and should be essentially complete. The figures for placer-platinum are, however, taken from official figures of production, and quite probably do not represent the total output. This, however, is but a small item.

TABLE XXXV

Production of Metals of the Platinum Group, From Canadian Sources, 1920-32

—	Platinum				Palladium		Rhodium		Ruthenium		Osmium		Iridium		Total	
	Lode		Placer													
	Fine ozs. troy	$	Fine ozs. troy	$	Fine ozs. troy	$	Fine ozs. troy	$	Fine ozs. troy	$	Fine ozs. troy	$	Fine ozs. troy	$	Ozs. troy	$
1920.....	8,345	....	17	719	10,199	....	b 522	....	.....	....	....	.....	.....	....	19,083	....
1921.....	5,412	402,508	23	1,585	7,729	446,588	b 277	12,938	.....	....	....	.....	.....	....	13,441	863,619
1922.....	4,802	468,762	12	1,154	6,862	446,030	b 124	9,920	.....	....	....	.....	.....	....	11,800	925,866
1923.....	6,810	793,617	7	816	8,511	584,280	b 304	40,736	.....	....	....	.....	.....	....	15,632	1,419,449
1924.....	9,181	1,090,858	5	569	8,923	811,993	367	27,500	78	2,106	69	4,924	79	16,590	18,702	1,954,540
1925.....	8,692	1,027,477	6	715	7,856	608,727	....	....	.....	....	c 432	40,242	.....	....	16,986	1,677,161
1926.....	9,471	919,349	50	4,258	9,790	626,166	204	9,969	16	791	....	.....	14	3,252	19,545	1,563,785
1927.....	11,217	716,653	11	960	11,247	541,319	222	6,853	31	1,073	....	.....	45	4,945	22,773	1,271,803
1928.....	10,483	706,090	49	2,819	11,909	511,998	895	20,951	561	16,331	....	.....	242	78,553	24,139	1,336,742
1929.....	12,491	845,057	28	1,699	12,408	471,614	3,037	151,850	1,376	66,048	....	.....	497	119,777	29,837	1,656,045
1930.....	34,007	1,542,490	17	771	29,959	689,217	b 4,133	206,650	.....	....	....	.....	.....	....	68,116	2,439,128
1931.....	44,725	1,595,117	50	1,783	a 46,918	1,217,717	....	....	.....	....	....	.....	.....	....	91,693	2,814,617
1932.....	27,284	1,097,021	59	2,372	a 37,613	901,890	....	....	.....	....	....	.....	.....	....	64,954	2,001,283
Total....	192,920	11,204,999	334	20,220	209,924	7,857,539	10,085	487,367	2,062	86,349	501	45,166	877	223,117	416,701	19,924,757

a Includes other metals of the platinum group, except platinum.
b Includes osmium, iridium, and ruthenium.
c Includes iridium and ruthenium.

It should be recalled at this point that, with the exception of placer platinum and small, irregular recoveries at Trail in British Columbia, and the as yet small production of platinum metals by Falconbridge Nickel Mines, Limited, the entire Canadian production of these metals comes from ore of the International Nickel Company of Canada, Limited, the whole output, further, being refined at the Acton plant in England.

Canada's position in the world's production of platinum is shown in the following table which is reproduced from the Mineral Industry. It will be seen that the figures for Canada do not check exactly with those given in the preceding table which is believed to be more accurate.

TABLE XXXVI

World's Production of Platinum[1] (From *The Mineral Industry*)

(In troy ounces)

Year	Australia	Canada (b)	Colombia (f)	Russia	United States (b)	Japan	South Africa	Sierra Leone (g)	Abyssinia	Total
1920	640	4,345	(c) 33,500	11,323	(e) 11,500	4,830	...	...	...	69,300
1921	189	5,412	(c) 34,000	5,500	2,899	8,014	...	...	...	55,200
1922	61	4,802	45,448	27,200	1,998	7,196	...	...	...	86,700
1923	415	6,810	48,348	38,000	2,114	4,665	...	...	...	100,000
1924	460	9,186	51,530	66,800	3,523	6,956	...	...	...	138,500
1925	405	8,698	62,000	94,800	4,325	4,519	600	...	...	175,300
1926	280	9,521	(d) 46,676	92,700	4,923	5,873	8,400	...	640	169,000
1927	160	11,217	(d) 70,055	(e) 100,000	4,449	6,169	16,800		1,200	(e) 200,000
1928	354	10,532	53,530	(d) 78,927	4,631	1,459	20,200		3,247	(e) 173,000
1929	128	12,519	45,576	(d) 93,800	5,620	...	25,400	29	7,716	(e) 192,000
1930	155	34,024	(d) 46,232	...	5,348	...	45,500	542	8,038	(e) 230,000
1931	238	44,745	(e) 42,000	...	5,595	...	36,110	594	...	...
1932	336	27,206	(e) 30,500	...	1,912	...	5,808	527	...	...

[1] Estimated content of fine platinum contained in crude output. There has been a small production in some years from India, Borneo, and other countries, but none of importance.

(b) Platinum of domestic source recovered by refiners.

(c) Estimated by J. M. Hill, U.S. Geol. Surv.

(d) Exports.

(e) Estimated.

(f) Imperial Institute figures; mostly crude.

(g) Crude.

The table includes platinum only, excluding other metals of the group and also iridosmine. Production of these latter has been referred to under the several countries and districts from which they are obtained. Most of the world's palladium has come from Canadian and United States ores. In addition to that obtained from Sudbury ores, there was in some years a small recovery at the Trail plant; in 1928 this amounted to 520 ounces. The Queensland Geological Survey bulletin *Platinum* (1920) states, on page 162, that the Canadian production of palladium for the period 1902-1913 amounted to 14,931 ounces troy, and that the United States produced 15,504 ounces during the years 1914-1918. It is also stated that, in the same period, the United States produced 1,383 ounces of iridium. No authority is given for these figures. South Africa now contributes an important amount of palladium each year, from ores of the Merensky Horizon, the platinum metals of which contain a considerable percentage of palladium as well as smaller amounts of other metals of the group. South Africa also leads the world in production of "osmiridium," having displaced Tasmania. At present Canada is easily the largest producer of palladium, and ranks second to Russia in output of platinum.

It has been apparent for some years, and is now definitely established, that the world is capable of producing, from readily available sources and with existing equipment, considerably more of the metals of the platinum group than it can at present consume. This condition has been accentuated, during the later years, by the discovery and exploitation of the remarkably rich and extensive lode deposits of Transvaal, South Africa. Consequently, maximum production by the major producing countries would lead to an excess of the metals being placed on the market and would mean a drastic drop in prices that would render exploitation of the metals unprofitable for all but the lowest cost producers.

MARKETING CONDITIONS

As a result of the conditions outlined above it is apparent that, unless the industry is to become seriously disorganized, some sort of production and marketing control is essential. Such control is at present established. A brief review of the manner in which the bulk of the world's platinum metals have been marketed in the past serves to emphasize the importance of some such accord. Up to 1903 the sale and price of platinum were largely controlled by Johnson, Matthey and Company, Limited, of London, England. Then this firm and other powerful interests joined a syndicate, formed by the Societe Anonyme d'industrie du Platine, a French company, that stabilized the price at about £9 an ounce in the years preceding the war. During the war this organization was dissolved, but soon after the armistice another powerful syndicate was formed. It included Johnson, Matthey and Company, Limited, Baker of New York, and interests of France and Germany, and controlled production and sales of the principal producers until 1927. In that year the quota allowed to Russia—between 60,000 and 70,000 ounces—was not sufficiently large to satisfy that country, although in view of increased production elsewhere the syndicate considered it too high and wished to reduce it. Rusplatina, the organization controlling exploitation of the Ural deposits, established its own marketing organization and the

Soviet output was placed on the market in direct competition with that of the syndicate. As a result the price of platinum fell from £22 an ounce in January to £13, 10s. in July. Unsettled conditions continued for nearly four years, so that with some fluctuations, the bottom price of $23 an ounce was reached in May, 1931. On the eighteenth of that month the price was raised to $27.50 and on June 8 to $40 an ounce. These increases presaged the formation of Consolidated Platinums, Limited, which was announced in October, 1931.[1] The purpose of this new corporation is " to import, buy, sell, insure, handle, store, dispose of, and (or) deal in metals of the platinum group, and compounds and residues thereof, etc." It will control the platinum output of the principal producers in Russia, Canada, South Africa, and Colombia and will promote the use of platinum through an intensive research and market development program, in co-operation with the existing producers, consumers, and distributers. The sales allotment under the new control, according to the Mineral Industry, gives Russia 50 per cent, Canada 26 per cent, South Africa 15 per cent, and Colombia 9 per cent. Sales will be through existing distributers and dealers.

Practically the entire platinum production of Canada and South Africa is controlled by the new accord. It would seem, therefore, that as long as the present agreement exists, Canada is definitely slated for the position of second largest producer of platinum, with an output of just over half of that of Russia. As the Soviet marketing organization is a party to the accord, it may be assumed that practically the entire production from Russia is controlled. Available statistics and estimates place this production at about 100,000 ounces a year. At that rate, Canada would contribute 52,000 ounces of platinum a year, considerably more than has yet been produced in any one year, but certainly not more nor nearly as much as International Nickel Company can produce, under maximum operations, from readily available ores; yet about twice as much as was produced in 1932, when operations were greatly reduced. But, as noted in Chapter IV, page 130, South African output of platinum metals was reduced in the second half of 1931 to 28,000 ounces a year, or about 23,000 ounces of platinum. On this basis Canada's output should be close to 40,000 ounces, or somewhat less than the 1931 official production. Actually, the production in 1932 was only 27,151 ounces.

For the last thirteen years, however, with one apparent exception, Canada's platinum production has been exceeded by her production of other metals of the group, principally palladium. As the recovery of these other metals is inseparable from that of platinum, it is apparent that Canadian total production of platinum metals will normally be more than twice that of platinum alone. Taking the official productions of the last three years, the amount of platinum is exceeded by the amount of other metals of the group by 12 per cent. Russia, exploiting alluvial platinum that contains, on the average, only a few per cent of other metals of the group and very little palladium, should not, at the outside, contribute more than 9,000 ounces of other metals of the group for 100,000 ounces of fine platinum, even assuming complete extraction of these metals from the crude material, giving a total production, on the basis of 100,000

[1] Eng. and Min. Jour., vol. 132, No. 9, 1931, p. 428. Min. Ind., 1931, p. 428. Chem. Trade Jour. and Chem. Eng., vol. 89, pp. 395, 422, 434, 1931.

In March, 1934, P. D. Merica informs the writers that advice from the Mond Nickel Co. indicates that Consolidated Platinums, Ltd., is not at the moment active in the platinum market.

ounces of platinum, of 109,000 ounces of platinum metals. Canada, on the basis of 100,000 ounces a year for Russia, would contribute 52,000 ounces of platinum and appreciably over that amount of other metals of the group. Using the average of the last three years, as noted above, the total production would be 110,240 ounces of platinum metals. If, therefore, the sales allotment of the new accord applies to the total, or practically the total, production from Canada and Russia, and if it is adhered to, it would seem that Canada will equal or slightly exceed Russia's production of the platinum metals, and thus share or attain the position of the world's largest producer. Of her ability to produce well over 100,000 ounces of these metals a year from Sudbury ores, there can be no doubt, provided general economic conditions permit of more extensive production of nickel and copper than under the present (1932) very restricted operations. The company is prepared, under maximum operations, according to official statement, to contribute 300,000 ounces of platinum metals, annually.

MARKET PRICES OF THE METALS

For many years after its discovery in Colombia, platinum remained more or less of a curiosity and few uses were found for the metal. Even after comparatively large supplies were assured by the discovery, early in the nineteenth century, of the extensive alluvial deposits in the Urals, there was for many years only a small demand for platinum, and as a consequence its price remained low. One of the main uses of the metal in those days was for coinage. Gradually, however, the unique chemical and physical characters of platinum opened up a variety of uses for the metal. The price began to mount, and in 1845 the Russian Government was forced to discontinue minting platinum coinage because its metal value exceeded the face value of the coins. This happened when the price rose above $7.15 an ounce. The rate of increase in the market price remained very slow, however, and in 1893 platinum was still selling at about $10 an ounce. Then it began to mount very rapidly, and had risen to between $20 and $21 an ounce, by 1903, and to about $45 an ounce, by 1913. During the war there was an extraordinary demand for platinum for certain essential purposes, and at the same time there was an almost complete cessation of supplies from Russia. As a consequence, the price of the metal soared to well over $100 an ounce, and maintained this level for ten years, reaching a maximum of about $120 in 1925. This was due to the fact that the Russian platinum-mining industry had become completely disorganized, and the yield instead of being some 200,000 ounces of new platinum annually, dwindled, until it reached a minimum of 6,582 ounces in 1921. Since that year, Russian production has gradually picked up again, and now amounts to some 100,000 ounces a year. At the same time, there has been a notable, and continuous, increase in the yield from Colombia, which in the past fifteen years has about doubled its rate of production; South Africa has entered the field with contributions of growing importance since 1925; and recoveries from Sudbury ores have shown a very considerable increase. The total result is that the world's annual supplies of new platinum, which had dropped to about 55,000 ounces in

1921, have now reached the 200,000-ounce mark, and are within measurable distance of the normal, annual supply of pre-war years. With this increase in supply has come a corresponding decrease in price, to an average of $35.66 in 1931.

The accompanying table gives the average market price of platinum (and of other metals of the group) over a period of years, as quoted in "The Mineral Industry."

TABLE XXXVII

Average Market Price of Platinum Metals

(From *The Mineral Industry*)

(In United States dollars a troy ounce)

Year	Platinum	Palladium[1]	Iridium[1]	Rhodium	Osmium	Ruthenium
1910	32·70	....	....	....	....	....
1911	43·12	55	62	....	....	....
1912	45·15	55	65	....	....	....
1913	44·88	50	65	....	....	....
1914	45·14	44	65	....	....	....
1915	47·13	56	83	....	....	....
1916	83·40	67	94	....	....	....
1917	102·82	110	150	....	....	....
1918	105·95	135	175	....	....	....
1919	114·61	130	255	....	....	....
1920	110·90	108	331	....	....	....
1921	75·03	59	195	....	....	....
1922	97·62	60	200	....	....	....
1923	116·54	....	....	....	....	....
1924	118·82	78–110	260–325	85–105	95–104	....
1925	119·09	75–83	325–400	85–90	100–115	....
1926	113·27	70	169	77	78	69
1927	84·64	58	120	50–75	55–70	....
1928	78·58	46	294	40–70	55–85	45–75
1929	67·66	35–44	200–275	40–55	55–65	42–55
1930	45·358	24–35	160–250	45–55	60–75	35–48
1931	35·665	18	75–190	45–55	60–70	38–65

[1] Prices for 1911-1921 as quoted by J. M. Hill in Eng. and Min. Jour. Press, Oct. 21, 1922.

The course of the platinum market during 1932 is shown in Metal and Mineral Markets for December 29, 1932, as follows, in United States dollars a troy ounce fine platinum.

January	$ 40 00	July	$ 35 20
February	40 00	August	35 00
March	40 00	September	33 80
April	40 00	October	33 00
May	39 50	November	33 00
June	37 50	December 6 on	30 00

At the end of the year the official price of the leading American interest was $30 a troy ounce of platinum, but cash transactions between dealers and refiners were quoted at several dollars less. The current London quotation was given as £8 17s. 6d. to £9. Palladium prices also fell during the year and at the end this metal was quoted at $17 to $18 a troy ounce.

London quotations were nominal, from £4 to £4 5s. Iridium at the year end was selling at $55 an ounce for 98 to 99 per cent sponge and powder, or £12 to £14 in London. Osmium was quoted at $60 to $65 an ounce, or £11 10s. to £12 and rhodium at $48 to $50 an ounce. Ruthenium was quoted at $40 to $45 a troy ounce.

COSTS OF PRODUCTION

Wagner contended (1929, page 288 *et seq.*) that, allowing for inevitable fluctuations and taking the actual purchasing power of gold as a basis, the world is spending just about the same amount on platinum at present (1929) as before the war and he felt that maximum world consumption of new platinum each year would not exceed about 175,000 ounces. Even allowing for an increase of this estimate to about 200,000 ounces a year, it is very apparent that, under favourable economic conditions, known deposits are capable of producing very much in excess of this amount. This excess of potential supply over demand has, as has been seen, necessitated and produced co-operative restriction of output with a view to stabilizing prices at a reasonable and profitable level. That level depends, of course, on the costs of the leading producers of platinum.

Wagner (1929, page 291) estimated these costs in 1929. He stated that, according to information from a very reliable source, the cost of producing platinum in the Urals ranged from £10 to £12 an ounce and that Colombian costs were apparently much the same. He concluded that, assuming his information to be correct, the major part of the platinum from these countries could not be produced at less than £10 an ounce. For the Transvaal, costs varied from about £6 an ounce for ores of the Merensky Horizon to £7 or £8 for dunite deposits, none of which is at present operating. Canada, however, is in a more fortunate position. Virtually the entire production comes as a by-product from nickel-copper ores and consequently the cost of production is very low. A recent article (Anon., 1931) states that the ultimate costs of refining are greatly influenced by the scale of operations, but that on the 1931 scale the cost of refining platinum metals at Acton works out at about 10 shillings an ounce, without any appreciable increase in the cost of producing the base metals, nickel and copper.

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