CHALCOPYRITE DEPOSITS IN NORTHERN MANITOBA.

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The deposits of chalcopyrite recently discovered and developed in Northern Manitoba lie near the western boundary of the province, a short distance northwest of Lake Athapapuskow, which is shown on Maps of Canada, fifty miles north of the Saskatchewan river. A large part of the journey from the railway at the town of The Pas, must be made by canoe in summer, or by sleigh in winter, and all the ore has been brought out during the winter months to the lakes that can be reached by steamers, and thence by scows down the Saskatchewan river.

TOPOGRAPHY.

The topography is rather monotonous for most of the distance from the railway to the producing area. Saskatchewan river flows in a number of changing channels through swampy country, and in many places is separated from broad, shallow lakes only by willow-covered levees. These lakes and the muskeg areas that border them act as reservoirs which are flooded during periods of high water. Northward from the Saskatchewan the same monotonously flat muskeg country continues to the boundary between the Pre-Cambrian and the Palæozoic formations. The rocks of the latter in many places stand up in an escarpment 70 to 80 feet above the lower lying but more rugged surface of the older rocks. In contrast to the unbroken level of the southern district with shallow, islandless lakes with low shores, the northern district abounds in ridges and hills, has only small muskeg areas and is dotted with almost countless, clear, island-studded, rock-bounded lakes of all sizes.

GENERAL GEOLOGY.

Since the rocks associated with the ores are all of Pre-Cambrian age it will be necessary only to mention that Palæozoic dolomites cover the older rocks south of lake Athapapuskow, and that Glacial and post-Glacial deposits form a discontinuous cover of varying thickness over all of the consolidated rocks.

The Pre-Cambrian succession is as follows:

- Granite
- Granite-gneiss
- Hybrid granitic rocks
- Intrusive contact
- Arkose and conglomerate
- Unconformity
- Slate
- Unconformity?
- Granite porphyry
- Intrusive contact
- Sedimentary and igneous gneisses
- Volcanic rocks and derived schists

Volcanic Rocks.—The oldest rocks are comparable to the oldest rocks of Pre-Cambrian age found in other areas; but, as they are separated from similar formations by great stretches of granites and gneisses to the east and by the Palæozoic cover to the south, it is not and may never be certain that they are of the same age as the Keewatin rocks of Lake Superior. They consist almost entirely of volcanic rocks of various types. The most common variety is massive, green to grayish-green in color and weathers to brownish color. The ellipsoidal structure figured in so many descriptions of Pre-Cambrian lavas is very strikingly developed and there are, in addition, certain other typical volcanic forms. Autoclastic bands have been formed by the rolling of the semi-solidified lava and by shearing. Pyroclastic beds are common. They have been formed by the incorporation of bombs of all sizes, from those a foot in diameter down to the finest ash, in the still molten rock. The pyroclastics have, superficially, much the appearance of some of the altered conglomerates.

erates of the district. All types, but chiefly the massive lava without the ellipsoidal structure, have been changed, locally, into chlorite schist by pressure and shearing. Some of this alteration occurred before the first period of erosion since, in the conglomerates overlying the volcanics, there are pebbles of schist which have not been sufficiently deformed by movements affecting the conglomerate to account for their schistose character. Associated with the volcanics there was probably deposited a certain amount of normal sediments, now altered to schists indistinguishable from those of igneous origin.

Complex of Gneissic Rocks.—Outside of the district in which the sulphide ores have been found there are areas of hornblendic gneisses and garnetiferous schists and gneisses that represent in part a sedimentary series apparently overlying the volcanics but with no recognized unconformity. These gneisses are intruded by granite sills and are cut by innumerable pegmatite dikes. The sills and dikes are believed to be of different ages, some of them older, some younger, than the conglomerates and arkose that lie above the greenstone series.

Granite Porphyry.—There is some evidence to show that one small batholith of granite porphyry is older than at least part of the sediments. The rock has rather peculiar bluish phenocrysts of quartz and under the microscope shows unusual, irregular, graphic intergrowths of quartz and feldspar, similar to intergrowths that occur in granite pebbles from the conglomerate.

Slate.—A narrow belt of slate has been found bounded on both sides by greenstone schist. No unconformity has been noted between the two rocks but the slate is lithologically like that lying unconformably above the volcanics farther west.

Conglomerate and Arkose.—The first formation that is clearly unconformable above the volcanic complex in the area is a thick series of conglomerate, arkose, and greywacke, now lying in closely folded synclines or as infaulted blocks in the older rocks. The folding following the deposition of these sediments has been so intense that even pebbles of quartz, granite, and quartzite, have been twisted, bent and drag-folded. Some of the lower beds consist largely of debris from the greenstone complex and

these have been reconstituted into rocks so closely resembling the igneous original that it is hard to delimit the exact boundaries of the sedimentary synclines.

Bedding in the sediments is not plainly marked, but in many places there is a lenticular arrangement, with very sudden variations both in composition and texture. These sudden changes, as well as the mineral constituents of the rocks, show rather conclusively that this series was deposited as outwash fans by rapid streams and probably under arid conditions. The close folding and the faulting that the sediments have undergone make a measurement of the thickness impossible but it must have been thousands of feet.

Granite Gneiss and Granite.—The diastrophic period that followed this final Pre-Cambrian sedimentation was accompanied by intrusions of granite. These took place through a considerable length of time and the intrusives vary somewhat in character but are believed to be differentiates from a common magma rather than products of different periods of intrusion. The ore is thought to be genetically related to certain of these differentiated magmas. Texturally, the granitic rocks are massive granite, in places porphyritic, and granite gneisses, faintly banded owing to a concentration of the basic constituents biotite and hornblende. There is no evidence of any great secondary rearrangement as the longer axes of the biotite foils are not parallel to the banding. In composition the gneisses are practically identical with the massive granite.

Analyses ¹ .	Granite Gneiss.	Granite.
SiO ₂	67.71	66.76
Al ₂ O ₃	14.69	15.39
Fe ₂ O ₃	2.07	1.27
FeO	3.73	1.49
MgO	1.00	1.50
CaO	4.94	2.56
Na ₂ O	3.39	4.47
K ₂ O	1.28	3.35
H ₂ O	0.25	0.60
TiO ₂	0.30	0.15
CO ₂	...	undet
	99.37	97.54

¹ Analyst: M. F. Connor.

There is no evidence that there was further deposition or intrusion nor any very marked disturbances from the time of the invasion of the granite, throughout the rest of the Pre-Cambrian, the Cambrian, and part of the Ordovician. It was probably a period of normal erosion and must have been very long. The great thickness of cover under which the granite batholiths lay was almost completely removed and the mountains of that early period were levelled to a surface much like that at present found in the Pre-Cambrian area. This erosion reached to so great a depth that only the bottoms of the old synclines are left and in many places where the rocks are not actually granite they are a hybrid dioritic rock formed apparently by the incorporation of basic rocks by the slowly advancing border of the intrusive. The deposition of dolomite during part of the Palæozoic does not directly affect the consideration of the ores and will not be discussed here.

The glacial period was important in that the ice swept away much of the disintergrated material lying upon the rock surface, but it is not likely that it removed any great thickness of unaltered rock. The deposition of lake and stream silts and the growth of muskegs in the undrained hollows have made it rather difficult to prospect much of the area, since the easily altered and eroded sulphides would naturally be removed to form the hollows in the rock floor, now filled with drift.

Geologic History.—The geologic history so far as it has been deciphered from the rocks of this district may be summarized as follows:

1. Outpouring of lavas and deposition of volcanic fragmental rocks with possibly some normal sediments.
2. Deposition without any break, of more acidic sediments now recrystallized into gneisses and schists.
3. Intrusion of granitic rocks.
4. A long period of erosion.
5. Deposition of two series of sediments, the later of which is largely terrestrial.
6. Mountain-making with a fairly long period of granitic intrusions during which the ores were brought in.

7. Extremely long period of erosion reducing the mountains to a mammillated surface of low relief.
8. Deposition of dolomite during the Palæozoic and possibly of shales during the Mesozoic.
9. Erosion of these to expose the Pre-Cambrian basement.
10. Glacial period.
11. Deposition of recent silts and formation of peat deposits.

THE ORE DEPOSITS.

Two important deposits of sulphide ores have been located, from one of which some ore has already been produced. The Mandy ore body is on a small point on the west shore of the northwest arm of Schist lake which drains into the north arm of lake Athapapuskow. The Flinflon deposit is on Flinflon lake, 4 miles northwest of the Mandy mine.

Both are in the volcanic series but there are marked differences in the character of the country rock and in the structure and mineralogy of the ore-bodies.

The Flinflon Lens.

The country rock to the east of Flinflon lake is massive greenstone displaying prominent ellipsoidal structure. To the west of the lake the greenstone is massive, dark green, and without this structure. Along a part of the deposit a narrow granite porphyry dike forms the hanging-wall; west of the ore zone there is a lamprophyre dike 25 feet in width. The sulphides occur replacing great shear zones in the greenstone. They form a series of overlapping lenses that unite and divide in a rather intricate fashion but, as only a small part of the zone is exposed, even the surface plan of the body is not known. Where it is exposed it has in one place a width of 75 feet but immediately south of this point, it divides around a horse of sparingly mineralized schistose rock. Diamond drilling on sections spaced at 500 feet, has proved that the sulphides extend for a length of about 2,500 feet and probably farther. The mineralized zone dips 60 to 70 de-

grees northeast and the drills are said to have proved its existence at a considerable depth.

The mineralization consists of almost solid sulphides bordered by disseminations in the wall rock. In the massive ore the only gangue materials are small blebs of quartz and some incompletely replaced country rock. Pyrite is the most abundant mineral but along certain zones there are bands of a fine-grained, purplish zinc blende and some chalcopyrite. Gold and silver are present but only in small quantities.

The Mandy Ore Body.

The country rock of the point upon which the Mandy is situated is dark green in color, with alternate bands of massive and of schistose rock. The ore body lies in one of the schistose zones. The ground plan of the body is elliptical, 225 feet in length by 40 feet in greatest width. It dips 75 to 80 degrees east. Leading out from the northwest and southeast sides of the lens, there are veins of sulphides striking parallel to the longer axis of the lens and to the schistosity of the enclosing rock. At the north end the ore pinches to a point and pitches beneath barren rock. At this point it is involved in a vertical fault zone that is approximately parallel to the strike of the lens but which does not show in the ore and possibly forms the hanging-wall of the ore body.

Glaciation has removed almost all the weathered products from the surface, practically fresh sulphides being exposed by removing the moss. The rocks are slightly stained by copper carbonates and it was this that first drew attention to the deposit. In small fissures in the sulphides, where water is not too abundant, crusts of chalcantite have formed from the alteration of the copper minerals.

Formation of the Lens.—The deposit lies in the southwest limb of a syncline, the axis of which is occupied by conglomerate and arkose. The folding of the sediments, consisting of beds of unequal competence, crumpled the weaker beds into numerous drag folds which due to the plunge of the syncline northwestward appear on the surface as shown in Fig. 49. During the intense de-

formation that these rocks have undergone, the softer beds have suffered thickening at the crests and troughs of the minor folds

*Drag fold on west limb of
northerly pitching sincline*

FIG. 49.

and thinning along the limbs. There has also been considerable shearing, the greatest amount of fracturing being localized at the troughs and crests of the folds. The surface plan of the ore

*Diagram of supposed underground
structure of Mandy sulphide body*

FIG. 50.

body, its supposed form underground (Fig. 50), and its position with reference to the major structure of the country have led to the suggested hypothesis that the sulphide body is a min-

eralized drag fold, conditioned by the alternations of massive greenstone and chlorite schist which, squeezed between the more competent greenstone, crumpled and sheared during the folding.

MINERALIZATION AND PARAGENESIS OF MINERALS.

In the Mandy deposit the varieties of sulphides are individualized in larger bodies than at Flinflon. Along both foot and hanging-wall the sulphide is almost pure pyrite; the middle of the lens is occupied by chalcopyrite and zinc blende, the former being in a fairly pure band on the footwall side. The zinc blende envelopes the chalcopyrite filling the whole north end of the lens, and there are also interbandings of the two minerals. At the surface the chalcopyrite lens is 10 to 12 feet in width and 100 feet in length; at the 100-foot level it has widened to over 18 feet. Its strike does not parallel that of the main lens but cuts across it slightly. Gold and silver are both present in the ore but only in small amounts. The apparently homogeneous chalcopyrite is somewhat lighter in color than pure chalcopyrite should be and an analysis gives only 28.96 per cent. of copper. Polished specimens show inclusions of material that is black by reflected light and probably is country rock taken up by the ores. These inclusions are impregnated by pyrite and the edges of some of them are granulated and recemented by chalcopyrite and zinc blende. The pyrite is clearly earlier than the chalcopyrite since the latter includes fractured and granulated masses of pyrite. Some particles of the pyrite have a square outline, due perhaps to the control of the direction of fractures by the cleavage directions of the pyrite or to the original cubical form of pyrite crystals disseminated in the replaced rock (Plate XI., *A*). Specimens also show sphalerite in intimate relationship with chalcopyrite and evidently deposited at the same time as the copper mineral (Plate XI., *B*). Where chalcopyrite and sphalerite are interbanded there is no evidence of any fracturing of one with introduction of the other, or of any replacement, but in all cases the chalcopyrite bands contain sphalerite, and the sphalerite bands contain chalcopyrite. Fractured and partially replaced pyrite is nearly always present.

It seems that there was an early introduction of pyrite which replaced and impregnated the crushed and sheared rock of the drag folded zone of schist. Later movements fractured and granulated the pyrite, and chalcopryite and sphalerite were introduced simultaneously. The segregation of these minerals into more or less individual zones may have been by selective precipitation due to the character of unreplaced country rock. There are still in the ore fragments of schist even after two periods of sulphide mineralization, and, naturally, there must have been even more unreplaced material before the deposition of the chalcopryite and zinc blende. Since the country rock was schistose even at the time of the first mineralization, its replacement by pyrite would take place most easily along the planes of schistosity and, where the removal of the rock was not complete, the original schistose structure would be preserved by a banded arrangement of pyrite, partially replaced, and possibly almost unaltered rock. When the later sulphide minerals came in, these zones might so influence the precipitation that the banding would still be retained but with laminations of chalcopryite and zinc blende taking the place of the pyrite and country rock of the first sulphide body.

ROCK ALTERATION.

The rocks in the vicinity of the sulphide deposits were originally dioritic in composition but have undergone great alteration, much of which was probably prior to the period of ore deposition. A massive ellipsoidal-weathering lava from Phantom lake, 2 miles west of the Mandy ore body, under the microscope shows a porphyritic texture with a few small scattered or nested crystals of plagioclase in a fine-grained groundmass. The crystals still retain the albite banding sufficiently to show that they are near oligoclase in composition. The groundmass consists of small crystals of much altered feldspar together with the products of the complete alteration of the original basic minerals now changed to epidote, chlorite, and calcite. The country rock on the east side of Flinflon lake is still more completely altered although it retains its ellipsoidal structure. Under the microscope

a thin section shows remnants of feldspar individuals but the alteration has gone too far to admit of the determination of their composition. The secondary minerals are chlorite, calcite, and sericite with considerable secondary quartz. This specimen was taken not far from the Flinflon sulphide body and it may have been affected to some extent during the period of mineralization.

A specimen from the hanging-wall of the Mandy ore lens is a fine-grained, grayish, banded rock that effervesces freely with acid. Under the microscope it is seen to consist largely of secondary quartz traversed by a network of calcite. Calcite bands along the planes of foliation are somewhat larger than the connecting veinlets and give the rock a banded appearance. The footwall rock is more coarsely crystalline and has a large amount of pyrite scattered through it. In sections of ore, chlorite is the mineral most commonly included in the sulphides. The most striking difference between the rocks close to the ores and those that have not been affected by the ore deposition is the complete or almost complete removal of feldspars in the vicinity of the ores, with an increase in the amount of secondary quartz and some increase in the proportion of calcite. The alteration that the original lavas have undergone to change them to the greenstone into which sulphides were introduced, and the additional alteration that the mineralization has produced, are essentially similar, with, however, some silicification during the ore period.

NATURE OF ORE SOLUTIONS.

To produce such an alteration it seems necessary that the sulphides should have been accompanied by hydrothermal solutions. Many of the secondary minerals are hydrated and the presence of quartz and calcite in greater quantities than are found in rocks not affected by the mineralization is most easily explained by the action of aqueous solutions at fairly high temperatures.

GENESIS OF ORE.

The late granites are the most likely source of the ore solutions. An indication of this genetic relation is given by the oc-

A.

B.

A. Polished surface of ore from the Mandy sulphide body. White, pyrite (note cubes); gray, zinc blende; black, rock inclusions. $\times 185$.

B. Polished surface of ore from the Mandy deposit. White, chalcopyrite; gray, zinc blende; black, included rock. This specimen shows the graphic intergrowth of the sphalerite and chalcopyrite. $\times 185$.

currence of sulphide lenses, although not always cupriferous, along the margins of small bosses and dikes. The silicification of the wall rocks indicates that the solutions, at some stage of the mineralization, carried quantities of SiO_2 , and solutions from a cooling granite mass would be expected to be siliceous in character. The copper zinc ores are referred to the late granite because they have not been crushed or altered by the movements accompanying the late intrusions. Bodies of granite are exposed at the surface at short distances from the ores and it is possible that the distance to the igneous rock may be even less underground than on the surface.

SUMMARY.

1. The rocks associated with the chalcoppyrite deposits of northern Manitoba are much altered volcanics overlain by remnants of sedimentary rocks, and intruded by granite of at least two periods. These are all Pre-Cambrian.
2. The ore being mined comes from a segregation of chalcoppyrite in a lens, made up of chalcoppyrite, zinc blende and pyrite.
3. Bodies of pyrite were formed in shear zones in the greenstone or as replacements of drag folds in schistose bands.
4. Later fracturing was followed by introduction of chalcoppyrite and zinc blende.
5. The sulphides are believed to be genetically related to the late granite intrusions.

GEOLOGICAL SURVEY OF CANADA,
OTTAWA, CANADA.