CANADA

DEPARTMENT OF MINES

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GEOLOGICAL SURVEY

W. H. COLLINS, DIRECTOR.

Summary Report, 1921, Part C

Geology and Mineral Resources of Rice Lake and Oiseau River Areas, Manitoba

BY

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OTTAWA
F. A. ACLAND
PRINTER TO THE KING'S MOST EXCELLENT MAJESTY
1922

No. 1947

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GEOLOGY AND MINERAL RESOURCES OF RICE LAKE AND OISEAU RIVER AREAS, MANITOBA

By H. C. Cooke

CONTENTS

Illustrations

INTRODUCTION

Rice Lake area of Manitoba has been known for years to contain deposits of native gold, but although many companies of various capitalization have been formed to exploit them, and have advertised the merits of their respective enterprises there are as yet with one small exception no producing mines in the district.

Bodies of copper-nickel ore were found in Oiseau (or Bird) River area in the summer of 1920. Although prospecting could not have been far advanced by the winter of that year, reports as to the immense size and value of the new ore-bodies were already being circulated.

Accordingly, the writer was instructed to examine these two areas in as detailed a manner as time would permit, to obtain first-hand information regarding the size and probable value of the ore-bodies opened up, and, if possible, to determine the origin of the ores, for the future guidance of prospectors and investors.

About a month was spent in the examination of Oiseau River area, and afterwards about six weeks at Rice lake. Leaving Rice Lake area by Wanipigow (or Hole) river, en route to lake Winnipeg, a brief examination was made of the gold deposits at Hay lake and Beaver river. A rapid trip was then made up Maskwa (Bear) river, to compare the nickel deposits there with those at Oiseau river, and also to examine some newly reported discoveries.

The results of the work are set forth fully in this report, which is accompanied by large scale maps of Oiseau River and Rice Lake areas illustrating the salient features of the geology. The mapping, however, is generalized rather than detailed. In Rice Lake area, for example, the part coloured on the map as Keewatin (Rice Lake series or schist-complex) is intersected, in reality, by numerous dykes of later age. No attempt was made to map them, as they are not economically important and the time available for field work was limited. It was possible only to ascertain their character and age relations.

The writer is indebted to many residents of Winnipeg for information and assistance, and in particular to the owners of the various mineral claims and to the companies which are exploiting the mineral deposits. The writer especially wishes to express obligation to Mr. Gordon MacTavish, of Winnipeg, for useful information and introductions; to the owners and managers of the Devlin, Gold Pan, Pan Extension, and Gabrielle mining companies for aid during the prosecution of the field work; and to Captain Ennis, for valuable assistance in the Wanipigow area.

Location and Means of Access

Oiseau river is a stream 100 to 150 feet wide, with a perceptible current, and a course somewhat south of west. Its mouth lies at the east end of lac du Bonnet, an expansion of Winnipeg river about 25 miles above lake Winnipeg. About 18 miles above lac du Bonnet Oiseau river expands to form Oiseau lake, a beautiful body of water 3 or 4 miles long and 1 mile wide. The nickel discoveries are on the north side of the river, about 3 miles below Oiseau lake, in sections 27 and 35, range 15, township 17.

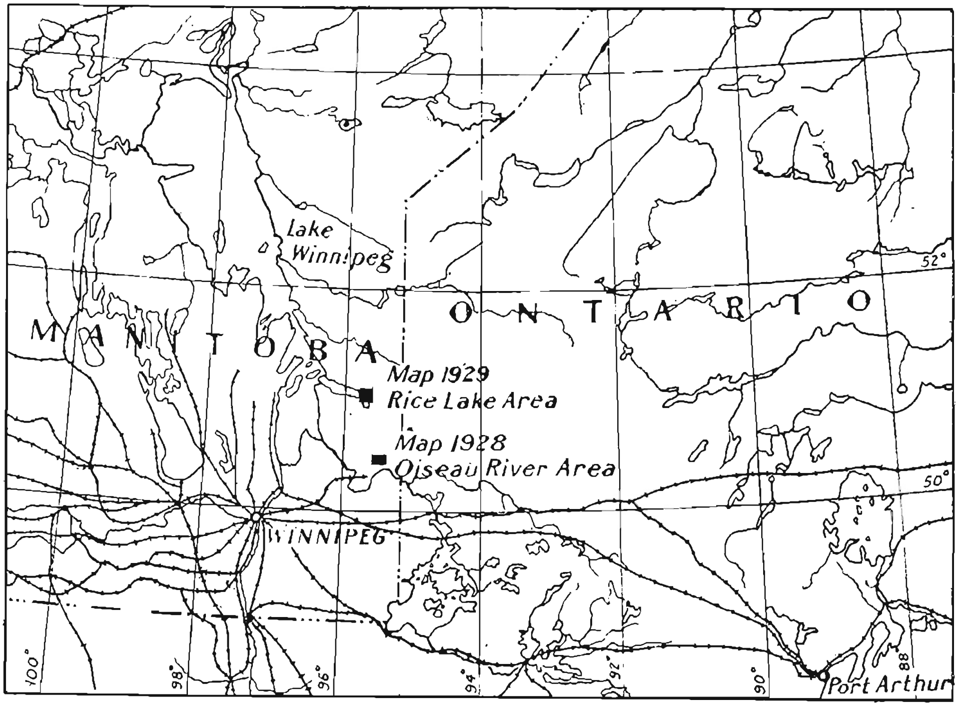


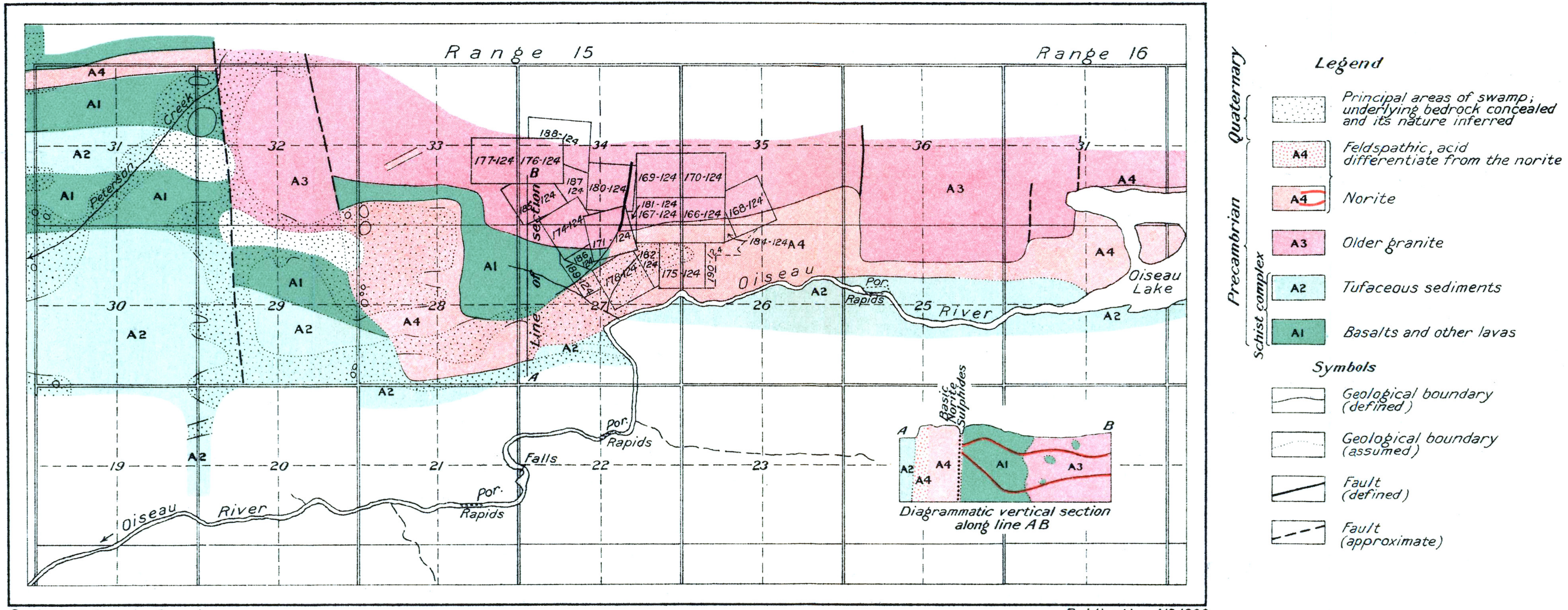
Figure 1. Index map showing the location of Rice Lake and Oiseau River map-areas, Manitoba.

The common method of reaching the district from Winnipeg is by the Canadian Pacific railway to Lac du Bonnet village, a small settlement on Winnipeg river 6 miles above lac du Bonnet. Here gasoline launches may be obtained to cover the 28 miles between the village and the first rapids on Oiseau river. The remainder of the route, up Oiseau river, must be travelled by canoe. The first portage is more than a mile long, but the others, five in number, are all very short; the whole distance between Lac du Bonnet village and the nickel discoveries may be easily covered in a day, travelling light.

Rice Lake district lies only about 35 miles slightly west of north from Oiseau lake, but there is no direct route between the two, and the speediest method of getting

Index to mineral claims giving their lot and group numbers

Lot	Group	Name of claim
166	124	Chance
167	124	Dumbarton
168	124	Copper Plate
169	124	Bella
170	124	Burn
171	124	Devlin
174	124	Martin
175	124	Wilfred
176	124	Lily Devlin
177	124	Glasgow
178	124	Elizabeth
180	124	Evelyn
181	124	Wynne
182	124	Galt Fl.
184	124	Dumfries
185	124	Gunner Fl.
186	124	Martin Fl.
187	124	Bruce
188	124	Kootenay Fl.
189	124	Elizabeth Fl.
190	124	Wilfred Fl.



Geological Survey, Canada. Publication Nº 1928

Oiseau River Area, (townships 17, ranges 15 and 16, East of Principal Meridian), **Manitoba.**

Scale of Miles

To accompany Report by H.C.Cooke, in Summary Report, Part C, 1921.

Geology by H.C.Cooke, 1921.

from one place to the other is via Winnipeg. A train or electric railway runs to Selkirk, and the Northern Fish Company run a steamer as far as Heola, whence a gasoline launch conveys passengers to the mouth of Manigotagan river, up which the canoe route to Rice lake is 30 miles.

For winter travel a road has been cut from Fort Alexander directly across country to Rice lake.

Previous Work

In 1912 a general survey of the water routes of the whole district was made by E. S. Moore, for the Geological Survey, together with a hasty examination of the shore geology. Wanipigow, Manigotagan, and Oiseau rivers were surveyed.[1] In 1916 a brief examination of the Rice Lake gold discoveries was made by J. A. Dresser and John Marshall, for the Geological Survey,[2] and in 1920 J. S. DeLury, for the Manitoban government, made a fairly thorough examination of the same area, and published a detailed account of the gold occurrences.[3] In the autumn of 1920 W. S. McCann, for the Geological Survey, examined the nickel discoveries up the Maskwa and his report[4] contained a map showing the outlines of the nickel-bearing intrusive, and the location of the principal discoveries.

GENERAL GEOLOGY

General Statement

The following geological column for the district was established by E. S. Moore:

Precambrian			Granite and gneiss
		Intrusive contact	
		Wanipigow series	Conglomerate, arkose, greywacke, etc.
		Probable unconformity	
	Keewatin	Rice Lake series	Lavas and their schists

Moore's results, good as they were, were limited by the hasty nature of his exploratory work, which confined him to the shore-lines. Had time permitted him to extend his work inland, other outcrops would have been discovered that would undoubtedly have altered his conclusions on the stratigraphy. Later workers, such as Dresser, Marshall, DeLury, and McCann confined their attention to the mineral discoveries, and accepted Moore's conclusions as to the geology without much question.

The writer's methods of work were the antithesis of Moore's, in that detailed examinations were made of small areas, which, moreover, were particularly suitable for such examination by reason of their complex geology and excellent rock exposures. In this way evidence was obtained that determines more completely the Precambrian history of the region and adds somewhat to Moore's geological column. The principal points of difference between Moore's conclusions and those of the writer may be briefly stated as follows:

In his map of 1912 Moore shows two bands of the Wanipigow series of sediments, a broad one extending from Wanipigow (Hole) lake through Rice lake, then southeasterly to the headwaters of Manigotagan river, the other extending through Oiseau River area. Marshall later showed that the mapping of the former band was incorrect and that a granite mass around Long lake divides the band into an eastern part and a western part. The writer was unable to examine the eastern area around the headwaters of Manigotagan river, but did study the other occurrences around Rice and Oiseau lakes; and was able to prove that the supposed sediments in both places are really bedded tuffs in large part, and that they rest with perfect conformity on the surface of the lava flows composing Moore's Rice Lake series. Moore's Rice Lake and

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1 Moore, E. S., Geol. Surv., Can., Sum. Rept., 1912, pp. 262-270.
2 Dresser, J. A., Geol. Surv., Can., Sum. Rept., 1916, p. 169.
3 DeLury, J. S., "Mineral Prospects in Southeastern Manitoba." Manitoba Bulletins.
4 McCann, W. S., Geol. Surv., Can., Sum. Rept., 1921, pt. C., p. 19.

Wanipigow series, therefore, become, respectively, the volcanic and sedimentary members of a single series of surficial rocks. In subsequent parts of this report the name Wanipigow series will, therefore, be omitted, and the whole body of volcanics and sediments will be called the Rice Lake series.

The volcanics and sediments are intruded by granites. Moore mentions only one period of granitic intrusion, but the evidence obtained during the past summer proves that there were really two such periods. The two granites will hereafter be referred to as to the "earlier granite" and the "later granite." Between the intrusion of these two granites there intervened a very long period of time, during which great deformation of the region took place, together with intrusion of a variety of basic igneous rocks. The most important and probably the latest of these was a gabbro which formed sills and laccoliths of varying size. Apparently it preceded by a very short interval the intrusion of the later granite.

The geological column established by the writer's work is, therefore, as follows:

Table of Formations

Precambrian			Later granite
			Gabbro.
			Relations unknown
			Diabase dykes
			Feldspar porphyry
			Relations unknown
			Hornblende porphyry
			Earlier granite
	Keewatin?	Rice Lake series	Tufaceous sediments
			Confortable contact
			Lavas and breccias

Rice Lake Series

PETROGRAPHY OF VOLCANIC PORTION

Basalt

The volcanic portion of the Rice Lake series is made up of lavas of varying composition. In Oiseau River area most of the lavas are massive, rather fresh-looking basalts, in flows that vary from a few feet to more than 100 feet in thickness. Pillow structures were observed in a few places, but were rare, and flow textures were not seen. The grain varies from fine, almost glassy, at the upper edges of the flows, to a maximum of perhaps 1 mm. in their lower parts. The coarser-grained parts of the basalt flows so strongly resemble some of the finer-grained phases of the nickel-bearing gabbro that the two are frequently confounded. The basalt, however, maintains its fine grain over distances of hundreds of feet, whereas the grain of the gabbro is fine only near a contact, and increases rapidly with distance from the contact, becoming much coarser than any part of the basalt.

Only one specimen of basalt was examined microscopically. It is a somewhat porphyritic rock, in which phenocrysts of biotite, partly chloritized hornblende, and andesine form 30 per cent to 40 per cent of the mass. The phenocrysts average 0·3 mm. in diameter. They are embedded in a matrix of 0·01 to 0·02 mm. grain, made up of about 30 per cent of pale green actinolite in small needles, and 70 per cent of fine-grained feldspar, probably andesine. There is no evidence that the hornblende present is secondary after augite, unless the whole rock has suffered recrystallization. The lava seems, therefore, to be an andesite rather than a basalt.

Dacite

In Oiseau River area there also occurs, in section 29, a black, fresh-looking lava, composed of numerous good-sized phenocrysts of white feldspar embedded in a fine-grained black matrix. Under the microscope the rock is seen to be partly granulated and altered. The phenocrysts, of all sizes up to 1·5 mm. in diameter, include both quartz and andesine feldspar. They are badly granulated, and the feldspar largely altered to sericite or paragonite. There is a good deal of an incompletely chloritized mineral present, that may have been biotite. The groundmass is somewhat altered and hardly distinguishable from the granulated parts of the phenocrysts. It appears to have been composed mainly of feldspar. The lava, therefore, might be termed an altered dacite.

Andesite

Basalt, with good pillow structures, occurs on the north shore of Rice lake, but the main body of the volcanic rocks in the area consists of porphyritic andesites. Phenocrysts of andesine feldspar up to 3 mm. in length form perhaps 25 per cent of the bulk of this rock. The matrix, of about 0·03 mm. average grain, is composed of similar feldspar and needles of chlorite probably secondary after actinolite. A good deal of calcite, epidote, and sericite is present. In some of the fresher hand specimens the matrix appears glassy and almost black, but more commonly it has a greyish green tinge, due to the presence of alteration products.

Breccias, extremely common around Rice lake, include both flow and tuff breccias, but are mainly flow breccias that grade into massive lava by decrease in the number of fragments.

Rhyolite

Rhyolite, also, occurs at the northeastern end of Rice lake, on the Rachel claim, L. 47-124. The rock is very light grey and fine grained. It is slightly porphyritic, containing a few phenocrysts of quartz and oligoclase feldspar up to 0·5 mm. diameter. The matrix, with an average grain of 0·05 mm., consists mainly of oligoclase feldspar with 2 or 3 per cent of quartz and about 20 per cent of chlorite needles. The form of the chlorite suggests that it is secondary after actinolite. The minerals have been more or less granulated, presumably by the strains of folding.

PETROGRAPHY OF SEDIMENTARY MEMBER

The sedimentary member of the Rice Lake series includes those rocks formerly known under the name of the Wanipigow series.

Cherty Tuff

In Oiseau River area the basal beds are thin-bedded cherts, composed of fine-grained volcanic ash more or less converted to silica and albite feldspar by the action of solutions accompanying or following the volcanic outbursts. The chert beds are interstratified with coarser-grained, thicker beds of relatively pure ash. The ash beds grade upward into the prevailing rock of the series, a sandy greywacke or impure quartzite with occasional slate beds.

Conglomeratic Tuff

In section 31 there is a wide belt of interbedded greywacke and coarse tuff. The tuff contains numerous rounded pebbles of basalt, and thus strongly resembles a conglomerate. The resemblance is heightened by the fact that different varieties of rock appear to be represented in the pebbles; but close examination proves that the apparent differences are due to the varying textures of the basalts that supplied the pebbles. The rock is, therefore, an intraformational conglomerate, the materials of which were probably derived from adjacent rocks by rapid erosion, and deposited in a local basin. Such a conglomerate does not imply the existence of any great time interval between its formation and that of the underlying lavas.

Rhyolite Tuff

In Rice Lake area the basal sediments again consist of a very fine-grained chert, or cherty tuff, that rests directly on the glassy surface of the rhyolite previously described (page 5) and is composed of numerous fragments of quartz and sodic feldspar, up to 0·15 mm. diameter, embedded in a very fine-grained, highly sericitic groundmass. The sericite is probably secondary, formed under the pressures that folded the rocks.

This tuff is overlain on the south side by a bed of coarse rhyolite tuff some hundreds of feet in thickness, made up of sharp-angled fragments of rhyolite averaging about an inch in diameter, in a finer-grained matrix of the same material.

Grit

It is overlain in turn by a well-bedded grit, composed of sharp-angled fragments of quartz, feldspar, and rhyolite, and is well exposed on the southeast corner of the large island in Rice lake. This, again, is overlain by the normal sedimentary rock of the region, a massive quartzite more or less converted to sericite schist over considerable areas.

Quartzite

The bedding of the quartzite is commonly so thick, and the character of the material so uniform, that observations on the strike and dip of the beds are difficult to obtain. In places, however, the normal quartzite grades into finer-grained, muddier material in the upper parts of a bed, and this in turn is overlain by the coarser-grained quartzite of the succeeding bed.

The quartzite is a grey rock with an average grain of 0·5 mm. Grains of this size compose about 60 per cent of the rock, and are mostly of quartz, with a few of oligoclase feldspar. They are to some extent granulated and drawn out into "eye" shapes. The remaining 40 per cent of the rock is mainly very fine-grained quartz and muscovite or paragonite, the last probably formed by the metamorphism of the feldspar constituent.

STRUCTURAL RELATIONS

Stratigraphy

The work of the past summer was not sufficient to show whether the sedimentary part of the Rice Lake series overlies all the lava flows composing the volcanic member, or is interstratified between them. In Oiseau River area the sediments overlie the lavas, but their upper side was not seen. In Rice Lake area they appear to be both underlain and overlain by lavas, but strike faults are so numerous that the apparent structure may be due to repetition of beds from this cause, although no direct evidence of faulting along contacts could be observed.

In Oiseau River area the relations between the lavas and sediments were established as follows: In many places a careful examination discovered the lines of contact of two lava flows. At such places a relatively coarse-grained variety of basalt, the slowly cooled bottom of a flow, is in sharp contact with a very fine-grained, almost glassy basalt representing the rapidly cooled surface of an earlier lava flow. From such contacts the strike and dip of the lavas can be determined. All the determinations thus made give the lavas approximately east-west strikes and vertical dips, and the glassy phases, the original surfaces, invariably form the south part of the now vertical flows. Since the south side of the flows is, therefore, the upper, it follows that any given bed or flow is younger than beds or flows to the north of it, and older than beds or flows to the south of it.

In one place, along the line between sections 27 and 28, good pillow structure is developed in the basalts. Pillow structure is believed to be most commonly developed in lavas when they are extruded under water, and when the flows are fairly thick the structure does not extend through the whole mass of lava, but affects only the parts near the surface. In such circumstances it can be used to determine structure, as the pillowed parts of a flow will be the upper side. A careful examination of the structure in Oiseau River area confirmed the conclusions drawn from other data, that the folded lavas have a general east-west strike, a vertical dip, and face southward.

Since the lavas of the volcanic series face south, and the sediments are found south of the lavas, the sediments must overlie the lavas.

This determination does not settle the question, however, as to whether the sediments overlie the lavas conformably or unconformably. Very careful search was, therefore, made for actual contacts of the two series, and such contacts were found in several places in sections 29 and 31. In each case the contact is between sediments and the glassy upper parts of lava flows, never between sediments and coarse-grained basalts; indicating that the sediments were laid down directly on the surfaces of lava flows, before erosion had the opportunity to wear away the flows or cut channels into them. The sediments are never conglomerates at the contacts, but are either cherts or slates, neither of which is a product of the erosion of the underlying lavas. Evidently, therefore, there was no interval of erosion between the deposition of the basalts and that of the overlying sediments. In addition, no folding took place between the formation of the two, for the strike and dip of the sedimentary beds are the same as that of the lava flows. The two formations are, therefore, perfectly conformable.

The conformability of the sediments and lavas is further seen in lot 31. Here the contact of the two formations is not a sharp line, but a broad band in which flows of lava alternate with varying thicknesses of sediments. On the map, north of the main body of sediments in section 30, there is shown a single wide band of lavas, followed by a band of sediments, which is succeeded again by lavas. The mapping does not fully represent the true state of affairs. In reality there are numerous narrower alternating bands of sediments and lavas, particularly in the lava band mapped to the south of the norite band, and in the northern part of the succeeding band of sediments. The mapping here merely expresses which material, lava or sediment, was predominant.

Evidently, therefore, sedimentary deposition began as the period of lava extrusion drew to a close, but sedimentation was locally interrupted from time to time by the extrusion of more lavas. Such facts emphasize the lack of any time break between the deposition of the two formations.

In Rice Lake area the sediments form a band that runs through the lake in a general east-west direction, and lavas are found both north and south of this band. Moore assumed that the sediments form a syncline, and that the lavas dip beneath them both on the north and south. However, examination of the lavas by the methods described shows that they have a similar strike and face toward the south on *both* sides of the sediments. The band of sediments is, therefore, either overlain as well as underlain by lavas, or else the lavas to the south have been faulted into their present position. Although no direct evidence of such faulting was obtained, the possibility cannot be altogether dismissed, since the southern contact of the sediments and lavas is hidden by drift, and faults parallel to the strike of the contact are common in the area.

The sedimentary beds at Rice lake have already been shown to consist on the north side of fine-grained cherty tuff in direct contact with glassy rhyolite; the cherty tuff is succeeded on the south by coarse rhyolite tuff, finer tuffaceous grit, and then by quartzite. All of these members are interbedded with each other at their contacts, indicating a smooth and continuous sequence of deposition between the rhyolite and the quartzite; hence as the south side of the rhyolite is the upper, the sediment must overlie it with perfect conformity.

To sum up: the sediments around Rice lake overlie a part of the volcanic rocks conformably; they are overlain in turn by more lavas, unless there is a strike fault at their southern contact which brings the underlying volcanics into apparent stratigraphic superposition over the sediments.

Folding

The Rice Lake series has been closely folded, and the strata thrown into approximately vertical attitudes, or locally overturned. The areas examined are not large enough to contain whole folds, from a study of which axial directions might be determined, so that only a simple statement of observed dips and strikes can be made. In Oiseau (Bird) River area the sediments and lavas strike uniformly north 70 degrees west, except where drag folding has caused local variations. The dips are all vertical or nearly so. The beds all face the south, thus forming the north limb of a syncline whose axis lies to the south of the area studied. The corresponding anticline to the north has been destroyed by the intrusion of the earlier granite. In Rice Lake area the strike of the sediments and lavas varies from about north 75 degrees west north of the Rice to about north 50 degrees west in the southern part of the area. The southwest side of the beds and flows is the upper side, so that they also form parts of the north limb of a syncline. The dips are mostly nearly vertical, but around Rice and Red Rice lakes there has been strong overfolding, giving the strata reversed dips toward the north. The overthrust was so severe that near the southern contact of sediments and lavas the overturned strata dip as low as 30 degrees north. The southern limb of this overturned syncline is cut off by the intrusion of the later granite, and the earlier granite has obliterated the anticline to the north.

The folding described did not all take place at one time. There is good evidence that there were two periods of folding, corresponding roughly to the times of intrusion of the earlier and later granites. This question is considered more fully in a subsequent part of the report. The pressure causing the folding is supposed to have come from the northeast, as faulting was due to thrust from that direction.

Faulting

The Rice Lake series, together with the earlier granite, has been greatly broken up by large faults in both the areas examined. The faults are important from an economic point of view, in that they controlled the intrusion of the gabbro magma in Oiseau River area, and the formation of the gold-bearing veins in Rice Lake area.

In Oiseau River area the peculiar shape of the northern contact of the gabbro mass attracted the attention of the writer. Although the gabbro forms a sill-like mass, intruded parallel to the east-west strike of the sediments and lavas, its northern contact is repeatedly stepped due north for greater or less distances. The line of these north-south sections of the contact is generally a narrow valley or depression.

Some of these narrow valleys were followed northward beyond the turning point of the contact, until outcrops in the granite were obtained, and in each case zones of strong shearing were found in the bottom of the valley. The shearing is such as to convert the otherwise massive granite into highly fissile sericite schist over various widths. Evidently the granite has been faulted, probably with great displacement, along these lines of shear.

Faulting must have preceded the gabbro intrusion since the southern boundary of the sill is not displaced by the faults, but runs along in a smooth, gently curving line, and the faults merely had the effect of localizing the intrusion. This question will be fully discussed, however, in the description of the bodies of gabbro.

The only fault in Oiseau River area whose direction of displacement can be determined occurs in the western part of sections 29 and 32. This fault shows an horizontal displacement of approximately 1,500 feet, the east side having moved toward the south. It thus resembles the faults of Rice Lake area. The faults of Oiseau River area differ from those of Rice Lake area in having a somewhat more northerly trend.

As the faults of Oiseau River area have no known economic significance other than their effect in controlling the intrusion of the gabbro, they were not traced for any great distance. In Rice Lake district, however, the faults have been the fissures in which the gold ores were later deposited, and on this account the larger ones were traced as far as possible. The faults so traced are shown on the accompanying map No. 1929. There are also smaller unmapped faults very difficult to trace, because, though in the softer rocks they may form well-defined shear zones, in the harder rocks they are apt to pass into vaguely defined zones of fracture. Moreover, they are so numerous that it is impossible to project one of them through even a small drift-covered area without being in doubt as to whether a fault is, on the far side of the interval, the fault previously traced, or a neighbouring one.

The faults vary considerably in direction, as the map shows, but are in general north 60 degrees west, north 30 degrees west, and north 10 degrees west. Those with a strike of about north 60 degrees west may be termed strike faults, as they either parallel or cut at a small angle the strike of the lavas and sediments. The others cut the bedding of the sediments and lavas.

Small strike faults with almost vertical shear planes are very common throughout the area. The planes of the larger strike faults, particularly the large shear zone on the south of Rice lake, and that northeast of Red Rice lake, dip to the north at varying angles, sometimes steeply, sometimes flatly. The direction of the shear planes together with other data, indicate that they have been formed by overthrusts from the north or northeast.

The other classes of faults have shear planes either vertical or dipping 70 degrees to 80 degrees toward the east. They exhibit a uniform direction of movement; the eastern side has always moved toward the south, relative to the western side. The movement has been almost an horizontal one, with a slight tendency to the scissors type. At the northern end of the faults the east side has been forced upward as well as southward; near the centre of the area the movement is practically horizontal; whereas at the south ends of the faults there has been a slight but distinct downward movement on the east side, in addition to the lateral movement.

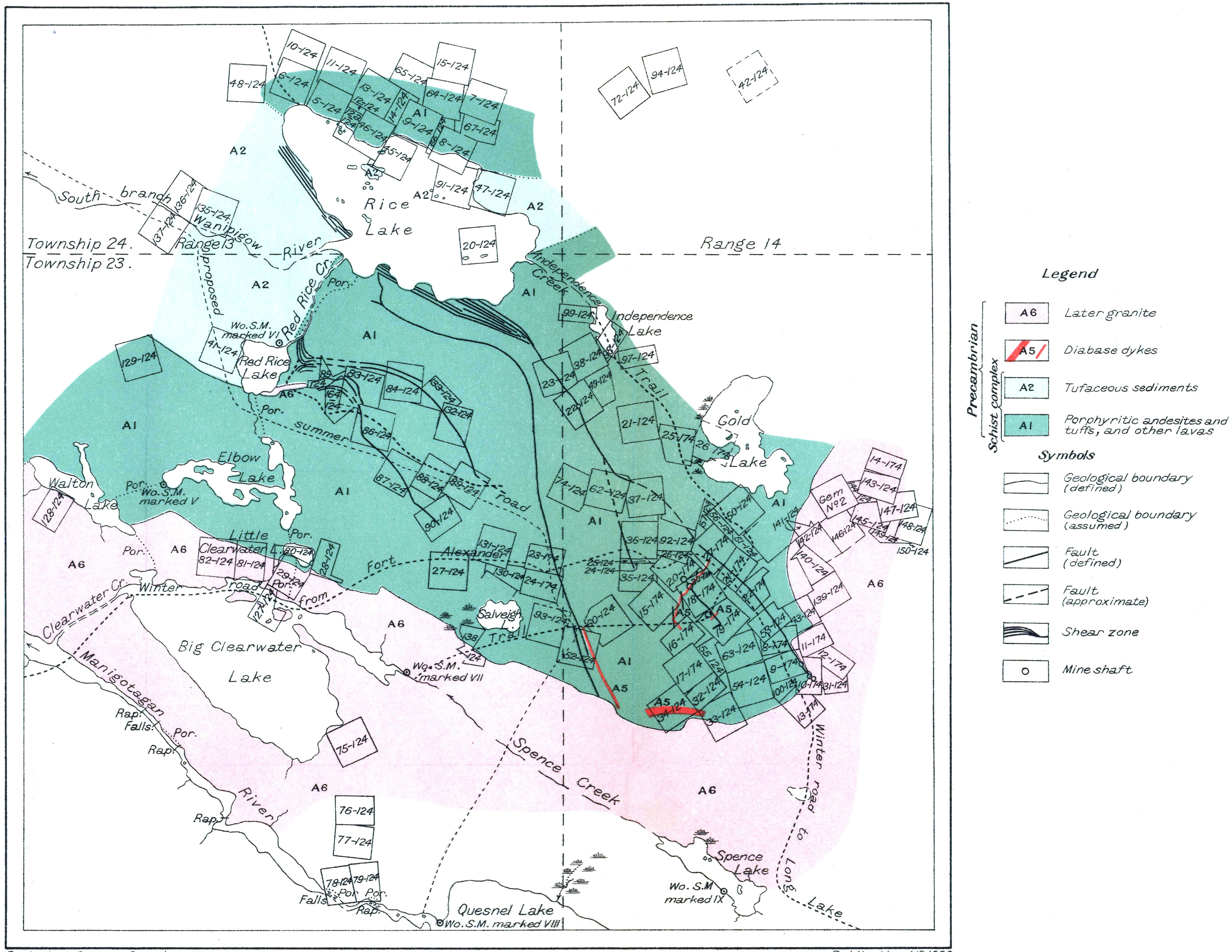
As the map shows, the faults with the more northerly strikes turn at their northern ends so as to become the strike faults; there is, therefore, no real reason for separating the different classes. Distinction has been made principally because of the differences in the character of the faults, displayed in their different courses. Faulting has cut the area up into a series of fault blocks. The thrust from the north or northeast has tended to raise each block above, and thrust it over, the adjoining block to the southwest.

Along the lines of faulting the rocks have been transformed into belts of schist of varying width. The softer varieties, more incompetent to resist the shearing stresses, have been convertod into fissile schists, as much as 60 or 70 feet in width. Smaller faults yield narrower belts of schist, a few inches or feet in width.

In harder rocks the effect of faulting is much less striking. The larger shear zones narrow to 2 or 3 feet in places, but the smaller ones pass into vaguely defined zones of fracturing. The wider belts of schist reappear where the fault re-enters softer rock, after passing through the belt of harder rock. The shear zones thus resemble a series of lenses placed end to end, rather than a ribbon-like band of uniform width. The lenticular structure is accentuated by certain other factors, so that it appears even where the rocks cut by a fault are all much the same.

Index to mineral claims giving their lot and group numbers

Lot	Gr.	Name of claim	Lot	Gr.	Name of claim
5	124	Gabrielle	82	124	Crescent
6	"	Cartwright	83	"	Wolf
7	"	Goldfield	84	"	Fisher
8	"	Emma	85	"	Wolf Fl.
9	"	Scarabe	86	"	Yankee Girl
10	"	West Scarabe	87	"	Golden Rocket
11	"	Annex	88	"	Sandstorm
12	"	North 200' of Ross Fl.	89	"	Gold Pick
12a	"	Ross Fractional	90	"	Snowstorm No.2
13	"	DeLuxe	91	"	Big Rice Lake No.1
14	"	Mite Fractional	92	"	Johanna
15	"	Jumping Cat	93	"	Eagle
20	"	Combine	94	"	Sultan
21	"	Odellas	97	"	Lady Jessie
22	"	Ranger	98	"	Lady Helen
23	"	Golden Rod	99	"	Lady May
24	"	Josephine Fl.	100	"	Moose Fl.
25	"	Olive Fractional	127	"	Procter
26	"	Pan Fractional No 2	128	"	Lexie
27	"	Old Baldy	129	"	Gilbert
28	"	Black Fox	130	"	Arkley Fl.
29	"	Glenroy	131	"	Paystreak
30	"	Pan Fractional	132	"	Gold Dollar
31	"	Bull Moose	133	"	Martin
32	"	Morning	135	"	Cypress
33	"	Hudson	136	"	Lenora
34	"	New York	137	"	Runa
35	"	Mildred	138	"	Reno
36	"	Josephine	139	"	Monarch
37	"	Black Bess	140	"	Washington
38	"	Rex	141	"	——
41	"	Alice	142	"	Commonwealth Fl.
42	"	Saxton	143	"	September Morn
43	"	Moneta	144	"	Canada
45	"	Island Fractional	145	"	Casey No1
46	"	San Antonio	146	"	Ottawa
47	"	Rachel	147	"	Bruce
48	"	Augustina	148	"	Bruce No.2
49	"	Thistle	149	"	Bruce Fl.
50	"	Brooklyn	150	"	Mina
51	"	Curtiss Fractional	164	"	Spruce
52	"	Lucky Strike	8	174	Saxton
53	"	Golden Vein	9	"	Bluebell
54	"	Bella	10	"	Moose
55	"	Gold Seal Fractional	11	"	Sunbeam
56	"	Brooklyn Fractional	12	"	Moose Horn
57	"	J.N.4D. Fractional	13	"	Surprise
60	"	Little Jack Fl.	14	"	Gold Plate
62	"	Snowstorm	15	"	Columbia
63	"	Randall	16	"	Chackawana Fl.
64	"	Gold Cup	17	"	Kootenay
65	"	Gold Cup No.2 Fl.	18	"	Gold Pan
66	"	Big 4 Fractional	19	"	Gold Seal
67	"	Gladonna Fl.	20	"	Gold Pan Fractional
72	"	Gold Dyke	21	"	Roland
74	"	Telena	22	"	Sunlight
75	"	Palm Beach	23	"	Pilot
76	"	Townsite No.1	24	"	Jumbo
77	"	Townsite No.2	25	"	Chicamon
78	"	Townsite No.3	26	"	Contact
79	"	Townsite No.4	27	"	Nevada
80	"	——	–	–	Gem No.2
81	"	Talisman			



Geological Survey, Canada. Publication No 1929

Rice Lake Area (townships 23 and 24, ranges 13 and 14, East of Principal Meridian), **Manitoba.**

To accompany Report by H.C.Cooke, in Summary Report, Part C, 1921.

Scale of Miles: 1 3/4 1/2 1/4 0 1 2

Geology by H.C.Cooke, 1921

When the pressures causing the faulting first began to act, rather crooked fractures were produced (Figure 2) presumably because there were joints or other pre-existing lines of weakness in the rocks, and fracture followed these lines of weakness. Later thrusts caused horizontal movement along the fault planes, as already

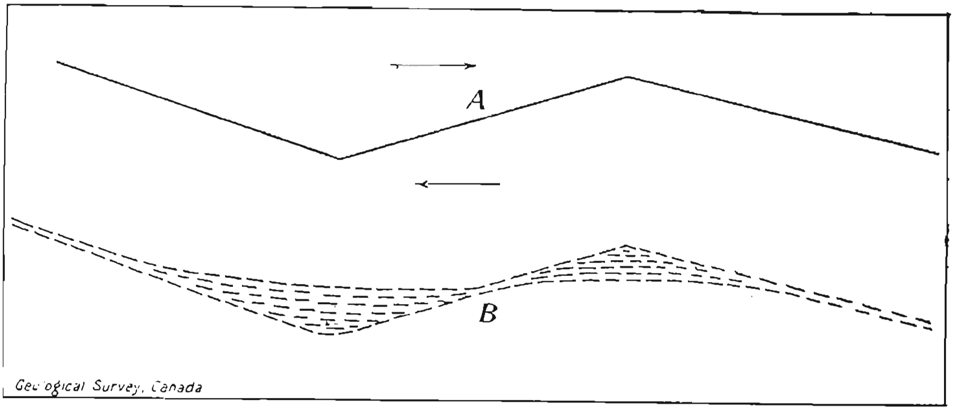


Figure 2. Diagram showing formation of lenticular sheared zone by lateral displacement along a crooked fault.

described, and straightened the bends by cutting off the corners (Figure 2). Thus the bends are now wide zones of sheared rock, and, between bends, the shear zones are much narrower. On the Bluebell property, L. 9-174, from this cause alone the shear zone varies from 33 feet in width to 2 feet within a distance of 150 feet along the strike.

Lateral movement along the fault planes has in places caught up parts of soft beds, to form drag folds within the sheared zone (Figure 3). The formation of such a drag fold, in trebling the thickness of the sedimentary bed, has been accompanied by widening of the sheared zone, seemingly by pushing out its walls. This was observed only in one or two places.

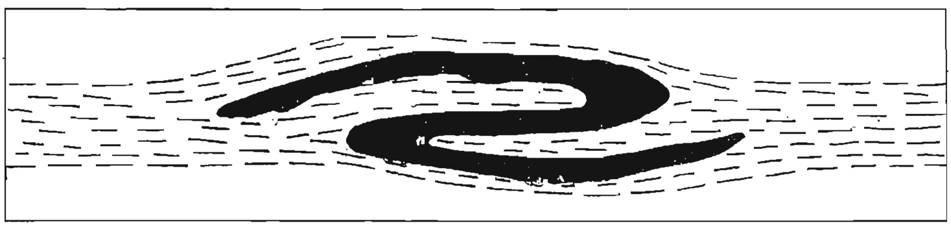


Figure 3. Diagram showing how an included bed (in solid black), drag-folded, may widen a sheared zone (in broken line).

A third cause of change in width is the splitting of the shear zone. A shear zone frequently splits into two belts which, in some cases, reunite around a horse or body of unsheared rock. In other instances the two sheared belts remain apart. Several cases of such splitting on a large scale are shown on the map; the combined zone of shear is larger than either of the two zones into which it splits.

Zones of sheared material are commonly replaced partly or completely by intrusions of igneous rock. Fault zones are easily intruded by igneous magmas, and many dykes on encountering such zones have found it easier to follow than to cross them. In many instances the dyke material now occupies the whole width of the sheared zone, in others only a part, thus diminishing or entirely replacing the sheared material.

Time of Faulting

The faults cut the folded rocks of the Rice Lake series, hence are of later date than the folding. The faults have cut the earlier granite, and made wide, sheared zones in it; therefore they are later than the intrusion and consolidation of the granite. The various dykes of the Rice Lake area cut into and across the shearing planes of the faulted zones; hence much of the faulting preceded the intrusion of the dykes. However, the dykes themselves are in cases badly fractured or slightly sheared where they lie within the fault zones, and may be displaced a few feet laterally where they cross a sheared zone, so that although the main faulting took place before the intrusion of the dykes, there was some later movement along the same planes of weakness. The faults do not greatly displace or fracture the later granite and this second period of movement must have occurred between the intrusion of the latest or diabase dykes, and that of the later granite. The later granite is, however, greatly jointed parallel to the earlier set of faults, and small movements, of an inch or a few inches, have occurred along the joint planes; evidently, after the intrusion of the later granite, another small movement occurred, jointing and slightly faulting it.

Faulting thus occurred at three different periods; the first and most intense, after the intrusion of the earlier granite but before the intrusion of the various dykes; the second, less severe, after the intrusion of the dykes but before the intrusion of the later granite; the third, comparatively slight, after the intrusion of the later granite.

Time of Folding

It has been shown that a folding movement occurred prior to the faulting of the Rice Lake series. Although it is not known precisely whether this folding took place before or after the intrusion of the earlier granite, it is inferred to have taken place before intrusion. The massive granite in places contains schistose blocks of the Rice Lake series, in which schistosity must have been developed before they were broken off by the intruding magma. Folding and mountain building are, moreover, usually accompanied or closely followed by granitic intrusion, and granitic intrusion is not known to precede folding.

In Oiseau (Bird) River area the nickel-bearing gabbros cut across the faults in the earlier granite and Rice Lake series without being themselves displaced, and the sills are tilted up on edge. Thus the sills, which are younger than the faults, have also suffered folding. There must, therefore, have been a second folding movement quite late in the history of the region, later than the earlier granite, later than the faults that cut it, and later than the intrusion of the gabbro. Since batholithic intrusion often follows folding, it may be inferred that the later folding just preceded the intrusion of the later granite.

There appear, therefore, to have been at least two periods of folding in the Precambrian of eastern Manitoba, the first preceding or accompanying the intrusion of the earlier granite, the second with similar relations to the later granite.

Relations of Rice Lake Series to Younger Formations

The Rice Lake series is the oldest formation in either of the districts examined, so that all its external relationships are to younger rocks, all of which are igneous and intrusive. The facts of intrusion were established in each instance by the usual methods; the intrusive was observed to cut across the bedding of the Rice Lake series, to have chilled edges at contacts, and to contain inclusions of the older rocks.

EARLIER GRANITE

The earlier granite is found on the north side of the band of Rice Lake series that extends from Rice lake to the mouth of Wanipigow (Hole) river (See Map No. 1285 by E. S. Moore, 1912). It extends north of Wanipigow river for a considerable distance at least, for the writer went north 6 miles from Wanipigow (Hole) lake without encountering any other rock. The earlier granite is also found on the north side of the band of Rice Lake series in Oiseau River area. Its width here also is unknown, though it must be less than 12 miles, since later granite is found around the Maskwa River nickel deposits.

Methods of Distinguishing the Earlier and Later Granites

It is impossible to distinguish the earlier granite from the later granite by petrographic means, either in hand specimens or thin sections. The writer searched with the utmost care for some petrographic characteristic that might be used to distinguish the two, but without success. There is no single characteristic of composition, texture, or alteration in either granite that may not be matched in specimens from the other.

It is true that a larger proportion of the earlier granite than of the later appears to have suffered alteration by weathering. Perhaps half the rock specimens collected from a body of earlier granite will contain dull-looking, altered feldspars, and partly chloritized ferromagnesian constituents, whereas such a specimen from the later granite is rare except from the actual surface. On the contrary, feldspars in the later granite are fresh and glassy, and its ferromagnesian minerals without a trace of alteration. However, in places perfectly fresh and unaltered specimens may be collected from the earlier granite, so that it would be extremely unsatisfactory to endeavour to distinguish between the two by such means. Other and better criteria are available, and it is better to rely on them entirely.

It has been pointed out that the earlier granite is cut by the faults of the region, but that the later granite is not. Accordingly there are wide shear zones in the earlier granite, along which it has been converted into a highly fissile schist. Shear zones of this sort are very prominent in the granite north of Wanipigow river and lake, and common, though less prominent, in the granite of Oiseau river. No such feature is to be found in the later granite, in which the most pronounced deformation is jointing, with lateral movement of a few inches at most along the joint planes.

The earlier granite is cut by basic dykes. In the area north of Wanipigow river the dykes are of diabase, in Oiseau River area of gabbro. In both places dykes are fairly numerous. The later granite, apparently, is not cut by dykes of any kind, except those of pegmatite. On the contrary, it cuts across the diabase dykes in Rice Lake area, and the gabbro in Maskwa River area.

Petrography

The earlier granite is a coarse-grained, grey, greenish grey, or reddish rock, usually equigranular, but in places containing porphyritic feldspars. It varies a good deal from place to place, both in composition and degree of alteration. In Oiseau River area it is a very fresh, reddish rock with a porphyritic tendency, and an average grain of 2 to 3 mm. The specimen examined microscopically is composed of nearly 50 per cent quartz, 2 or 3 per cent of biotite, 35 per cent microcline, and 10 per cent of albite, with a few crystals of orthoclase. The albite has been somewhat altered to sericite or paragonite, but the other feldspars are almost unaltered.

The earlier granite north of Wanipigow river is much more largely altered, and characterized by the greenish tints due to the presence of alteration products. When fresh, it is a grey or white rock, with an average grain of 1 to 2 mm. The composition averages about 30 per cent quartz, 10 per cent to 15 per cent of ferromagnesian mineral, mostly common green hornblende with a little biotite, the remainder a feldspar, all of whose optical characters are those of andesine Ab_{60} An_{40} except the refringence, which is a little low. It is probable, therefore, that some orthoclase is dissolved in the andesine and reduces its refringence. The composition of tho Wanipigow River granite indicates it to be a granodiorite rather than a true granite. Altered phases show alteration of the feldspar to sericite or paragonite and epidote, and of the hornblende to chlorite.

Structural Relations

The earlier granite is intrusive into the Rice Lake series. The mapping shows the granite cutting across the bedding of the Rice Lake series, in some places completely through the older volcanic rocks and up into the younger sediments. The usual swarm of stoped-off fragments is found in the granite near contacts. Dykes from the granite penetrate the Rice Lake series for greater or less distances from contacts.

The earlier granite has suffered from the faulting of the region and presumably also from the later period of folding although no especial folding effects were obtained. The faulting has produced zones of schist up to 100 feet in width. In the area north of Wanipigow river and lake the faults with a general east and west strike have made broad zones of schist, whereas those with northerly strikes have formed very much narrower zones, rarely exceeding 3 or 4 feet in width. The later folding, due to stresses from the north, may have made use of the east-west planes of weakness established by the faulting as slipping planes, along which movements relieving the stresses from the north, may have made use of the east-west planes of weakness

The earlier granite is cut by the various later intrusives of the region. No feldspar porphyry dykes were observed in it, but the diabase dykes of Rice Lake district, and the gabbro dykes and sills of Oiseau River district both intrude it. No contact of the earlier and later granite was seen, although there must be such a contact between the Oiseau River and Maskwa River areas.

The earlier granite was thus intruded prior to the intrusion of the various basic igneous rocks of the region, prior to the faulting and subsequent to the deposition of the Rice Lake series. It probably accompanied or closely followed the folding of tho Rice Lake series.

HORNBLENDE PORPHYRY

A few dykes of hornblende porphyry were found in Rice Lake district, cutting the bedding of the series or intruded parallel to it. The porphyry is a hard, fresh rock, composed of needle-like phenocrysts of hornblende up to half an inch in length embedded in a fine-grained grey matrix. Its external relations are not known, as it was not found in contact with any of the rocks of the region, with the exception of the lavas of the Rice Lake series.

FELDSPAR PORPHYRY

Dykes of feldspar porphyry are numerous in Rice Lake district. Singularly enough, they were observed to cut only the volcanic rocks of the Rice Lake series, although the facts at hand indicate that they are later, not only than the Rice Lake series as a whole, but also than the earlier granite. They were not seen in Oiseau River area.

Petrographically, the feldspar porphyry is a light grey rock, fresh, hard, and massive, made up of squarish crystals of feldspar up to 2 or 3 mm. in diameter, embedded in a fine-grained light grey matrix. The phenocrysts, which form as much as 25 per cent of the volume of the rock, are andesine Ab_{60} An_{40}. The matrix in which they are embedded has an average grain of 0·03 mm., and consists of chlorite and andesine in about equal proportions. Tho chlorite forms fine needles and is probably secondary after actinolite. The needles have a pronounced parallel arrangement, giving the rock a definite schistosity. The feldspars are more or less altered to epidote, calcite, and kaolin.

The feldspar porphyry not only cuts across the bedding of the Rice Lake lavas, but forms sill-like bodies parallel to it. It is cut by the diabase dykes of the district. It was intruded after the first main period of faulting, as is shown by the fact that where dykes meet shear zones they either cut across the sheared material or turn and follow the shear, often fingering into the sheared material to form a number of small parallel dykes separated by bands of schist. The dyke material in such places is not itself sheared, but in places is greatly fractured, indicating that some movement took place after intrusion.

DIABASE

The latest igneous rock in Rice Lake district, except the later granite, is a diabase which forms very numerous dykes, of all sizes up to 300 feet in width. Dykes of the same material are very common also in the earlier granite north of Wanipigow river and lake. They were not observed in Oiseau River area.

The diabase is a fine-grained black rock, fine-grained even in dykes of considerable size. On the surface it is usually partly chloritized to some depth, and rather soft. It has been called diabase more because of its occurrence in dykes and to distinguish it from the nickel-bearing gabbro, than because of its diabase texture. In fact, the rock is so badly altered that any such texture, if it existed, has been obliterated. The thin section examined is a mass of alteration products in which almost all the original feldspar has been altered to epidote and most of the ferromagnesian mineral to chlorite. Some hornblende is present in large crystals that are probably original, as they do not possess the leafy or fibrous structure characteristic of a hornblende secondary after augite.

The diabase cuts the Rice Lake series, the earlier granite, and the feldspar porphyry dykes, and is, therefore, later than they. It is cut off by the later granite, and is, therefore, older. When dykes of diabase meet a shear zone, they either cut across the sheared material, or turn and follow the shear zone, apparently replacing or absorbing an equal bulk of the sheared rock. The dykes are, therefore, later than the first period of shearing, but are themselves more or less fractured and sheared, especially at their edges. That there must have been some movement along the shear zones after the intrusion of the dykes is indicated at the shaft of the Gold Pan mine, where a diabase dyke cuts across a narrow shear zone, and the later movement along the shear zone has shifted the outcrop of the dyke laterally for a distance of about 20 feet.

GABBRO

Gabbro does not occur in Rice Lake area, so far as known. It was studied in Maskwa and Oiseau Rivers areas.

Petrography

The gabbro occurs in dykes and sills. The dykes are black or dark grey, medium-grained rocks. Their composition is uniform throughout, owing undoubtedly to rapid coolings that prevented any differentiation with resultant changes in composition. The material of the sills, on the contrary, varies greatly in composition from place to place. It will be shown that the variations are such as would be produced by the processes of differentiation acting while the great masses of molten rock were slowly cooling and crystallizing.

The Oiseau (Bird) River sill is more than 5 miles from east to west, and of variable width, the greatest being slightly over a mile. The variation in its composition is found along any line from north to south.

The sill is cut by dykes up to 3 or 4 feet in width of light grey, white, or pinkish aplite. They are apparently confined to the gabbro and there is no later intrusive in the region, from the differentiation of which they might have been formed; hence they undoubtedly represent a siliceous differentiate of the gabbro magma.

They are all highly siliceous rocks, quartz forming from 40 per cent to 70 per cent in different dykes. The remaining constituent is nearly all albite, though a little muscovite and biotite are nearly always present. The greatest amount of ferromagnesian constituent noted in any section examined was 5 per cent. Most of the dykes are more or less porphyritic, made up of phenocrysts of quartz and albite up to 2 mm. in diameter embedded in a matrix of about 0·1 mm. average grain.

The southernmost rim of the sill, which is exposed in one locality only, on the line between sections 27 and 28, is a light grey, rather fine-grained, equigranular rock. It consists of 75 per cent to 80 per cent of andesine feldspar ($Ab_{60}An_{40}$), 15 to 20 per cent of tremolite, and perhaps 4 per cent or 5 per cent of fine-grained quartz. The grain averages about 0·5 mm. This material forms an east-west band some 20 feet in width, the southern edge of which is covered with drift. On the north side it grades rather suddenly into rock of somewhat darker colour but about the same grain, consisting of about 30 per cent tremolite, andesine feldspar ($Ab_{60}An_{40}$), and a few scattered grains of quartz, and forming a band about 15 feet wide. A still darker coloured and somewhat coarser-grained rock succeeds that last described, grading into it at the contact. In it, actinolite, a hornblende containing iron, takes the place of tremolite, which contains no iron, and there is 50 per cent to 60 per cent of it present, in place of the smaller proportions of the bands to the south. The actinolite forms an interlacing network of cleanly crystallized laths, and andesine of the same composition as before ($Ab_{60}An_{40}$) forms small grains filling the interstices between the laths. A very few grains of quartz are probably present. Zircon is accessory.

The latter band grades on the north into the normal medium-grained feldspathic gabbro of the top of the sill, composed of about equal parts of common hornblende, and andesine (Ab_{60} An_{40}), with a little quartz, zircon, apatite, and calcite. The feldspathic gabbro gradually becomes coarser in texture northward, and so merges into the very coarse-grained, highly feldspathic type that forms roughly the southern third of the whole sill. It consists of about 75 per cent of labradorite feldspar (Ab_{30} An_{70}), and green hornblende, with accessory biotite, magnetite, and titanite. The grain of the crystals averages about 4 mm., and the large crystals of feldspar, which show no sign of alteration, are crowded with small lath-like inclusions of the hornblende. The hornblende also occurs in large original crystals.

The coarsely crystalline material described gives place in turn to a medium-grained, dark grey diorite or gabbro, that near the contact of the two types is composed of about 65 per cent of labradorite ($Ab_{30}An_{70}$ to $Ab_{35}An_{65}$) and 35 per cent of actinolite—in small laths about 0·1 to 0·15 mm. in length. The average grain of the feldspar is less than 1 mm. This medium-grained, dark grey rock forms the northern two-thirds of the sill.

At the contact of the medium-grained type and the coarse feldspathic type, there is a broad zone of hybrid rock, consisting of a matrix of the medium-grained type that surrounds and encloses great numbers of blebs of very coarsely crystalline material. The blebs are of all sizes up to 50 feet in length, of very irregular shape, with rounded flowing outlines; at their edges they show a rapid gradation, within about an inch, into the finer-grained material of their matrix. Their composition is like that of the feldspathic material on the south, but, if anything, slightly coarser in grain and more feldspathic.

The medium-grained material that forms the northern two-thirds of the sill appears in the field to be of much the same composition throughout, except at the northern edge. Under the microscope, however, differences may be observed. The hornblende of the rock on the south is displaced by augite toward the north, and the proportion of augite to feldspar gradually increases. The feldspar remains of much the same composition, but decreases in proportional amount. The rock thus changes from a hornblende to an augite gabbro.

At the north boundary of the sill, feldspar disappears entirely, or almost so, and the bulk of the rock consists of augite crystals, crowded together. The augite is colourless in thin section, and perfectly fresh. For 6 or 8 feet from the northern contact the rock is finer in grain than elsewhere, the result presumably of chilling. The crystals in the chilled zone average 0·05 mm. in diameter, and are approximately equidimensional. This matrix of fine-grained, fresh augite crystals contains augite crystals of much larger size, up to 1·2 mm. diameter, but otherwise like the crystals in the matrix.

The matrix also contains crystals of common green hornblende up to 12 mm. or more in length and commonly gathered together in small blebs up to a foot in length. Most of the hornblende crystals are fresh, but some of them have suffered an alteration that will be described later. Finally, sulphides and oxides of various kinds are present. Pyrrhotite is the sulphide, magnetite the oxide, present in greatest amount, and chalcopyrite, pentlandite, and ilmenite are minor constituents. They may be aggregated in solid masses, or scattered in grains of various sizes.

The changes in composition from south to north may be summarized as follows:

1. Quartz diorite—quartz, andesine, tremolite.
2. Quartz diorite—andesine, actinolite, a little quartz.
3. Quartz diorite—andesine, common hornblende, a little quartz.
4. Hornblende gabbro—labradorite, hornblende; coarse-grained, highly feldspathic.
5. Hybrid phase—mixture of 4 and 6.
6. Hornblende gabbro—labradorite, hornblende; less feldspathic than No. 4, medium-grained.
7. Augite gabbro—labradorite, augite.
8. Augite pure augite, with blebs of hornblende, magnetite, and sulphides.

Differentiation

The above table indicates a uniform variation in the specific gravity of the various rock types between the south and north edges of the sill. The specific gravities of the different minerals present are: quartz, 2·66; andesine, 2·67; labradorite, 2·713; tremolite, 2·93; actinolite, 2·99; hornblende, 3·11; augite, 3·1–3·2; pyrrhotite, 4·6; chalcopyrite, 4·2. Without making specific gravity determinations of the various rock types it is evident that the rocks on the south side are aggregates of the lighter minerals, and that the specific gravity of the various mixtures must increase continuously to the northern edge, where the rock is composed exclusively of the heaviest minerals, augite, hornblende, and the sulphides. A variation of this sort is only produced, so far as known, by the action of gravity on a molten mass of rock throughout a long period of time. The action causes the heavy constituents of the crystallizing rock magma to seek the bottom of the igneous mass, whereas the lighter constituents naturally take up their positions at the top. This process, by which a magma of originally uniform composition is separated into rocks of widely different composition, is known as differentiation.

Several theories have been advanced as to the method by which differentiation is brought about. A detailed consideration of these is out of place in this report, but the most plausible, in the writer's opinion, is that advocated strongly in recent years by Bowen,[1] which supposes that during the slow course of crystallization of a body of magma, the first-formed crystals sank through the hot liquid toward the bottom of the sill. Although any constituent present in large amount may crystallize first, the first crystals formed are usually those of basic minerals, such as magnetite, ilmenite, sulphides, olivine, pyroxene, and hornblende. Each of these minerals contains relatively larger proportions of iron, magnesia, lime, and alumina, and smaller proportions of silica, potash, and soda, than an original gabbro magma. Their crystallization and sinking, therefore, leave the upper parts of the magma richer in silica, soda, potash, and volatile constituents than at first, whereas the lower parts are enriched in the constituents carried down, i.e., magnesia, iron, lime, and to some extent, alumina. As long as this process continues, therefore, the upper parts of the magma become more siliceous, the lower parts more basic.

[1] Bowen, N. L., Journal of Geology, vol. 23 (1915), Supplement.

The facts supporting this step, supplied by a study of the Oiseau River sill, may be listed as follows:

The uniform increase in the specific gravity of the different parts of the sill, from south to north, indicates that a gravitative differentiation has occurred.

The composition of the minerals, taken in conjunction with the proportions in which they are present in the different rock types, shows that southern types are relatively rich in silica and soda, whereas lime and magnesia are small in amount, and iron is altogether absent. The northern types, on the contrary, are very rich in iron, magnesia, and lime, with minimum amounts of silica and little or no soda.

Hornblende, mica, and quartz are all minerals that characteristically crystallize from "wet" magmas, that is, magmas containing a good deal of water and other volatile constitutents, whereas, augite is equally characteristic of "dry" magmas, containing small amounts of water. The presence of hornblende, mica, and quartz in the southern parts of the sill, and of augite in the more northern parts, indicates that the volatile constitutents of the magma were segregated in the southern parts, in the manner required by the hypothesis.

The above tends to prove gravitative differentiation, without favouring the method of differentiation advocated by Bowen above those advanced in other theories of differentiation. The following facts, however, prove more definitely that crystal sinking occurred:

The large crystals of augite in the finely crystalline augite of the north edge of the sill may have sunk to their present position from higher levels. On the contrary, they may also have formed in place, like phenocrysts, having commenced their crystallization sooner than the crystals of the matrix, and thus had a longer period of growth. In itself, therefore, the presence of these crystals constitutes no decisive proof of sinking, but their association with large hornblende crystals does indicate sinking. The hornblendes cannot be phenocrysts formed in place, as the conditions requisite for the formation of hornblende and augite differ considerably, and if phenocrysts were formed in place at all, they were augite phenocrysts. The hornblendes could, therefore, attain their present position, only by sinking from the upper levels of the magma where, as the composition of those parts shows, it would form.

The blebs of coarsely crystalline feldspar and hornblende found at the southern edge of the medium-grained hornblende gabbro zone (No. 5, page 16) are explained in a similar way. The large crystals of which the blebs are composed must have commenced their crystallization sooner than the comparatively small crystals by which they are surrounded and would be among the first crystals to form in the liquid magma. But the labradorite crystals, instead of being heavier than the surrounding magma, as were the hornblendes, were lighter, and would tend to float up through it. Rising, they would encounter other crystals and be rafted with them to form the aggregates now found. During this process a number of hornblende crystals were included in the rafts, but the feldspars were apparently sufficiently lighter than the surrounding magma to support these. They would rise through the molten magma, become more acid and lighter upwards, until they reached the horizon at which the specific gravity of the liquid was equal to that of the crystal masses, and would float there until consolidation took place.

After the magma hardened into solid rock, further cooling was undoubtedly accompanied by cracking. Into the fissures so formed flowed the still liquid, highly siliceous residues of the magma, forming the present aplite dykes.

Nomenclature

As the writer, in naming the rock of the sill gabbro, instead of norite, differs from previous writers on the subject, it may be well to summarize briefly the evidence for doing so.

The writers mentioned—R. J. Colony and W. S. McCann—studied the Maskwa River sill, a body identical with the Oiseau River sill in every respect, lying 12 miles to the north. Colony's statement as to the petrography of the sill is as follows:[1]

"The norite is of simple composition, but varies both in texture and mineral make-up to some degree because of differentiation. In general it is composed almost wholly of basic feldspar ranging from andesine to labradorite, and carries as the only ferromagnesian component a green amphibole, or actinolite, derived by uralitization from a former magnesian pyroxene, probably hypersthene. One of the most striking features of the rock is the manner in which the uralitized pyroxene encroaches upon, cuts through, and penetrates the feldspar (which is otherwise perfectly fresh and unaltered) in every conceivable direction; it is clearly a product of magmatic end-phase-consolidation matters upon an original containing both magnesia and iron, i.e., hypersthene."

McCann makes no statement as to the petrography of the "norite," beyond stating that "The following petrographic description of the norite by Dr. R. J. Colony agrees with the present writer's observations."

It appears from the above description, therefore, that the rock specimens collected and studied by Colony did not contain any pyroxene, but only hornblende, corresponding thus to those from the southern half of the Oiseau River sill; and, further, that finding it naturally difficult to believe that sulphides would be segregated from a rock with composition such as he described, he concluded it better to assume that the hornblende was formed by the alteration of a hypothetical primary mineral, hypersthene, even though no remnant of such an original mineral is left, or no indication that such an alteration had taken place is to be seen.

The writer's examination indicates that augite, not hypersthene, is the pyroxene present in the intrusive. It is possible that a more detailed examination might reveal hypersthene or enstatite, but none was found in the three thin sections from the basal parts of the sill that were studied. The rock is, therefore, properly a gabbro rather than a norite.

Neither can the writer agree with Colony that the hornblende has resulted from the alteration of pyroxene. The hornblende forms massive, often very large crystals, lacking entirely the leafy structure usually found in the alteration product of pyroxene. Again, it rarely happens that large crystals of pyroxene alter to hornblende so completely that there are not some small remnants of pyroxene remaining in some of them. Nothing of the sort is here observable. Further, numerous small crystals of hornblende enclosed in large crystals of perfectly fresh labradorite are to be seen in many thin sections. If these are alteration products of pyroxene it is difficult to see how solutions could have saturated the feldspars so completely as to cause the alteration, without at the same time altering the feldspar. Finally, the augite found in the basal parts of the sill is without the smallest sign of alteration, even where filled with blebs and veinlets of sulphide, where alteration might naturally be expected.

The writer has, therefore, concluded that the hornblende present is not an alteration product of pyroxene, but was normally formed during the crystallization of the upper parts of magma; presumably because there was in these parts a concentration of the water and other volatile constituents of the magma.

Structural Relations

Structure of the Intrusive. The large mass of gabbro in Oiseau River area parallels the bedding of the Rice Lake series in a general way, and, therefore, is termed a sill. For a great part of its length the intrusive has followed the contact of the granite and Rice Lake series, but toward its west end it has left this contact and broken across the Rice Lake series to the contact between the volcanics and the sediments. The north contact of the gabbro and granite, seen in several places, is vertical or steeply inclined to the south, corresponding to the general dip of the Rice Lake series.

[1] Colony, R. J., Bull. C.I.M.M., No. 103, p. 867.

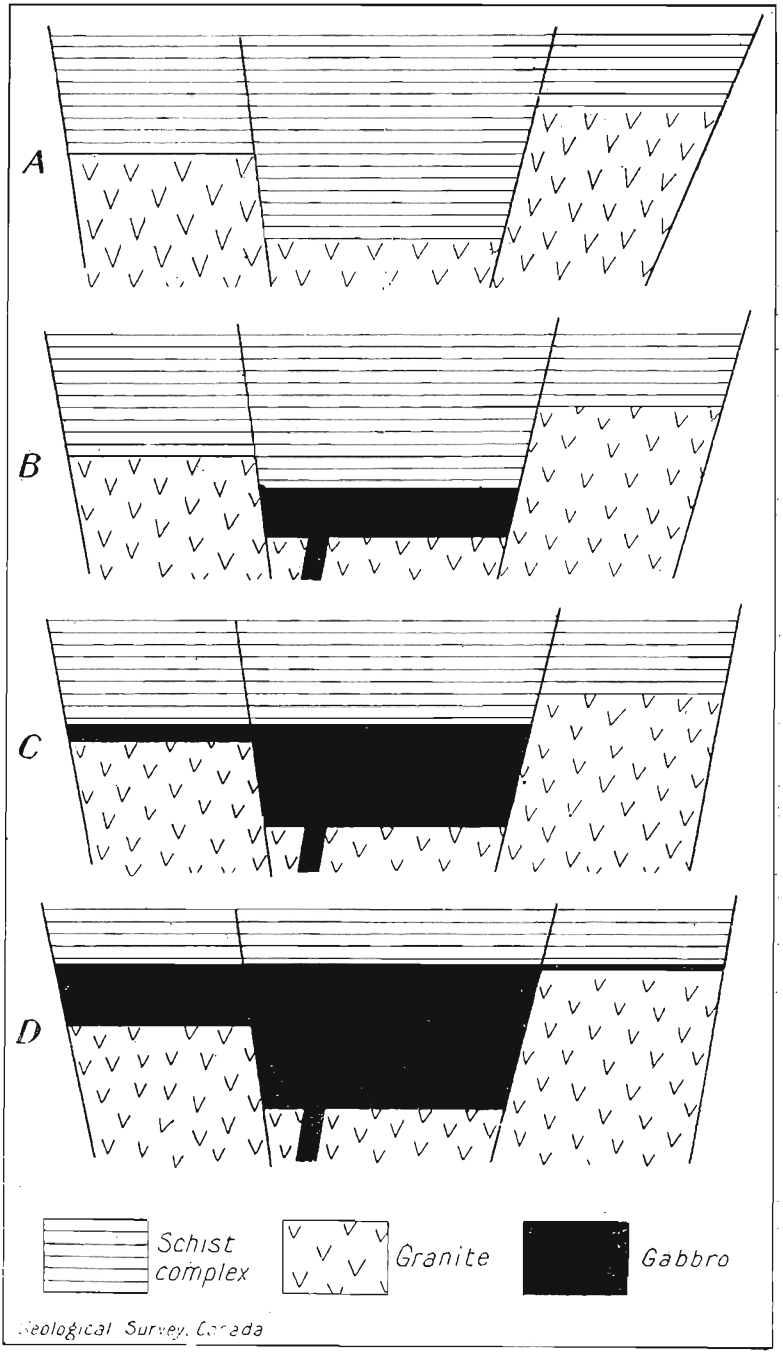


Figure 4. Diagram showing a possible mode of intrusion of the gabbro of Oiseau Lake area.

Detailed mapping of the boundaries shows that the gabbro does not form a normal sill, however, but is made up of a number of sections of different widths. The width of the individual sections is nearly uniform from end to end, and the strike of each section is approximately parallel to that of the adjacent Rice Lake series. The narrowest section is only about 500 feet in width; the widest over 6,000 feet. At the junction of two sections, the end of the wider is a straight line running nearly north and south.

The mapping also shows that all the changes in width are effected by the shifting of the north boundary only; the south boundary of the sill is a gently curving line with a general east and west direction. In section the sill, therefore, looks like a succession of rectangular blocks of different thickness, placed end to end on a gently curving surface.

Search for the cause of these peculiarities revealed that the north-south lines bounding the ends of the thicker blocks are faults that have formed belts of schist of varying width in the older rocks but did not fracture and displace the gabbro, since its southern boundary is not displaced. The faults were there before the gabbro was intruded, and merely controlled the intrusion.

An attempt to portray the possible mechanics of the intrusion has been made in Figure 4. Figure 4 A represents the supposed original structure of the rocks after faulting had occurred, and before the intrusion of the gabbro. The gabbro may be supposed to have entered first into the deeper fault blocks, splitting them apart along the contact of the granite and Rice Lake series, and raising bodily the overlying mass of Rice Lake series (Figure 4 B). When the block was raised so far as to bring the gabbro up to the granite—Rice Lake series contact in the next fault-block, the gabbro entered along this plane also and proceeded to raise the adjacent block of Rice Lake series (Figure 4 C). Repetition of the process might produce the present condition (Figure 4 D).

Intrusion of the gabbro was controlled, primarily by the bedding of the Rice Lake series, and secondarily by the faults cutting that series and the earlier granite. The question still remains to be considered, was the sill intruded in its present vertical or steeply inclined position, or was it folded into that position after its intrusion and consolidation. The writer believes that the facts already presented support the view that when the sill was intruded it lay either in a horizontal or at most a gently inclined position, and that, therefore, it has been thrown into its present steeply inclined position by later folding.

The beds and flows of the Rice Lake series are so folded that their former upper side now faces toward the south. If the sill was intruded before the Rice Lake series attained this position, its south side should also be the upper side, and should exhibit characteristic features accordingly. On the contrary, if the gabbro was intruded in its present position, and has maintained that position unchanged since intrusion, there would be no reason to expect the southern edge to differ in any way from the northern edge, any more than the two edges of a large dyke differ from each other. But it has already been pointed out that there are very great differences, both in composition and grain, between the northern and southern parts of the sill; and that these differences are such as could be produced by gravitative differentiation. In fact the differences are identical with those produced by gravitative differentiation in gabbros that have been undisturbed since consolidation; and whose original top and bottom are, consequently, definitely known.

The variations in the composition of the sill, therefore, indicate that it once lay in a flatter position than at present, and that it has been so folded as to make the original upper side face the south. There are two other facts tending to confirm this conclusion. The granite on the north side of the sill is filled with dykes of gabbro trending toward the large sill, but no such dykes occur on the south side. If the sill was originally flat-lying, the dykes were probably its feeders, and as such must lie on its original lower side. If the sill was intruded in a vertical position originally, there would be no need for such feeders, and the dykes must be supposed to be merely offshoots of the larger body; in which case it is difficult to see why they should be confined to the north side of the sill.

Finally, intrusion of the sill was controlled by the faults of the region, in such a way that the inflowing igneous rock pushed out the rocks on the present south side, giving the south side a smoothly flowing outline. This is conceivable if the sediments now forming the south side were flat-lying at the time of intrusion, and hence free to move upward, but it is very difficult to explain if the rocks at the time of intrusion lay in their present position, for intrusion must in the latter case have been accompanied by great horizontal compression.

The writer believes that these reasons justify the conclusion that the Oiseau River sill has been tilted into its present position since its intrusion. It has already been shown, however, that the first period of folding undergone by the Rice Lake series preceded the period of faulting, and probably preceded or accompanied the intrusion of the earlier granite. Yet the gabbro sill was intruded *after* faulting, and lay almost flat during its consolidation. To reconcile these apparently inconsistent facts we must conclude that the first period of folding affecting the Rice Lake rocks was not very severe and produced rather low dips, not over 20 degrees or 30 degrees perhaps. The gabbro could have been intruded as a sill into rocks with such dips, and still have undergone the gravitative differentiation it now exhibits. It is of interest in this connexion that there is good evidence to prove that the first folding affecting the Keewatin rocks to the south of James bay gave these rocks dips of about 20 degrees.

Relations to Other Formations. The gabbro is found in contact with only three of the rock formations of the district, the Rice Lake series, and the earlier and later granites. Its relations to the dyke rocks of the Rice Lake area are, therefore, undetermined. The feeders of the gabbro sill cut through the earlier granite in Oiseau River area, and the sill itself is chilled at the edge in contact with the earlier granite. It, therefore, is intrusive into the earlier granite, and into the older Rice Lake series.

The gabbro is found in contact with the later granite in the Maskwa River area. Good contacts indicate that the granite is intrusive in the gabbro. At one sharp contact the massive coarse-grained granite is chilled to a fine grain, and possesses a distinct flow structure indicating movement of the chilled and viscous granite along the contact, whereas the gabbro, very coarse-grained and feldspathic, maintains its grain unchanged at the contact. In several other places dykes of granite cut the gabbro, but, unlike Oiseau River area, no dykes of gabbro were seen in the granite.

MASKWA RIVER GABBRO

Maskwa River area has been described by McCann in the Summary Report of the Geological Survey, 1920, and a report on the same district has also been made by R. J. Colony. These writers differ somewhat in their interpretation of certain facts, and both assign a structure to the Maskwa River gabbro different from that which the writer has shown the Oiseau River mass to possess. As similarities rather than differences might reasonably be expected in two bodies of nickel-bearing gabbro so close together, it seemed advisable to make a rapid trip into Maskwa River area in order to compare the two gabbros, and to obtain data that might reconcile the differences in interpretation. In addition, it was decided to examine another body of gabbro reported a short distance to the east of that described by McCann.

McCann and Colony show by the structure sections accompanying their maps that they consider the Maskwa River gabbro to be a stock-like mass, that is, a body whose depth is as great or greater than its length. The Oiseau River gabbro, on the contrary, is a sill, or pancake-shaped body; and in addition, the sill has been tilted on edge. The economic importance of determining the structure correctly is obvious. If the Maskwa River body be a stock, there is no reason why nickel ores may not be found at any point along the outer edge; and, since the ore minerals tend to sink through the molten rock, rather than to move toward the sides, concentration would not, probably, be great enough at the sides of a stock to make valuable ore-bodies. If on the other hand, the mass be a tilted sill, like that at Oiseau lake, the ores will be found along one edge only, the original lower edge, and concentration might be great enough to form ore-bodies.

McCann and Colony differ in their interpretation of the geological relationships of certain masses of Rice Lake lava within the limits of the Maskwa River intrusive. McCann regards them as mere inclusions—bits of lava broken off during the intrusion of the molten gabbro, that floated around in it until it consolidated. Colony, on the other hand, considers them as parts of the roof or base of the mass brought into their present position by faulting. Colony accordingly maps the gabbro and Rice Lake series in alternate parallel belts separated by faults, whereas McCann maps the gabbro as a single large mass containing isolated bodies of Rice Lake lavas.

If Colony's interpretation were correct, and the masses of lava were parts of the base on which the intrusive lies, the fact would be of the greatest importance to the prospector, as nickel ores might be expected to occur along all the contacts of the gabbro and Rice Lake rocks, and the area favourable for prospecting would be enormously increased. If they are downfaulted parts of the roof, no ores would occur around them. If they are inclusions, then again they will not influence in any way the deposition of ore-bodies.

Examination of the Maskwa River body convinced the writer that it is similar in every way to the Oiseau River mass. Towards its north side it has the same very coarse grain and highly feldspathic composition that distinguishes the south side of the Oiseau River sill; and the coarse-grained material gives place successively to medium-grained hornblende gabbro, augite gabbro, and augitite containing large hornblende crystals, magnetite, and sulphides in exactly the same manner as described for the Oiseau River sill. All the sulphide concentrations occur along one side of the body of gabbro—the south side. The writer, therefore, concluded that the Maskwa River mass is also a tilted sill, that differs from the Oiseau River sill only in having the upper side facing north instead of south. Evidently the Maskwa River sill lies on the north side of the anticline of which the Oiseau River sill forms the south side.

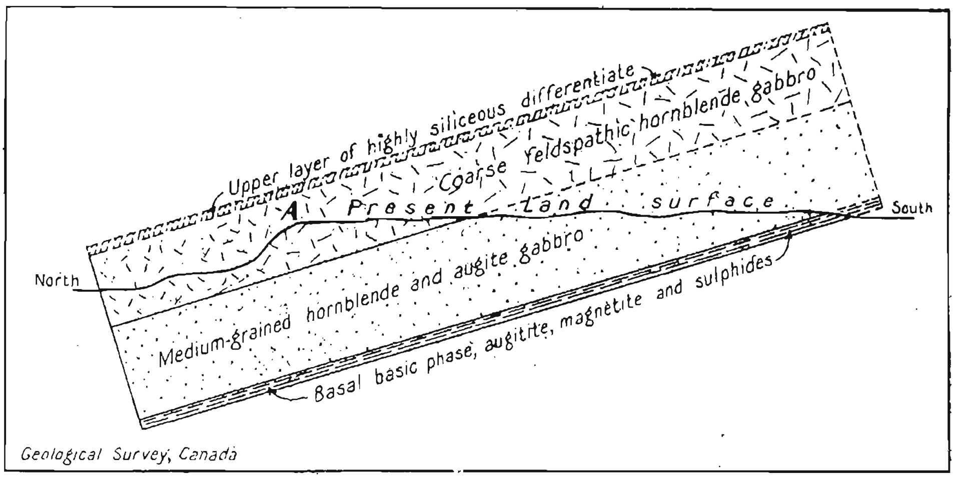


Figure 5. Diagram showing inferred structure of Maskwa River sill and the removal of its upper part by erosion. The most feldspathic differentiate occurs at A.

The Maskwa River sill does not, however, appear to be tilted into a vertical position, like the Oiseau River sill, but to have rather a low northward dip of 20 degrees or 30 degrees. This conclusion was drawn because the most feldspathic differentiate does not occur at the northern edge of the sill, but 20 to 25 chains to the south, and at a higher elevation. Figure 5 illustrates the relations that occur, and the inferred structure.

The writer then investigated the contacts of the bodies of Rice Lake series lying within the gabbro mass. If these bodies are really parts of the original roof or basement of the sill, the gabbro should show chilled edges against them, for such chilled edges are prominent features of true contacts, and are 5 or 6 feet in width. On the contrary, if these masses are merely inclusions, broken off by the fluid gabbro, and floating around in it until it became consolidated, they would have become thoroughly heated by the time consolidation occurred, and the gabbro in contact with them would not be chilled, but would crystallize coarsely. Examination showed that the contacts are not chilled, and, further, that the bodies of Rice Lake series have undergone strong heating, or baking, as might be expected if they are inclusions. Again, there is no difference in the composition of the gabbro on the two sides of a body of Rice Lake lava. If the lava was a part of the original basement or roof of the sill, such a difference in composition would be inevitable. The bodies of Rice Lake series within the limits of the Maskwa River intrusive are, therefore, not parts of the original roof or basement of the sill, brought into their present position by faulting; but are merely inclusions or roof pendants, as McCann concluded. It follows that they have no influence on the deposition of the copper-nickel ores, and that only along the main southern contact of the sill with the Rice Lake series may such ores be expected to occur in paying quantities. The writer may add that his traverses indicate that the inclusions of Rice Lake series are shorter and rounder than as mapped by McCann.

An important shear zone, striking north 70 degrees west and dipping 50 degrees south where observed, cuts the Maskwa River gabbro, crossing the west boundary of surveyed timber limit 2692 about 25½ chains south of Cat Creek crossing and 9½ chains south of post marked T.B. 2692. The shearing has converted coarse feldspathic gabbro into a highly fissile schist. Two belts of schist, 4 feet and 2 feet wide respectively, were observed, separated by 3 or 4 feet of unsheared rock. Information received from prospectors indicates, however, that further belts of sheared rock are present, though concealed by drift where the writer made his observations. The rock on both sides of the fault is the coarse feldspathic gabbro. There is strong magnetic variation in the neighbourhood of the sheared zone, probably due to the recrystallization of some of the iron of the gabbro as magnetite, during the shearing.

The writer also visited the newly-discovered body of gabbro lying to the east of the body described by McCann. Time did not permit of the mapping of this body, which is about one-half mile in width from north to south, and is said to be at least 2 miles long. It is heavily covered by clay and wind-blown sand, so that outcrops are scattered. A number of mining claims have been staked on this body by Messrs. D. A. McLeod and A. Campbell, whose camp is situated near its west end, and about 3½ miles, by trail, east of Restawhile camp on Cat creek (See map No. 1841, by W. S. McCann).

The newly-discovered body is bounded on both the north and south sides by the later granite. Good proofs were obtained that the granite is intrusive into the gabbro. The granite has stoped away almost all the Rice Lake series into which the gabbro was originally intruded, and has even cut into the sill itself. The original edges of the sill being thus removed, it is improbable that good ore-bodies will be found along the contacts. If parts of the lower contact can be found, along which there still remains some of the older Rice Lake series, such places might be worth prospecting.

Like the Maskwa River sill, this one appears to lie at a low angle, with a dip to the north, so that the southern edge is the one along which deposits, if present, are likely to occur.

LATER GRANITE

The later granite occurs around Maskwa river from the mouth to the nickel deposits; on Winnipeg river from Maskwa river down to lake Winnipeg; and up Manigotagan river from lake Winnipeg to Clearwater lake. It may occupy the whole of the belt between these districts.

Petrography

The later granite is a coarse-grained, grey, white, or pink rock, commonly equigranular, but locally exhibiting strong porphyritic textures. The composition appears to vary somewhat in thin section, different sections containing from 10 per cent to as much as 40 per cent of quartz. The ferromagnesian mineral is either all biotite, or a mixture of hornblende and biotite. It is usually small in amount, although forming perhaps 15 per cent of the rock around Maskwa lake. A little muscovite, apatite, and zircon may be present. The feldspar is largely or entirely albite or albite-oligoclase, variations in composition from pure albite to Ab_{70} An_{30} being observed in different districts. Microcline may also be present, in greater or less amount. In a section from the mouth of Maskwa river microcline forms two-thirds of the total feldspar; in a section from the neighbourhood of the Maskwa River nickel deposits, about one-fourth; and in a section from Clearwater lake, on Manigotagan river, no microcline was observed.

In places the granite exhibits gneissic phases, due to the flow movements of the viscous magma during consolidation, and to digestion of inclusions.

Metamorphism of Rice Lake Series

Around Clearwater lake (Rice Lake district) the intrusion of the later granite has strongly metamorphosed the older Rice Lake series. Along the contact there is a zone of Rice Lake series about half a mile in width, that has been so metamorphosed and intruded lit-par-lit by the granite, that it is almost impossible to draw a boundary line between the two. The boundary, shown on the map, represents the southern boundary of unaltered Rice Lake series, to the south of which lies the one of granite dykes and altered Rice Lake rocks, all mapped together with the granite.

The alteration of the Rice Lake lavas in the contact zone appears to have been largely a granitization; that is to say, the older rocks seem to have absorbed, like a sponge, much siliceous and feldspathic material from the granite. This material, entering along planes of schistosity and other channels, acidified the older rock both by admixture and by combining chemically with some of the more basic constituents. The resulting rocks are hybrids, like neither of the parents, but with some of the characteristics of both. Most of them retain more or less perfectly the bedding or schistosity of the Rice Lake lavas and their greenish colours; but differ in being highly quartzose, more feldspathic, and coarser grained.

Structural Relations

Jointing and Faulting. The later granite is cut by numerous joints and faults with small displacements, not exceeding a couple of inches. Large faults with wide, sheared zones, such as are found in the older rocks, do not occur in the later granite. Where such belts of schist strike from the older rocks towards the granite, they are cut sharply off at the contact, and the projection of the fault line is marked merely by a joint. Evidently the later granite was intruded subsequent to the main periods of faulting, but slight movements, of sufficient strength to joint the granite and fault it slightly, followed the intrusion.

The jointing in the granite follows the same trends as the earlier faults of the district. There are in all three or four sets of these joints and small faults, which, although undoubtedly produced all within a short time, exhibit a definite sequence of formation.

The first to be formed comprises apparently two sets, one striking north 10 degrees east, the second north 50 degrees east, although there is some variation from these directions. Those striking north 10 degrees east seem to be merely joints, without horizontal displacement of any kind between the two sides; but thin seams of black gouge-like material in them suggest that there might have been a little vertical movement. Those striking north 50 degrees east are distinct faults, with small horizontal displacements. The northwest side has been shifted toward the southwest.

A third set of small faults has a general strike of north 20 degrees west. In these the east side is displaced horizontally toward the south, like the larger faults in the Rice Lake series. These small faults are distinctly later than the first set of joints, for joints between a pair of the faults have been rotated and widened (Figure 6). Their relations to the faults striking north 50 degrees east are not definitely known.

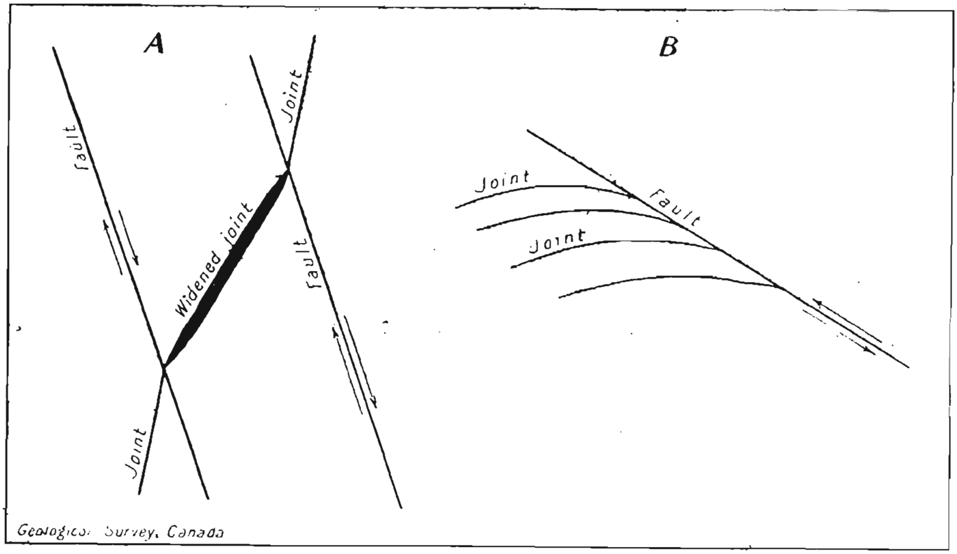


Figure 6. Diagram showing: (A) rotation and widening of a joint between two small faults; (B) relation of joints to a fault.

All these joints and faults are filled locally with thin dykes of aplite, indicating that they must have been formed very soon after the consolidation of the granite, while there was still some liquid siliceous magma left to fill them.

The last set of small faults has a general strike of north 70 degrees west. Movement along them has been almost horizontal, as shown by the direction of the fault striæ, which rarely dip more than 30 degrees. The north side of these faults has been quite uniformly shifted toward the west, as shown by the displacement of small aplite dykes. These faults are commonly filled with hard vitreous quartz, probably the last exhalation of the granite magma. In places the quartz has been shattered, implying slight further movement after the deposition of the quartz.

The formation of the latter faults has been accompanied by jointing of rather irregular direction. Figure 6 B shows the connexion of the joints with a fault, and indicates the variation in their strike. Slight movement along the joint planes may also be observed.

Relations to Other Formations. The later granite intrudes all the other rocks of the region, and hence is the youngest rock present. In Maskwa River area it cuts into the gabbro, sends dykes into it, and shows a chilled edge with a gneissic texture against it. In Rice Lake area it intrudes and metamorphoses the Rice Lake series, and cuts off the diabase dykes that intrude it. Dykes of the granite also pierce the Rice Lake series, and cut across all the other dykes of the vicinity.

CORRELATION

No extensive correlation of the eastern Manitoba district with others can be attempted at present, both on account of the lack of work in intermediate areas, and the scantiness of the geological record in the areas studied. However, attention may be called to the similarity of the granites to those described by Lawson in the Rainy Lake area 150 miles to the southeast. Lawson states[1] that in the Rainy Lake area there are granites of two ages. The older, which he terms Laurentian, has suffered from marked deformation and shearing, whereas the younger, termed by him Algoman, is typically fresh and unsheared. The similarity to the granites of eastern Manitoba is self-evident, and it seems probable, therefore, that the Manitoba granites were intruded at the same time as those around Rainy lake.

The Rice Lake series bears the same relation to the earlier granite as Lawson's Keewatin bears to his Laurentian granite. The Rice Lake series may, therefore, be tentatively correlated with the Keewatin of Rainy lake.

ECONOMIC GEOLOGY

Nickel-Copper Deposits

Discoveries have been made in Oiseau (Bird) and Maskwa (Bear) River areas of bodies of sulphides containing considerable quantities of nickel and copper. Those at Maskwa river have already been described by McCann.

The principal ore mineral in both districts is pyrrhotite containing more or less pentlandite and chalcopyrite. Ilmenite and magnetite are also present in large quantity. In each district the ore minerals are concentrated within the gabbro near the original base of the sill. In Oiseau River area this is the northern contact; in Maskwa Lake area the southern contact. Elsewhere in the sills only an occasional grain of sulphide or magnetite may be found here and there.

The sulphides and oxides do not occur in veins, but as irregularly shaped accumulations, or segregations, within the gabbro. In places the concentration has been sufficient to form solid masses of ore minerals several feet in thickness. Where less concentrated, the ore minerals are mixed with varying amounts of the minerals of the gabbro. There is no sharp boundary between a mass of ore and the surrounding rock; the proportion of ore minerals very gradually decreases, and that of the rock minerals increases, until pure gabbro results.

The concentration along the lower edge of the sills ranges from solid masses of sulphide or oxide in one place to sparse accumulations too lean to form ore in other places. From north to south, however, the concentration varies more uniformly, being always greatest near the former bottom of the sill and becoming rapidly less upward. The basal zone containing a notable proportion of sulphides is rarely over 100 feet in thickness, and commonly less.

The facts that the sulphides are scattered throughout the gabbro, and the rock minerals form everywhere the gangue in which they occur, indicate that they, together with the magnetite, are original constituents of the magma. They are the heaviest constituents of the rock, and are everywhere found concentrated along the original base of the sill, and they, therefore, like the augite and hornblende of the rock, sank while the main part of the intrusive was still liquid. Hence the ordinary processes of gravitative differentiation have caused the primary concentration of the sulphides, as at Sudbury.

Examination of thin sections of ore and rock from the base of the sill shows, however, that processes of secondary concentration have also been busy. The large crystals of green hornblende are in places cracked across, and solutions entering the cracks have leached the iron from the green hornblende, forming a colourless variety, tremolite, for from one-fourth to one-half millimetre on each side The alteration

[1] Lawson, A. C., Geol. Surv., Can., Mem. 40, 1913.

may extend for several times this distance, along cleavage cracks in the hornblende. The tremolite so produced may be massive and optically continuous with the original hornblende, extinguishing with it; or it may form a multitude of grains, laths, and fibres. Calcite and sulphides fill the fissures, and also to a small extent replace the tremolite; the sulphide appears in places to be slightly later than the calcite, and to replace it. Small grains and strings of sulphide are also to be seen filling the interstices between the laths and grains of tremolite.

In other places sulphide fills small discontinuous cracks in the augite matrix. The augite on the sides of such cracks shows no sign of alteration. Other similar cracks are filled with tremolite fibres. Certain large crystals of hornblende have been completely altered to masses of tremolite fibres, and masses of sulphide have formed around the edges of all such altered crystals; grains and strings of sulphide fill spaces between the fibres.

The whole set of phenomena is worthy of more detailed study than the writer has been able to give it. The facts obtained indicate, however, that the sulphides, primarily concentrated in their present position by gravity, have been more or less brought into solution again and redeposited by solutions, or vapours, acting about the time of consolidation of the norite. The cracks mentioned as occurring in the augite matrix, filled with sulphides, are so discontinuous, running for perhaps 10 or 15 mm. and then ending in massive rock, that they must have been formed before the rock was completely hardened, so that fissures closed at once unless they were filled. The leaching of the iron from the hornblende implies the presence of solutions or vapours rich in sulphur; at the same time the amount of sulphide surrounding an altered hornblende crystal is many times too great to have been formed from the iron of the hornblende alone. The freshness of the augite likewise implies that the solutions of vapours were acting at a very early stage in the consolidation of the magma; had they been much later and cooler, the augite would probably have suffered alteration, as it would not have been in equilibrium with them.

To sum up: it is concluded that the oxides and sulphides were brought into their present position by sinking through the liquid gabbro. As the gabbro consolidated, cracking slightly at the same time, solutions or vapours carrying sulphur and iron permeated it, leaching iron from the hornblende, altering the hornblende to tremolite, and depositing iron sulphide in cracks and in and around the altered hornblendes. Singularly, there appears to have been some formation of calcite also, although the data on this point are not very definite. Prospecting should be confined to the former bases of the sills, the northern edge in Oiseau River area, the southern edge in Maskwa River area. At Sudbury the richest deposits have been found in former holes and depressions in the base of the sill, owing to the natural tendency of the heavy sulphides to gravitate to the lowest part of the base. It is highly probable that the same tendency was operative in the districts under consideration, hence search should be made for such depressions.

Attention may be called to the fact that ore-bodies cannot occur in connexion with any bodies of gabbro other than the large sills that have undergone the differentiation described. Bodies of gabbro of all sizes are to be found in many places throughout the district—dykes, which even an untrained observer can see to be of similar composition from edge to edge. It is absolutely useless to search for ore-bodies in the neighbourhood of such masses; the effort is merely a waste of time and money.

Values

The values, in the discoveries so far made, are principally in nickel, although copper in some amount occurs locally. Prospectors reported to the writer that they had obtained up to 5 per cent of nickel from some of the solid masses of sulphides. A small grab sample taken by the writer from such a mass gave, on analysis, 3·07 per cent of nickel, 0·07 per cent of copper, and 14·22 per cent of insoluble mineral matter.

Prospecting has not shown whether the discoveries so far made include any orebodies of commercial importance. Much more work should be done to determine the length, breadth, and depth of bodies already found, and further search should be made for new bodies before the district can be pronounced a potential producer.

Parts of the district are rather thickly drift-covered, making prospecting by the ordinary methods difficult and expensive. In view, however, of the magnetic quality of the deposits, due to their content of pyrrhotite and magnetite, the district is particularly suited to prospecting with the dip needle. A large area might be rapidly and cheaply traversed with this instrument, that requires for its proper use only elementary information, obtainable from the vendor. By locating with it the spots where the magnetic attraction is locally above normal surface exploration could be concentrated on those places, and much labour and expense avoided.

Gold

MINING CONDITIONS IN THE DISTRICT

Gold has been known for many years to occur in Rice Lake district, and the area has been rather extensively prospected. In several instances companies carried on considerable underground work and have even erected milling machinery. Nevertheless there is as yet only one producing mine. An important deterrent has been the expense of transportation, which, with the general low-grade character of the deposits, has kept well-established mining companies from locating there. Others, however, less well-advised, have established workings foredoomed to failure by the poverty of the deposits exploited; and in still other instances more or less work has been done by companies as the basis of extensive stock-selling campaigns.

Rice Lake and adjoining districts have already been described by DeLury, who has given detailed and accurate descriptions of the veins on all the more important claims, and readers who desire such information are referred to his work. The present writer will confine himself to a general statement of the methods of occurrence and the origin of the gold deposits.

GOLD VEINS AND THEIR ORIGIN

Gold deposits are found in three general positions; in the later granite, in the earlier granite, and in the Rice Lake series. They were at first found in the Rice Lake series. Afterwards, some deposits were found in the later granite; and later, veins of considerable size were located in the earlier granite, to the north of Wanipigow river and lake. The deposits in the Rice Lake series and the earlier granite are found entirely in the shear zones, or belts of schist, that were formed as a result of the faulting of these rocks. Their maximum size is, therefore, limited by the size of these zones.

Veins in the Later Granite

The deposits in the later granite consist of auriferous quartz filling cracks formed by jointing and faulting. Most of the joints so filled appear to be of the last set formed, with a strike north of 50 degrees west. The veins of this type are, naturally, all small, at least so far as present discovery has shown. The largest seen by the writer is that on the Pendennis claim, a lens some 200 to 300 feet in length, and about a foot wide on the surface. The width is said to increase downward to about 4 feet at a depth of 40 feet. Most of the other veins seen by the writer in the later granite are 3 or 4 inches wide at most.

Veins in the Rice Lake Series

The veins in the Rice Lake series exhibit some interesting and important areal relationships. In the first place, those of importance occur, with one exception, in the shear zones that strike predominantly northward, that is, away from the granite contact to the south; rather than in those with a more westerly strike, that are approximately parallel to the granite contact. The exception noted is the Wolf vein, near Red Rice lake (claim No. L. 83-124), a large vein with good reported values; and it is to be noted that it lies close to a small outcrop of later granite, which may be the top of a larger body beneath.

When one of the large shear zones is traced throughout its length, another strikingly important fact becomes evident. At the end nearest to the later granite the shear zone is well filled with quartz, that replaces a great part of the schistose rock. At increasing distances from the later granite the amount of quartz in the sheared zone gradually decreases and finally disappears, leaving a sheared zone of country rock. The transition from quartz-filled to quartzless shear zones was traced in each of the large shear zones examined and the conclusion is inevitable, that the solutions carrying and depositing the quartz originated in the later granite.

The distance to which these solutions travelled along the shear zone and deposited quartz presumably varied with the ease of penetration, the volume of solutions available, and the pressure behind them. In the cases investigated the greater part of the deposition ceased within a mile and a half of the contacts; except the most eastern shear zone mapped (which also happens to be the largest in the area) where lenses of quartz 2 to 4 feet in width are found 2½ miles from the later granite.

Quartz is the principal vein mineral. Associated with it are certain sulphides, principally iron pyrites, with small amounts of chalcopyrite, and occasionally a little galena and sphalerite. Non-metallic minerals include albite, iron-bearing carbonate (ankerite or siderite), a little calcite, and in places a little mica and tourmaline. Gold, usually in the free state, is the principal economic constituent.

The minerals mentioned, with the exception of the free gold, crystallized with the massive quartz, indicating that they were all deposited from the same solutions at the same time. In addition to filling the veins, there was a certain amount of replacement of the adjoining schist by the vein minerals, particularly by the sulphides.

Variations in Composition

The mineral composition of the veins exhibits an interesting variation that also indicates the solutions to have originated from the later granite. The veins in the later granite itself are characteristically composed of quartz containing more or less albite. Hand specimens were taken from such veins which consist almost entirely of fine-grained albite. The veins contain rather large proportions of sulphides, and, it is reported, rather high values in gold, up to $50 per ton or even more.

Just outside the later granite the veins consist wholly of quartz, without albite or iron carbonate, so far as observed. They contain moderate amounts of pyrite, although less than the veins in the granite, and are reported to carry gold values in the neighbourhood of $10 to $12 a ton. Iron carbonate begins to appear in the veins, with the quartz, at distances of about a mile from the granite contact. Within this distance the proportion of sulphides diminishes with increasing distance from the granite, and presumably the gold values also, although very little information is available on the subject.

The iron carbonate is first to be observed in the schist near the veins, and in thin offshoots from the veins, rather than in the main veins themselves. With increasing distances from the granite it invades the main veins, and rapidly displaces the quartz. Finally quartz disappears entirely, and the vein material consists almost wholly of iron carbonate. In the most eastern shear zone mapped, this substitution occurs 2¾ miles from the point where the shear zone is cut off by the later granite.

These changes in composition are due to the changes in concentration and temperature undergone by the solutions while passing away from the granite. While still within the granite they must have been very hot and concentrated, carrying the constituents of albite as well as quartz and sulphides, and depositing them on slight cooling. All the albite constituent was deposited by the cooling of the solution as it entered the cold rocks beyond the granite, and consequently quartz is the chief constituent of these veins. With increasing distance from the granite, the solutions would become still cooler and less concentrated through the deposition of their quartz, until finally conditions were favourable for the deposition of the last constituent, iron carbonate.

Values

In Rice Lake district the sulphides do not apparently carry important values in gold and the values of the veins appear mainly due to their free gold content. The free gold, where observed, forms leaflets along minute cracks or fissures in the quartz, and, therefore, is of slightly later age—presumably deposited by the last remnants of the magmatic solutions, after the earlier quartz had been shattered by slight movement. The quartz is nearly or quite barren of values where it has not been so shattered, but remains hard and vitreous.

In the district north of Wanipigow (Hole) lake, however, the sulphides form a much larger proportion of the veins than in Rice Lake area, and also appear to carry the principal gold values, although free gold is also prominent in some of the deposits.

It may be added that information regarding values was difficult to obtain, and not wholly reliable. Many of the deposits have not been worked for some years past, and several of these are the ones concerning which information is most desirable. The Gold Pan, Gold Seal, and Pan Extension properties, which were active at the time of the writer's visit, are mainly free gold properties, without important concentrations of sulphides.

It may be conceived, however, that since the free gold was deposited from later solutions that seeped through small fissures in the quartz of the veins, the movement of such solutions would be brought to a standstill not far from the edge of the later granite; and the solutions would not get as far away from the earlier granite as did the quartz-bearing solutions. Even if penetration to equal distances did take place, the solutions might have deposited the great part of their load of gold within a short distance from the granite. The meagre facts at hand seem to support the supposition. In two of the shear zones the higher values are comparatively close to the granite, whereas the parts farther away carry lower values.

Shape of Veins

The size and shape of the bodies of vein material in the shear zones depend very largely on the shape of the shear zone itself. Therefore, the extreme variations in size that the shear zones exhibit (page 31) are an important factor in vein formation, and affect seriously the mining value. The quartz veins, like the shear zones, are not regular in shape, but form a series of lenses placed end to end. Sometimes the lenses are connected by a fairly wide neck of quartz, but in many other instances there may be only a narrow stringer of quartz joining them, or none at all. The more continuous veins, naturally, lie nearest their source, the later granite. The veins have the same lenticular shape in depth as on the surface. Even where the shear zone is not lenticular, the bodies of quartz in it are apt to be. This is more particularly the case at some distance from the later granite.

Enrichment from Other Bodies of Granite

Besides the large body of the later granite on the south side of Rice Lake area, smaller granite bodies lying within the Rice Lake series seem to have caused deposition of quartz, gold, and sulphides in the shear zones. Thus, on the Wolf claim, L. 83-124, enrichment is greatest at the western outcrop, and decreases rapidly eastward; and about a quarter of a mile to the west, across an area largely drift-covered, a large dyke-like body of the later granite outcrops. Again, a large dyke of granite outcrops in a swamp a little north of the south boundary of the Gold Pan Fractional claim, L. 20-174. As this dyke has an east-west strike it probably runs west into the Mildred claim, L. 35-124. On the north side of the Mildred claim is an outcrop of a strong vein of quartz—said to carry fair values—that runs north about a quarter mile, where it splits into discontinuous lenses and dies out. On the south side of the Gold Pan Fractional claim a narrow, rather discontinuous vein outcrops, exhibiting in places rich samples of gold; and at the contact of this vein with a dyke of later diabase, on the Gold Pan claim, L. 18-174, there is a rich concentration of free gold. The dyke, although fractured by later movement along the fault plane, acted probably as a partial dam to solutions flowing along the sheared zone from the granite dyke; so that cooling and deposition were favoured at the junction.

Detailed Descriptions

It may prove of some value to describe the mining claims as they occur on the various shear zones of which they form parts.

The easternmost shear zone examined is one of the largest in the area. It meets the contact of the Rice Lake series and the later granite on the Moose claim, L. 10-174, and runs northwesterly through the Bluebell, Saxton, Golden Vein, Sunlight, Roland, and Nevada claims successively. On the north side of the Nevada claim it passes into a large swamp, three-quarters of a mile wide. The north side of the swamp is thoroughly burned over, and is now all bare rock. This was carefully examined, and a number of shear zones were observed. Only one of these is at all comparable in size to the great shear zone on the south, the others being only about one-tenth the size. As the large sheared zone is also aligned with the Nevada shear zone, the two are presumably parts of the same zone. The shear zone thus picked up is first seen near the northern side of the Snowstorm claim, L. 62-124. It continues north into the Ranger claim, L. 22-124, and the Golden Rod claim, on the north side of which it swings somewhat to the west and becomes a part of the great shear zone along the south side of Rice lake.

On the Moose claim and northward the shear zone has an average strike of north 28 degrees west, although locally this varies between north 10 degrees west and north 45 degrees west. The shear zone maintains a definite strike as a rule over lengths of 3 to 10 chains only, at the end of which a change in strike occurs. This results in great variation in the width. The straight parts are generally narrow—in one place only 2 feet—whereas the bends widen to as much as 36 feet. There is a good deal of fairly well mineralized quartz, the width of which varies with that of the shear zone, from 9 feet, in the wider shears, down to no quartz at all in the narrower parts.

From the bottom of a shaft said to be 100 feet deep, on the Moose claim, L. 10-174, about 180 feet has been drifted. To the north of the shaft several prospect pits, and a shallower shaft, now filled with water, have been put down.

To the north the shear zone gradually widens, perhaps because it traverses less resistant rock, and on the Nevada claim, L. 27-174, it consists of two sheared belts, 20 and 8 feet wide, separated by about 60 feet of slightly sheared rock. The amount of quartz in the zone diminishes, until on the Nevada claim it forms only discontinuous lenses up to 6 feet wide.

The shear zone is overlain by swamp on the north side of the Nevada claim, but what is probably the same zone reappears on the north side of the Snowstorm claim, L. 62-124. Here it is somewhat wider, varying from 6 feet in straight parts to 50 feet on bends. Very little quartz is to be observed, although on the Ranger claim, L. 22-124, there are a few short lenses of quartz and iron carbonate, 2 or 3 feet wide.

To the north of the Ranger claim almost no quartz is to be seen. At the boundary between the Ranger claim and the Golden Rod claim, L. 23-124, the vein fillings consist almost wholly of iron carbonate. About 10 chains to the north of the Golden Rod claim the shear zone suddenly widens to 5 or 6 chains, and the strike swings westward. No vein-filling is present. The sheared zone maintains this width for several miles along the south side of Rice lake.

A second wide and important shear zone has its south end in the Lucky Strike claim, L. 52-124. South of the middle of the claim the sheared material has been intruded and replaced by a large diabase dyke that enters it at the north end of the claim. The sheared zone runs northward through the Jumbo and Pilot claims, L. 24-174 and 23-174 respectively, to a point 8 chains west of the northwest corner of the Golden Rod claim, L. 23-124. Here it turns sharply westward, parallels the shear zone last described for about a mile, then turns north again and joins it near the mouth of the creek that drains Red Rice lake.

At its south end in L. 52-124, the shear zone contains considerable quantities of quartz. The source of the quartz may be the large body of earlier granite to the south, but in view of the choking of the shear zone by the diabase dyke, it seems more probably to have originated from two large dykes of granite that cut into the shear zone near the north boundary of the claim. Near the northern boundary of L. 52-124 the sheared zone has a maximum width of 25 feet, which decreases to 1 or 2 feet at the ends of lenses. There is a maximum width of 10 to 12 feet of quartz in the shear zone here, but the average width is not more than half as much. To the north the quartz decreases slightly in amount, but maintains widths of 3 to 5 feet, on the average, in the larger parts of the lenses, almost to the northern boundary of the Pilot claim, L. 23-174. On the Pilot claim there are important amounts of iron-bearing carbonates mixed with the quartz. To the north of the Pilot the shear zone attains widths of 60 feet or more, resembling in this respect the shear zone previously described. The quartz vein-filling rapidly disappears, however, and very little is to be seen north of the Pilot claim.

The third shear zone to be traced outcrops first on the north side of the Mildred, L. 35-124, and runs northwesterly through the Josephine, L. 36-124. The south side of the shear zone is covered by a wide swamp, beyond which the shear zone could not be identified. This zone is characterized by a strong and continuous vein of quartz, 12 feet wide at its southern end, and traceable northward for about a quarter mile, where it begins to assume the lenticular shapes characteristic of the other veins of the region. Almost no quartz is to be seen north of the north boundary of the Josephine. The shear zone itself is rather a zone of fracture than one of strong shear. Very little schist is found on the sides of the quartz vein; and after the vein-filling disappears, north of the Josephine, the shear zone becomes only a vaguely defined zone of fracture, traceable only with great difficulty. It is supposed to be an offshoot of the strong shear zone to the east, splitting off from it at the bend near the north boundary of L. 62-124.

The fourth shear zone traced is that on which the Gold Seal, Gold Pan, and Gold Pan Fractional claims are located, respectively numbered L. 19-174, L. 18-174, and L. 20-174. In the south part of L. 20-174 the shear zone runs into a large swamp, across which it could not be traced. In the swamp, about 6 chains north of the south boundary of L. 20-174, is a dyke of granite with an east-west strike which is supposed to be the source of the vein material filling the shear zone. The zone has an average width of 3 feet or less and, as usual, the quartz is still narrower, averaging less than a foot for the whole zone, and rarely exceeding 3 feet at any point. The zone extends somewhat east of south to the middle of the Gold Seal, where it joins a shear of similar size which strikes off to the east. The two evidently form the sides of a small fault block.

Although small, this shear zone has attracted public attention owing to the rich specimens of free gold obtained from it. Their discovery led to considerable underground prospecting; for a description of which the reader is referred to DeLury's report. The underground work has emphasized the irregular nature of the mineralization; rich specimens of ore alternate with bodies of barren quartz. The results, so far, raise doubts as to whether mining on the lode will ever be profitable, except perhaps on the Gold Pan which is being worked by the Canada Mining and Leasing Company on a small scale, and at a moderate profit. The main shaft is located on the intersection of the shear zone and a diabase dyke, 20 to 30 feet wide, that has been fractured by the later movements along the shear zone, so that its east side is shifted about 25 feet southward. On the broken face of the western part of the dyke there has been a precipitation of free gold, so rich it is said, that in the first discovery plates of gold as thick as the finger were found. Although nothing approaching this has been recently found, the quartz is still exceedingly rich, specimens seen by the writer being literally bound together with wires and leaves of the precious metal. The disadvantage of the deposit lies in its smallness, confined as it is in length to the single face of the dyke, 25 or 30 feet in length, and in width to the width of the shear zone. The ore-body is, in effect, an almost vertical pipe.

This extraordinary concentration is not, apparently, due to the action of the dyke rock in precipitating gold from the ore-bearing solutions, for the dyke rock in the shaft is hard, glassy, and unaltered. The dyke magma itself did not originate the solutions, as the dyke was intruded, hardened, and faulted before the formation of the ore. The only possible conclusion is, as suggested on a previous page, that the dyke, cutting partly across the sheared zone, acted as an imperfect dam against the movement of the ore-bearing solutions; so that deposition was favoured at this particular point. Deposition on the broken face of the western arm of the dyke rather than on the face of the eastern arm to the south, would indicate, if this theory be correct, that the solutions were moving southward through the shear zone; a conclusion already inferred from the occurrence of the granite dyke on the north and the lack of any other body of granite cutting the shear zone on the south.

The fifth shear zone that was traced outcrops on the west side of the Wolf claim, L. 83-124, east of Red Rice lake. It appears first on the west side of a large hill, and runs down on the west into a low clay-covered area. On the hillside there is about 15 feet of quartz, well mineralized with pyrite, chalcopyrite, and ankerite. Assays of more than 1¼ tons of this ore, made by the Department of Mines, Ottawa, gave values of 1·07 ounces gold, 1·50 ounces silver, and 1·43 per cent copper. The vein and shear zone are traceable for only about 150 feet eastward, after which the shear becomes too small to follow.

Other shear zones in this vicinity are indicated on the map. Nearly all are characterized by quartz in considerable amount at their western ends, although in all except the one described the quartz appears to be barren or poorly mineralized. In all the quartz filling gradually decreases and finally disappears toward the east. These facts suggest strongly that the source of the vein materials for this set of shear zones was the small body of granite southeast of Red Rice lake.

SUMMARY

The gold deposits of Rice Lake district are vein fillings and replacements in belts of schist formed by earlier faulting. The principal veins are found in shear zones that cut through the older rocks to contacts with the later granite, rather than in shear zones that do not so terminate. The veins gradually decrease in size with increasing distance from the granite contact; and their composition varies in such a way as to indicate deposition from hot concentrated solutions in and close to the granite, and from cool dilute solutions at a distance. It is, therefore, concluded that the vein materials were deposited from solutions emanating from the later granite.

The shear zones are found in the Rice Lake series and the earlier granite. The later granite also was jointed, and the joints were filled with auriferous quartz. Such veins are mostly small, although lenses 3 to 4 feet in width have been found.

Prospecting in the later granite, therefore, although probably less apt to be rewarded than in the older formations, may reveal the presence of small deposits of fairly rich ore.

The vein materials are principally quartz, albite, iron carbonate, pyrite, chalcopyrite, and free gold. The carbonate is characteristically deposited at a distance from the granite, the quartz closer to it, the albite in or very close to it. The sulphides may or may not carry gold values.

The free gold appears, in most cases at least, to have been deposited in the quartz after it was shattered by movement. In great part it seems to have been deposited fairly close to the later granite, although found in small quantities at quite considerable distances away.

The bodies of quartz, like the shear zones in which they occur, vary greatly in width from place to place, forming lenses both in horizontal and vertical section. Small bodies of the later granite may have formed enriched veins like the larger bodies, but the veins so formed are commonly rather short.

Apparently, therefore, the most favourable localities for prospecting lie in the Rice Lake series or the earlier granite, near a contact with the later granite. The earlier granite may be recognized by the belts of schist and the basic dykes that cut it. The later granite is not thus cut, although it may be more or less jointed.

GEOLOGIC HISTORY

The geologic history of the Rice Lake and Oiseau River districts may be stated as follows, from the data at hand. The lack of sedimentary formations makes the history of necessity incomplete, but fuller information must be obtained from other areas, where more complete sections are available.

The first recorded event is the outpouring of the great floods of lava that formed the lower volcanic member of the Rice Lake series. The nature or position of the basement on which the lavas were poured is unknown; no trace of such a base was discovered. The lavas in Oiseau River area are mainly basalts, with some dacite, whereas in Rice Lake area andesites predominate, with minor amounts of basalt and rhyolite. The local occurrence of pillow structure indicates that in places the lavas were extruded under water; but the lack of such structures universally may indicate that in great part the lavas were extruded on a land area. If they were, the disturbances of the drainage accompanying extrusion almost certainly produced lakes, in which later flows could produce the pillow structures locally observed.

The deposition of sediments, probably in local lake basins, began with slackening of volcanic activity. At first sedimentation was interrupted locally by small lava flows, resulting in an interbedding of sediments and lavas; but even this extrusive activity died away, and sedimentation went on uninterruptedly. The sediments first laid down were largely ash rocks, mingled with more or less chemical matter deposited from hot waters following the flows; but later they appear to have been formed by normal processes of erosion. They are largely sandy-textured greywackes. There is evidence, in Rice Lake area, that sedimentation was followed by a renewal of volcanic activity; but faulting has so broken up the rocks there that any conclusion should be fortified by evidence from other localities before being deemed definite.

Following the consolidation of the Rice Lake series there was a period of compression, during which the series was thrown into low folds with average dips of about 20 degrees, probably, and an average strike of north 70 degrees to 80 degrees west. The folding was accompanied or closely followed by intrusion of great batholiths of granite. As folding and batholithic intrusion are common only in mountainous areas, it is inferred that the area was mountain-built and raised above the sea. The lack of later sedimentary formations may indicate that it was never there-after submerged in Precambrian time; although the possibility also exists that later sediments may have been deposited, but have been entirely eroded away.

Faulting followed granite intrusion, the faults trending from north to north 70 degrees west. In the faults with a northerly strike, the east sides moved south, and in those with a more westerly strike, the north sides moved upward and westward. It is, therefore, inferred that the stresses causing faulting came from the northeast. The westerly faults are thrust faults, and their planes dip to the north. The faults with a northerly strike show by their striæ that the movement of their sides was mainly horizontal; hence they, also, were formed by compressive stresses, although their planes are vertical or nearly so.

The faulting broke up the Rice Lake series and the earlier granite into a series of fault blocks, separated from each other by schist zones of varying width. The larger zones attain widths of 300 or 400 feet under suitable conditions, and may be traced for many miles.

Faulting was followed by intrusion of a variety of basic rocks, most of them dykes. They comprise, in order of intrusion, a hornblende porphyry, a feldspar porphyry, a diabase, and a gabbro. The gabbro also formed large sill-like intrusions in the Rice Lake series or along the contacts between the Rice Lake series and the earlier granite. The gabbro of the sills underwent a pronounced gravitative differentiation while cooling, resulting in the formation of rock types of widely different composition, and in the concentration of metallic sulphides at the bottoms of the sills, forming bodies of copper-nickel ores.

The intrusion of the diabase and gabbro was followed by gentle compressive stresses, causing slight further movements along the old fault planes; then came a second period of folding, accompanied or closely followed by widespread intrusion of great batholiths of granite. The same folding, apparently more intense than the first, forced the Rice Lake series and gabbro sills into steeply inclined positions, usually vertical or even considerably overturned. The intrusion of the later granite was followed by more gentle movements caused by compressive strains, which cracked and jointed the granite in several directions, and gave rise to small lateral movements between the blocks so formed.

During its cooling the later granite emitted considerable quantities of aqueous solutions, loaded with silica, carbon dioxide, sulphur, and iron mainly, with minor amounts of gold and copper. These solutions escaped from the granite along the sheared zones in the older rocks. As they came in contact with the colder rocks of the shear zones, they began to deposit their load, forming quartz-gold veins near the granite, grading into veins of iron carbonate at greater distances from it.

INDEX