GM 35770

REVIEW OF PUBLISHED LITERATURE ON LAC TIO ILMENITE DEPOSIT

Documents complémentaires

Additional Files





Licence



License

Cette première page a été ajoutée
au document et ne fait pas partie du
rapport tel que soumis par les auteurs.

Énergie et Ressources naturelles
Québec

Report No. 25-71

QUEBEC IRON AND TITANIUM CORPORATION

RESEARCH DEPARTMENT

PYROMETALLURGY AND MINERAL SCIENCES

PROJECT NO. P-12-RS

REVIEW OF PUBLISHED LITERATURE

ON LAC TIO

ILMENITE DEPOSIT

BY

MICHEL BERGERON

MB:svc
August 27, 1971

Distribution: Messrs.: M. Bergeron, B. Bernard, G. G. Charette, M. Couture, J. E. deSouza, E. F. C. Foord, M. A. Gagnon, B. J. Grierson, G. Handfield, J. M. Herndon, W. F. Houghton, F. A. Kay, H. Y. Lee, S. A. Luciani, P. Parent, D. Poggi, Development Dept., Research Dept., Files

Ministère de l'Énergie et des Ressources
Gouvernement du Québec
Documentation Technique
DATE: 1980 MARS 0 3
No. G.M.: 35770

Table of Contents

	Page
List of Figures	iii
List of Tables	iv
INTRODUCTION	1
Location	2
History	2
REGIONAL TOPOGRAPHY	7
GEOLOGY OF ALLARD LAKE REGION	8
Petrology	8
Grenville Series	10
Morin Series	11
Granitic Rocks	14
Diorite, Gabbro and Metagabbro	15
Pleistocene and Recent	16
Structural Geology	17
Glaciation	18
Ilmenite Deposits in the Allard Lake Region	19
LAC TIO ILMENITE ORE BODY	21
Description of Ore Body	21
Faulting in Ore Body	23
Geological Sections of Ore Body	24
Magnetic Property of the Ore Body	28
LAC TIO ILMENITE ORE	31
General Physical Properties	31
Chemistry	31
Mineralogical Components	35
Crystallographic Properties of Ilmenite Crystals	40
Origin of Allard Lake Ore	42

Page

REFERENCES..... 45

SUBJECT INDEX..... 48

List of Figures

Figure No.		Page
1	Index map showing the location of Allard Lake area in relation to other anorthosite-gabbro masses in Quebec.	3
2	Map indicating the locality of some of the various ilmenite showings discovered by Retty in 1941	4
3	Surface outline of Tio mine	22
4	Surface outline of Allard Lake ore body showing the drill sections	25
5	Strike section of Allard Lake ore body	26
6	Dip section of Allard Lake ore body	27
7	Aeromagnetic map of Lac Tio area	29
8	Aeromagnetic profile of Lac Tio ilmenite ore body	30
9	Specific gravity vs. grade of Petit Pas drill cores	32
10	Relation between the grade and the amount of SiO_2 and Al_2O_3.	33
11	Polished section of an ilmenite crystal which has been cut parallel to its c-axis	36
12	Polished section of an ilmenite crystal which has been cut perpendicular to its c-axis	38
13	Lindsley's curves relating the 2θ diffraction angles off the (116) and (024) planes with the composition of the hematite-ilmenite solid solution.	41
14	Hematite-ilmenite solvus curve.	44

List of Tables

Table No.		Page
I	Rock Units in Allard Lake Region	9
II	Chemical Analysis of Bronzite Crystals	12
III	Ilmenite Analyses	19
IV	Analysis of Allard Lake Ore	31
V	Analysis of Allard Lake Plagioclase	37

INTRODUCTION

During the past 30 years, many reports have been published on the geology and mineralogy of the Allard Lake Region and in particular of the Lac Tio ilmenite deposit. These numerous reports are reviewed in the present paper in order to compile all of the information available on Q. I. T. 's ore body at Lac Tio.

More than half of the reports consulted were from Kennco Explorations Ltd., from the New Jersey Zinc Co. and from Q. I. T.. The others have been obtained using the "Bibliography of North American Geology" and the "Annotated Bibliography of Economic Geology". The "Bibliography and Index Exclusive of North America" was also consulted but no work related to the Allard Lake Region has been found.

A subject index has been incorporated to this report in order to facilitate the accessibility of the information contained in this reference work.

-Continued-

Location

The Lac Tio ilmenite deposit is located north of the St. Lawrence River, 130 miles east of Sept-Iles, Quebec, in the township of Parker. A 27 mile railroad connects the mine to the St. Lawrence seaport of Havre-St. Pierre. Its general location is shown in Figure 1.

History

The presence of ilmenite in the district of Allard Lake was first reported by the Quebec Department of Mines following a reconnaissance shore-line geological survey in the year 1941. The ensuing report by Retty describes the occurrence of a number of small ilmenite deposits about the shores of Lakes Allard, Petit Pas, Puyjalon and Bat du Diable. Figure 2 shows three of the lakes mentioned above. Lac Bat du Diable which is missing in Figure 2, is located about 4 miles south-west of Allard Lake. The showings discovered by Retty were later staked by Toronto and Montreal interests who carried out a certain amount of development work. During the late stage of World War II, the North American continent which was at that time dependent on foreign sources for high grade TiO_2, was faced with curtailment of shipment of this strategic material. For this reason, Kennco Explorations Limited (subsidiary of Kennecott Copper) optioned the claim groups and in the field season of 1946, initiated a detailed exploration program in the vicinity of the occurrences described by Dr. J. A. Retty in the hope of finding larger ore bodies. Accordingly, a number of geological prospecting parties were organized who carried out traverses between Lac Allard and Lac Puyjalon. Traverses were run at quarter-mile intervals in an east-west direction, normal to the strike of the previously known ilmenite occurrences. This work resulted in the discovery of a number of ilmenite deposits, among which was the large ore body of Lac Tio (Hammond 1952).

-Continued-

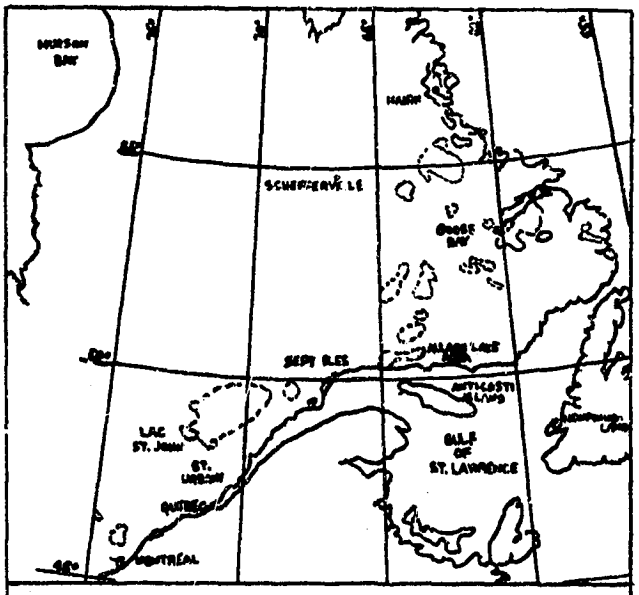


Figure 1. Index map showing location of Allard Lake area in relation to other anorthosite-gabbro masses in Quebec

-Continued-

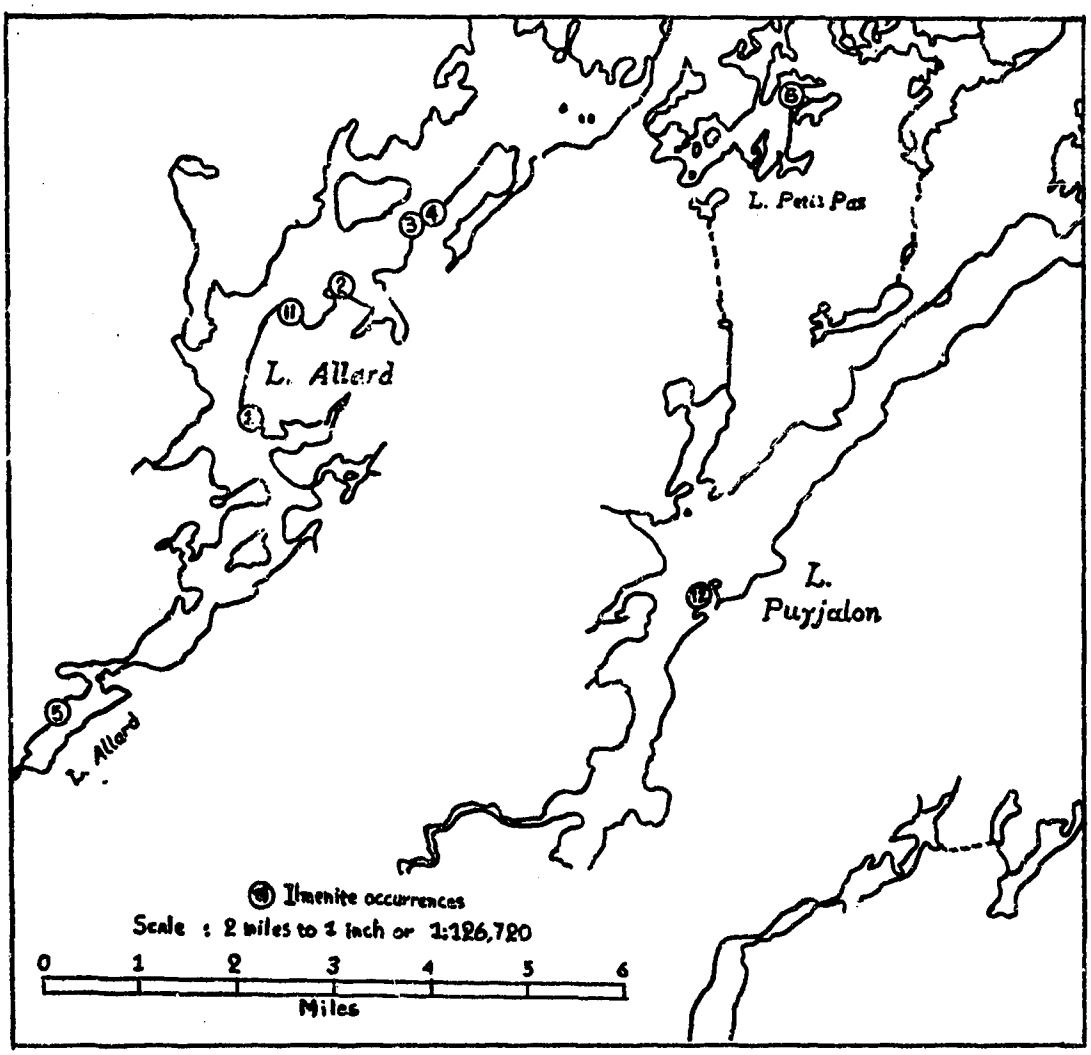


Figure 2. Map indicating the locality of some of the various ilmenite showings discovered by Retty in 1941. (Retty, 1944)

-Continued-

In 1950, mining started at the Grader ore body, now idle, but from which over 200,000 tons of ore was removed. Since then, Q. I. T. has been exploiting the Lac Tio ilmenite deposit which represents the largest body of titanium ore of its type now known in the world.

-Continued-

REGIONAL TOPOGRAPHY (Hammond, 1952)*

Along the coast, and northward to the west flowing portion of the Romaine River, is a flat coastal plain known as the lowlands. The lowlands consist of open muskeg dotted with many shallow lakes and ponds, and underlain by flat-lying Paleozoic limestones. Between the Romaine and Puyjalon Rivers, the ground is flat and sandy and represents part of an old marine terrace.

Beyond to the north, the terrain rises rapidly to form the uplands. Viewed in a general way, the surface has the appearance of an ancient peneplain so that the horizon presents a general uniformity of summits in all directions. In detail, however, the surface is a much dissected plateau with precipitous cliff faces and well entrenched valleys. At Allard Lake, the highest summits are 1,300 feet above sea level, with a slope to the south. Maximum relief is about 800 feet but the average relief is between 200 and 300 feet.

Glacial erosion appears to have been an important factor in producing the present topography. The larger lakes occupy north-south troughs, approximately parallel to the direction of ice movement. Many small lakes lie perched in irregular depressions at higher elevations and the secondary drainage system have been much disorganized.

The area is drained by the Romaine River system which heads near the Quebec Labrador boundary. The Romaine flows in a well entrenched valley, with numerous rapids and falls.

Throughout the uplands, a thin cover of boulders and soil rests on bed rock, and supports a stunted growth of spruce, balsam and pine. Many large glacial erratics, most of granitic nature, lie strewn about the surface.

*Reference used for this particular topic.

-Continued-

GEOLOGY OF ALLARD LAKE REGION

Petrology (Retty, 1944)

The precambrian rocks of North America occupy a large area in the form of a shield surrounding Hudson Bay. The South-East part of the shield forms the Ungava Peninsula. The Allard Lake region is located at the South boundary of the Ungava Peninsula, close to the separation between the precambrian rocks and the stratified paleozoic rocks.

In the vicinity of Lac Tio, the two great subdivisions of the Precambrian are represented:

1. The Archean, which consists of a series of metamorphosed sedimentary rocks, nowadays represented by some quartzites and paragneisses in which are found masses of anorthosite, gabbro, and metagabbro.

2. The Proterozoic, represented by diabase dykes.

The various rock formations found in the area are given in Table I.

-Continued-

Table I

Rock Units in Allard Lake Region

(Retty, 1944)

istocene and cent			Argillaceous rock, sand and gravel
	Proterozoic	Keweena-wian	Diabase
	Archean		Diorite containing quartz and biotite
			Granitic rocks: porphyritic granite, granite containing hornblende and biotite, pegmatites and aplites.
			Gabbro
			Metagabbro
ecambrian		Morin Series	Anorthositic dykes
			Anorthosite, anorthositic gabbro, anorthosite rich in ilmenite.
		Grenville Series	Gneiss and injection migmatite (Grenville sedimentary rocks which have been altered. These rocks contain numerous intrusions of more recent granitic rocks).
			Quartzite, gneiss containing quartz and biotite, gneiss containing quartz and hornblende, garnetiferous gneiss, amphibolite, garnetiferous graphitic schist, greywacke.

-Continued-

Grenville Series (Retty, 1944)

1. Quartzite

The quartzites are common in the region of Allard Lake. Ordinarily, these rocks are composed of small grains which are white and vitreous. They also contain a small proportion of biotite and magnetite and, in some places, garnets are disseminated in the quartzite.

2. Hornblende Gneiss and Biotite Gneiss

The hornblende gneiss and the biotite gneiss are also abundant in the region of Allard Lake. The banding in these rocks is well developed. The alternating variation in composition and grain size seems to be the cause of the banding in the gneiss. The principal minerals encountered in these rocks are: quartz, hornblende, biotite, orthose and albite. Various minerals assemblages are composed of some of these minerals to produce different rock types. The minerals apatite, zircon, magnetite and graphite are the accessory minerals usually associated with the gneiss.

3. Garnetiferous Gneiss

A good part of the Grenville gneiss in the Allard Lake region is garnetiferous. It is a variety of gneiss which is rich in hornblende. Also, it contains, apart from quartz, 15 to 20 per cent garnet with small quantities of albite, graphite and biotite.

4. Less Common Rocks of the Grenville Series in the Area

Among the less common rocks observed in the region, there are some graphitic garnetiferous schists, greywackes, amphibolites, migmatites and injection gneisses.

-Continued-

Morin Series

One of the most important lithological units in the Allard Lake region is constituted of anorthosite and its related rocks. As shown in Figure 1, in the Allard Lake area these rocks extend 70 miles in the South-West direction and are approximately 20-30 miles wide.

1. Anorthosite (Hargraves, 1962) (Retty, 1944)

Anorthosite is the major rock type in the vicinity of the Allard Lake area. As a rule, it is massive, coarse-grained and contains 95 percent or more plagioclase. In fresh exposure, it varies from pale gray to pink to somewhat resinous green where it contains more than 5 percent ferromagnesian minerals. In weathered outcrops, the anorthosite is usually gray to chalky white. Grain size of equigranular varieties ranges from about 3 to 6 mm but the anorthosite is characterized by sporadic coarse plagioclase phenocrysts 2cm 35cm long which are very similar in composition to the enclosing matrix.

In thin section, the texture of the anorthosite varies from hypidiomorphic to allotriomorphic granular, and the plagioclase grains (An40-52) range from 3mm to 12mm in diameter. Approximately half the 25 thin sections examined by R. B. Hargraves showed distinct evidence of cataclasis with scattered relics of larger crystals exhibiting undulatory extinctions, bent twin lamellae and fractured margins. The finer grained material surrounding these deformed fragments and composing the entire rock in some instances is anhedral with intricately sutured grain boundaries - a general appearance suggesting recrystallization of crushed material.

2. Anorthosite with Coarse Pyroxene Crystals (Hargraves, 1962)

In many places, zones in the anorthosite are characterized by coarse crystals, or clot of crystals of greenish bronzite. A chemical analysis of typical pure bronzite, separated from samples collected at Lac Tio is given in Table II

-Continued-

Table II

Chemical Analysis of Bronzite Crystals

(Hargraves, 1962)

SiO_2	51.81
Al_2O_3	2.80
Fe_2O_3	2.09
FeO	17.27
MgO	24.18
CaO	0.83
Na_2O	0.01
K_2O	0.00
H_2O^+	0.07
H_2O^-	0.03
TiO_2	0.52
MnO	0.29

-Continued-

3. Ilmenite Rich Anorthosite (Hargraves, 1962) (Retty, 1944) (Q. I. T. File)

The ilmenite-rich anorthosite (oxide rich norite of Hargraves, 1962) is characterized by medium grain and gneissoid foliation. The essential constituents of the rock, in paragenetic order, are in the relative proportion of these constituents, the mafic fraction rarely constitutes less than 50 percent by weight of the total. Sulfide (2-3 percent) is a constant accessory, and sporadically a little secondary biotite may be present.

A study of thin and polished sections of the oxide rich noritic anorthosite reveals that it contains the following minerals in roughly the volume proportions indicated:

Magnetite	10%
Hemo-ilmenite	10%
Pyrite with minor pyrhotite	2%
Plagioclase	30-40%
Hypersthene	20%
Augite	5-10%
Biotite	2-3%
Spinel	Traces
Apatite	5-10%

4. Anorthosite Dykes (Retty, 1944)

Three anorthositic dykes cutting the anorthositic massif have been observed by Retty in the area. These dykes generally have a composition identical to that of the anorthosite massif.

-Continued-

Granitic Rocks (Retty, 1944)

The rocks are usually coarse-grained and exhibit a porphyritic texture. In those rocks, the quartz is ordinarily opalescent and the mafic minerals, hornblende and biotite, are visible with the naked eye. In thin section, apatite, zircon and magnetite can be recognized as accessory minerals.

Retty has noticed in his reconnaissance survey that in some places the rock is poor in quartz and could be more appropriately called syenite.

-Continued-

Diorite, Gabbro and Metagabbro (Retty, 1944)

Diorite, gabbro and metagabbro have also been noted in the Allard Lake area. Since these archean rocks are not very common in the region, they will not be described in this paper.

-Continued-

Pleistocene and Recent (Retty, 1944)

In the lowlands, the glacial traces have been washed by the invasion of Champlain sea sediments. Sand, argillaceous sediment, and gravel are the main constituents of the marine deposit.

-Continued-

Structural Geology (Bourret, 1949)

There is much evidence that the area has been subjected to large scale structural disturbances over long periods, as indicated by the highly contorted and metamorphosed nature of the Grenville type rocks and the strong fault and joint systems developed within the anorthosites. In the vicinity of Allard Lake, the anorthosite is cut by numerous joints and faults whose attitude is steeply dipping to vertical. They strike north or north-east and represent faulting of a normal type in which one block has moved down with respect to the adjoining one. These features are everywhere apparent in the topography, giving rise to precipitous, cliff faces. In many instances, they are apparent in a series of step-like structures along the hill slopes.

Some of the major faults have been traced for several miles, and some continue without appreciable change in strike beyond the anorthosite body and into the surrounding granite. These fractures are open and obviously younger than any of the Precambrian rocks of the area.

It is usually impossible to determine relative displacements in an intrusive rock of uniform composition such as anorthosite. However, one major fault has been studied in considerable detail in the vicinity of the Lac Tio deposit, and it appears to have been an important factor in the preservation of the main ore body. Detailed exploration of this ore body has shown it to be in the form of a large, tabular, relatively flat-lying mass, and it can be reasonably assumed that the attitude of the ore was the same at the time of deposition.

A north-south fault, with a steep dip east, cuts through the middle of the deposit and has moved the east side of the ore downward, a vertical distance of approximately 300 feet. There has been apparently, no horizontal movement. The much greater thickness of ore on the east side of the ore body owes its preservation to this faulting, since it was moved to a deeper horizon and consequently preserved to a greater extent from erosion and pleistocene glaciation.

-Continued-

Glaciation (Retty, 1944)

In the region, the U-shaped valley of the North East Romaine river constitutes the main evidence of glaciation. The sand and gravel deposits along that river are considered to be of glacial origin.

Some glacial striations along the shores of Forget Lake indicate that the movement of the ice sheet was north and south. However, in the vicinity of Bernard and North-East Romaine rivers the striations seem to indicate a south-west displacement.

-Continued-

Ilmenite Deposits in the Allard Lake Region (Retty, 1944) (Hammond, 1952) (Dearden, 1958, 1961)

In 1941, many showings of ilmenite were found by Retty along the shores of the Lakes Bat-Du-Diable, Allard, Petit Pas and Puyjalon. The localities of these showings are indicated on Figure 2, Page 4.

Table III gives the results of the analyses that have been carried out at the Quebec Mines Branch Laboratories on samples taken at the various localities.

Table III

Ilmenite Analyses

(Retty, 1944)

Locality No.	5	1	2	3	4	6
Weight of Sample	2 lbs.	10 lbs.	5 lbs.	8.5 lbs.	6.5 lbs.	1 lb.
% Fe	45.01	41.18	45.08	43.33	43.41	43.64
% TiO_2	32.24	36.00	35.98	35.89	38.14	37.79
% SiO_2	1.36	2.57	1.78	0.96	0.87	1.42
% P	-	-	-	-	0.05	-
% S	0.14	0.47	0.47	0.16	0.16	0.11
% V	0.02	0.08	0.03	0.03	0.03	0.19

In 1946, further exploration by Kennco Explorations resulted in the discovery of the most important ore body, that of Lac Tio. During that survey the Grader lake deposit and a few more of less importance were also discovered.

Although all of the deposits are of the same origin, they may be divided into three broad groups on the basis of shape and attitude. These include flat-lying, tabular bodies of large areal extent(Lac Tio deposit and satellites), steeply dipping dike-like bodies(Puyjalon deposit), and lenticular masses which are very irregular in shape.

-Continued-

Six of these occurrences in the region of Allard Lake may be classed as being of importance, in each case a million tons or more of ore were estimated. Of these the most important is the Lac Tio deposit, which is now being mined.

In 1947, airborne magnetometer surveys were carried out over approximately 1,700 square miles of the anorthosite mass. This work revealed no previously undiscovered deposits but strong negative anomalies were obtained from deposits of massive ilmenite. Although existing aeromagnetic coverage of the Allard Lake anorthosite mass extends fifteen miles north of the Tio ore body, there is always the possibility of the existence of commercial ilmenite deposits beyond this distance.

A combined geological-geophysical ground program was also carried out in the Allard Lake region by Dearden in the field season of 1960. The results of this investigation which covered all the ilmenite deposits in the vicinity of Lac Tio are summarized in a report written by Dearden and submitted to Q. I. T. in 1961.

-Continued-

LAC TIO ILMENITE ORE BODY

Description of Ore Body (Hammond, 1949) (Dearden, 1958) (Lister, 1968).

The Lac Tio deposit is an extensive body of ilmenite lying between Allard and Puyjalon lakes, and 22.5 miles northeast of Havre St. Pierre on the coast. The deposit, as determined from surface exposures and diamond drilling results, is 3600 feet in length, 3400 feet in width, and occupies an areal extent of 134 acres. Figure 3 shows the surface outline of the Lac Tio ore body.

The direction of maximum elongation of the deposit is almost north-south, but its outline in surface plan is somewhat irregular, with broad areas of ore extending to the east and to the west. There are wide ranges of elevation on the deposit. A comparatively level valley extends through its centre to the southeast end of Lac Tio. On the west, the ground rises rapidly to as much as 440 feet above the valley level. The deposit may be considered to consist of three ore bodies; the Main, the Northwest and the Cliff. The Cliff ore body which is undoubtedly related in origin to the other two is separated from the Northwest ore body by a large block of anorthosite.

The Main ore body is by far the most important part of the deposit with respect to size, vertical depth, and areal extent. In the north it occupies a large, rudely rectangular area from which a smaller triangular portion protrudes south along the east side of Lac Tio. Along the west side, a north-south steeply-dipping fault has moved the eastern part of the ore body downward. The Northwest ore body which occurs to the west of this fault is a thin, flat-lying body from 25 to 200 feet thick, with a gentle dip to the east. The ore in the Main ore body comprises the most important and extensive part of Lac Tio deposit.

Inclusions and blocks of anorthosite, as well as areas of disseminated ilmenite, are present throughout the deposits. The blocks of anorthosite have no consistency in size or shape or orientation. They are presumed to represent blocks of country rock engulfed or included by the ore during its emplacement. Disseminated ore is commonly arranged within the massive ilmenite in bands which lie horizontally or have a flat dip.

-Continued-

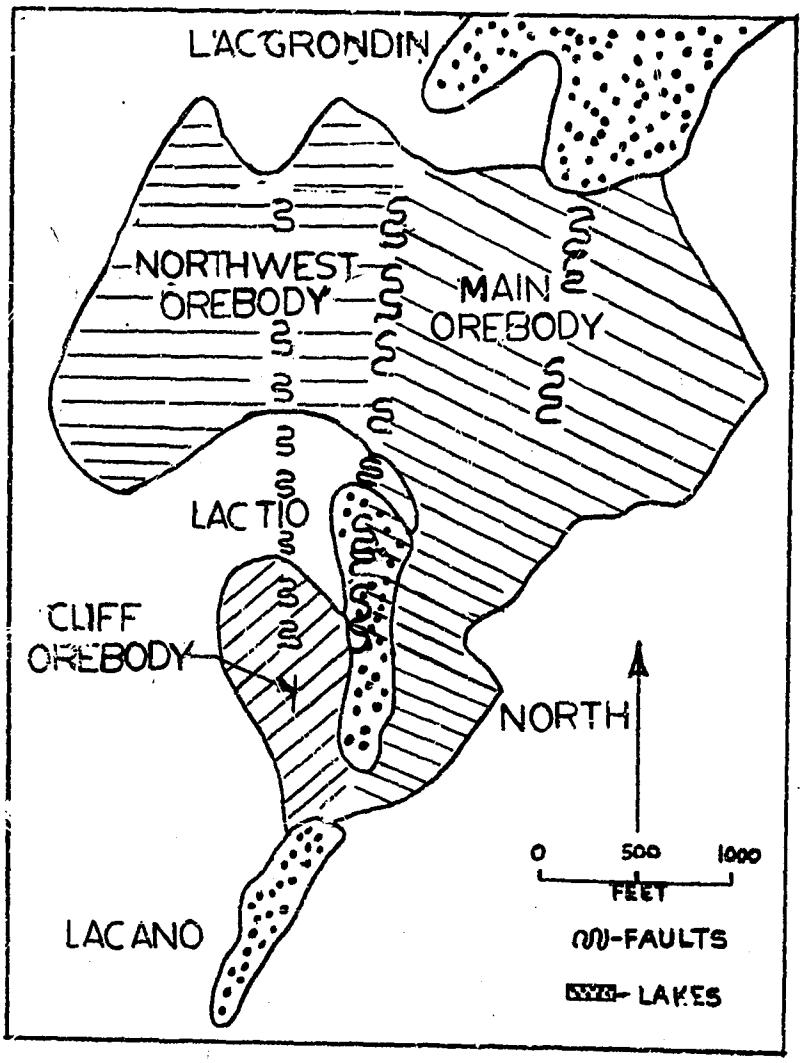


Figure 3. Surface Outline of Tio Mine. (Bourret, 1949)

-Continued-

The Cliff ore body is a broad, flat-lying, tabular mass of ilmenite rising sharply above the western shore of Lac Tio. It is rudely elliptical in surface plan, with dimensions of 1,240 feet in a north-south direction and 740 feet east-west. The average thickness of the ore is about 200 feet.

The eastern part of this ore body is well exposed along the shore of Lac Tio. The ore has a relatively uniform floor, which dips gently to the east and is in sharp contact with the anorthosite below. Drilling on the west side indicated the ore to be extending flatly under the anorthosite, while rapidly thinning and pinching out.

Faulting in Ore Body (Lister, 1968)

Three faults have been mapped in the mine area as indicated in Figure 3. The most important fault forms the boundary between the Main and Northwest ore bodies. Scissor faulting along this plane seems to have raised the west side approximately 300 feet at the north end of the ore bodies. Movement on this fault lessens towards the south and the fault seems to terminate within the Cliff ore body. Another fault extends southward from the southern tip of Lac Grondin.

At Lac Grondin, scissor movement on this plane has raised the east side less than 100 feet but movement on this fault decreases to zero about 1000 ft. southwards. A third fault had been mapped in the pit, extending northward from the western side of Lac Tio. Movement of the base of the ore body along this fault seems to be minor. The southern extension of this fault is thought to separate the Cliff ore body from the Main ore body.

These faults are part of the strong linear features, striking north-south and northeast-southwest, that are evident in the field and from air photographs in the general area. Topographic offsets suggest that the linears are faults with relatively minor vertical movement, probably less than 50 feet in most cases. These faults and the three faults described, appear to be tensional features related to post-ore-intrusion relaxation of vertical stresses and possibly related in part to the cooling of the body of ilmenite.

-Continued-

Some chloritization across a few inches or feet is generally evident where the steep faults cut the ore sheet. The feldspar and faulted anorthosite has been bleached, reddened, saussuritized or chloritized. In a very few cases there has been minor hydrothermal leaching of iron from ilmenite along a fault, resulting in brown, rutilized ilmenite for widths of a few inches.

Geological Sections of Ore Body (Lister, 1968)

Plan View of Tio Ore Body

Figure 4 shows a plan view of the Tio ore body where the diamond drill sections and the faults are indicated. The numbers (e. g. T-91-6) correspond to the locations of the holes drilled in the summers of 1966 and 1967.

Strike Section of Tio Ore Body

Figure 5 is a geological section corresponding to the line J-K on the plan view of the ore body and showing a strike section of the ore body.

Dip Section of Tio Ore Body

Figure 6 is a geological section corresponding to the line L-M on the plan view of the ore body and showing a dip section of the ore body.

-Continued-

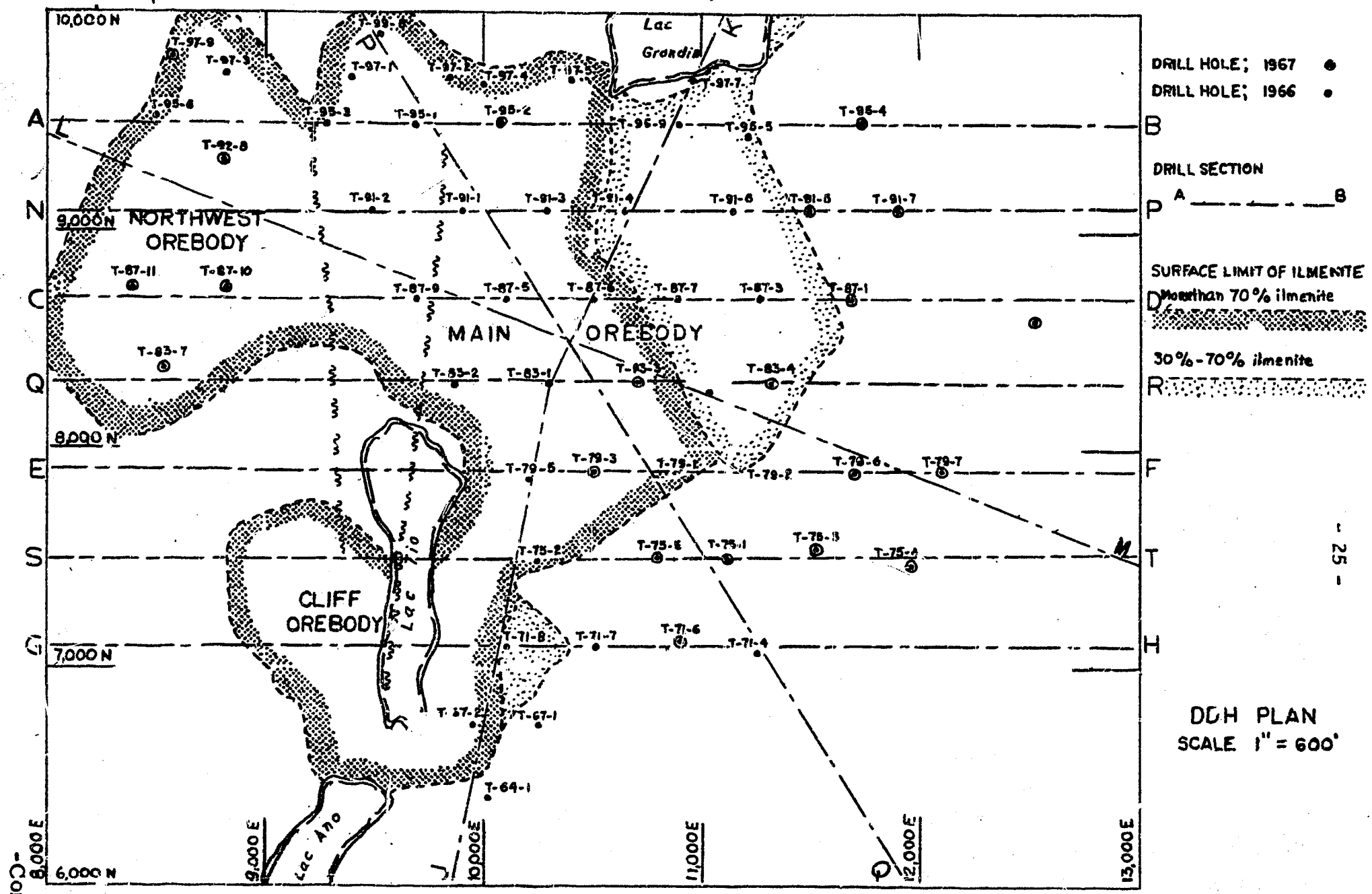
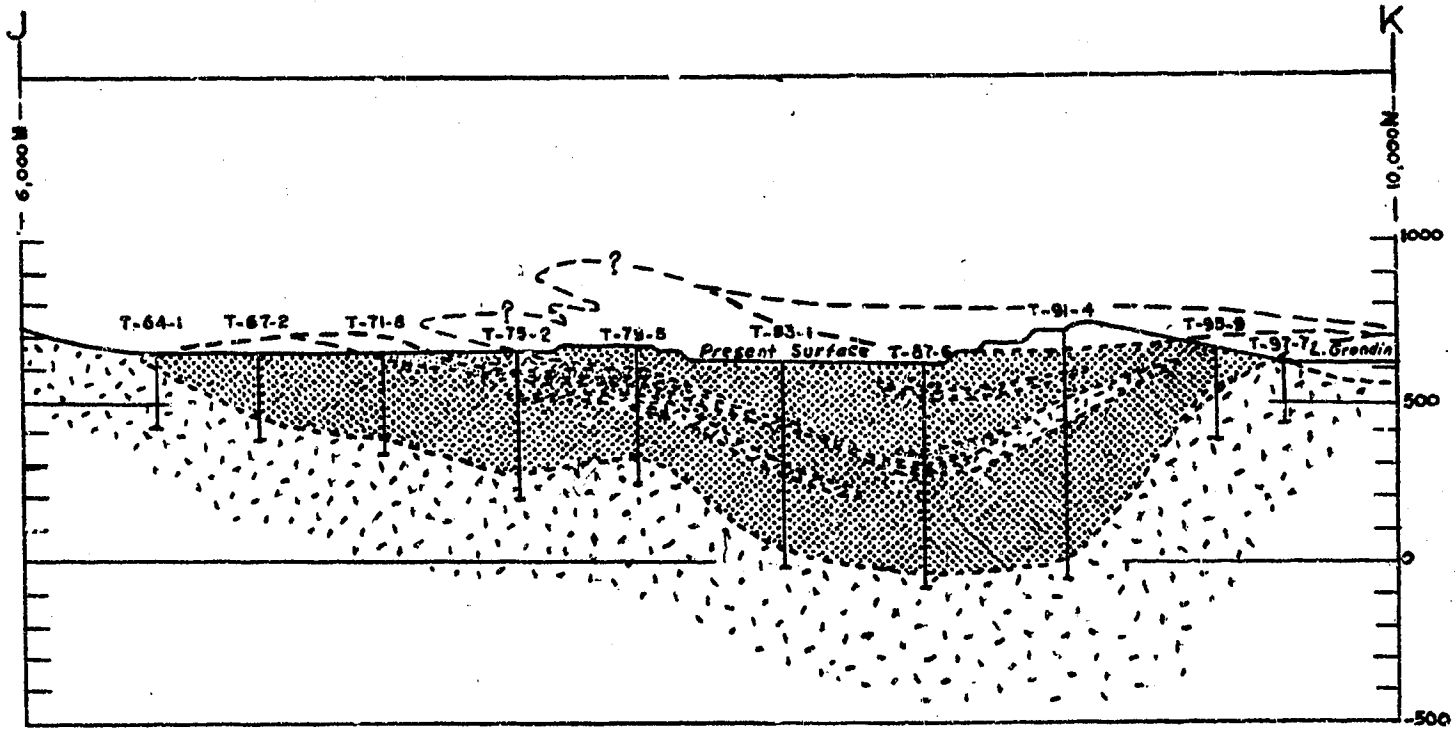


Figure 4. Surface outline of Allard Lake ore body showing the drill sections. (Lister, 1968)

-Continued-



LEGEND

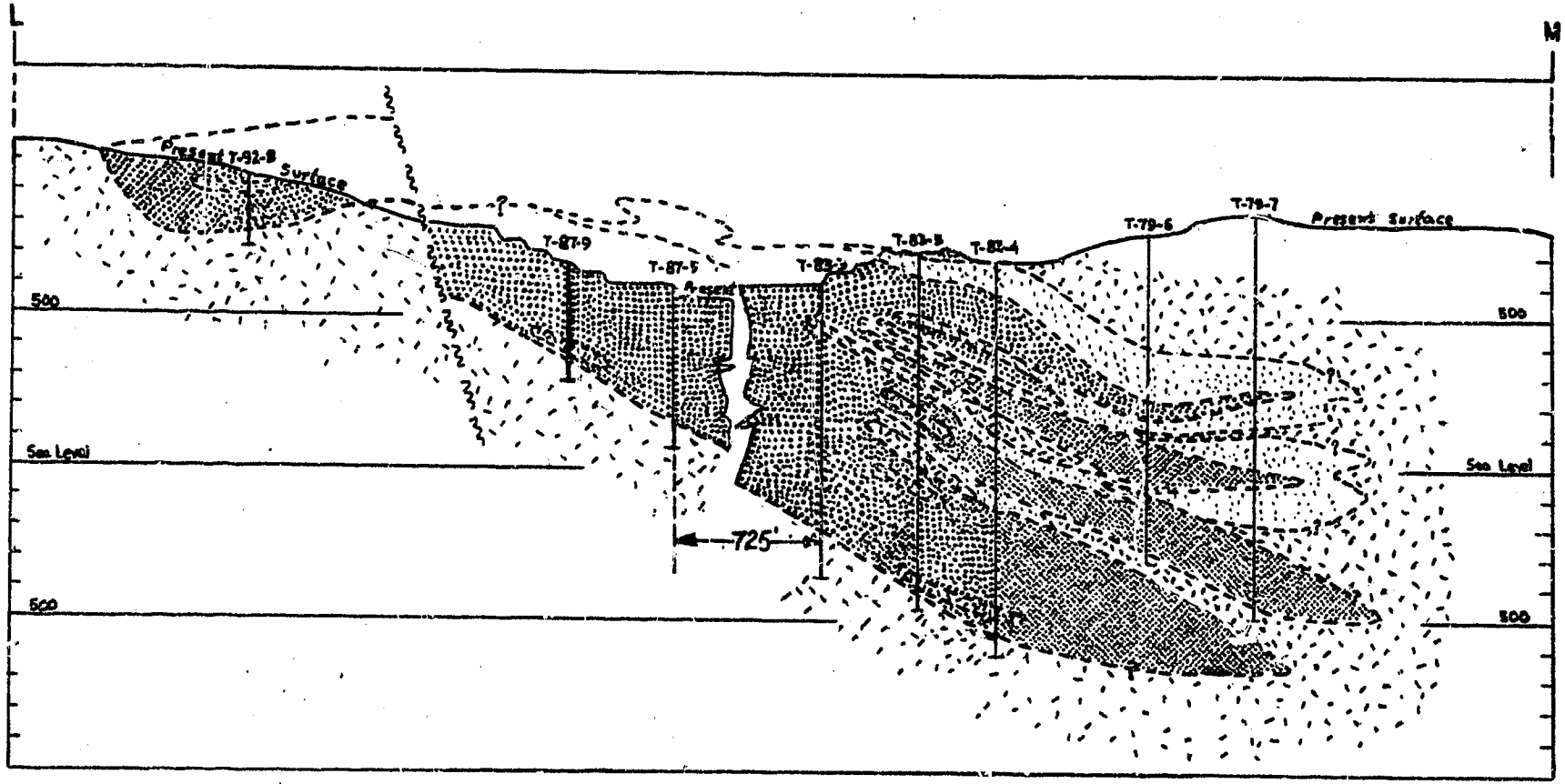
- > 70% HEMO-ILMENITE
- 30-70% HEMO-ILMENITE
- ANORTHOSITE
- LAKES

LAC TIO ILMENITE DEPOSIT

SCALE 1"=600'
DATA BY G.F.LISTER

Figure 5. Strike section of Allard Lake ore body. (Lister, 1968)

-Continued-



LEGEND

- > 70 % HEMO. ILMENITE
- 30 - 70 % HEMO - ILMENITE
- ANORTHOSITE

LAC TIO ILMENITE DEPOSIT

SCALE 1" = 600'
DATA BY G.F. LISTER

Figure 6. Dip section of Allard Lake ore body. (Lister, 1968)

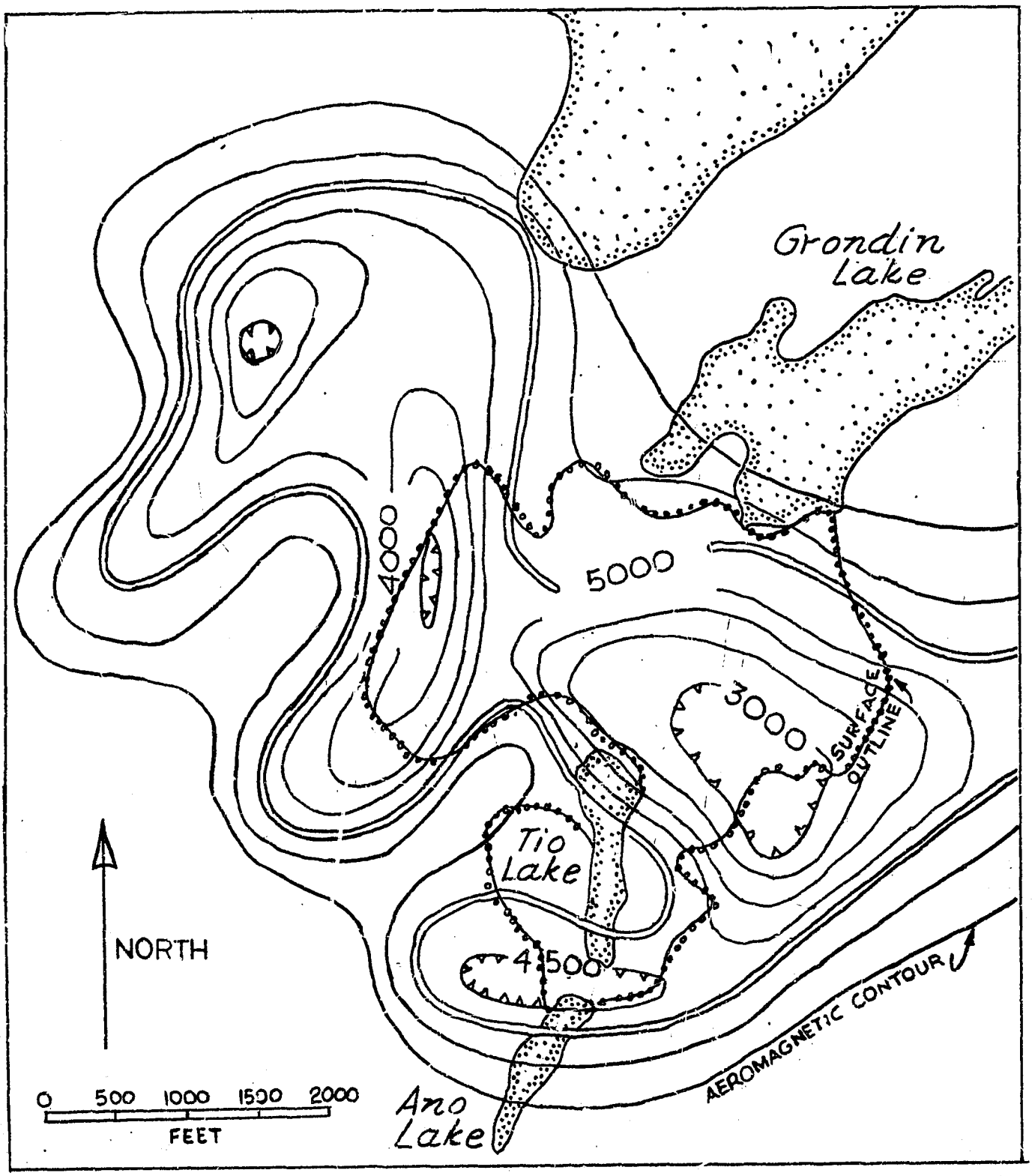
-Continued-

Magnetic Property of the Ore Body (Dearden, 1958) (Bourret, 1949) (Hammond, 1952)

Figure 7 is a plan of the airborne magnetic anomaly over the Lac Tio area, with the surface outline of the ore body superimposed on it.

Figure 8 illustrates clearly the strong negative anomaly above the Allard Lake ore body. The large massive deposit gave negative anomalies with very sharp gradients, in the magnitude of 3,500 gammas below the average plateau level. The strong negative anomalies are believed to be the result of negative polarization of the ore body itself. A detailed study of some ilmenite specimens by Carmichael has shown that the remanent magnetization is mainly due to the hematite lamellae.

-Continued-



Legend:

Surface outline of Tiomine.

Aeromagnetic contour- interval 500 gammas.

Figure 7 - Aeromagnetic map of Lac Tio area (Hammond 1952)

-Continued-

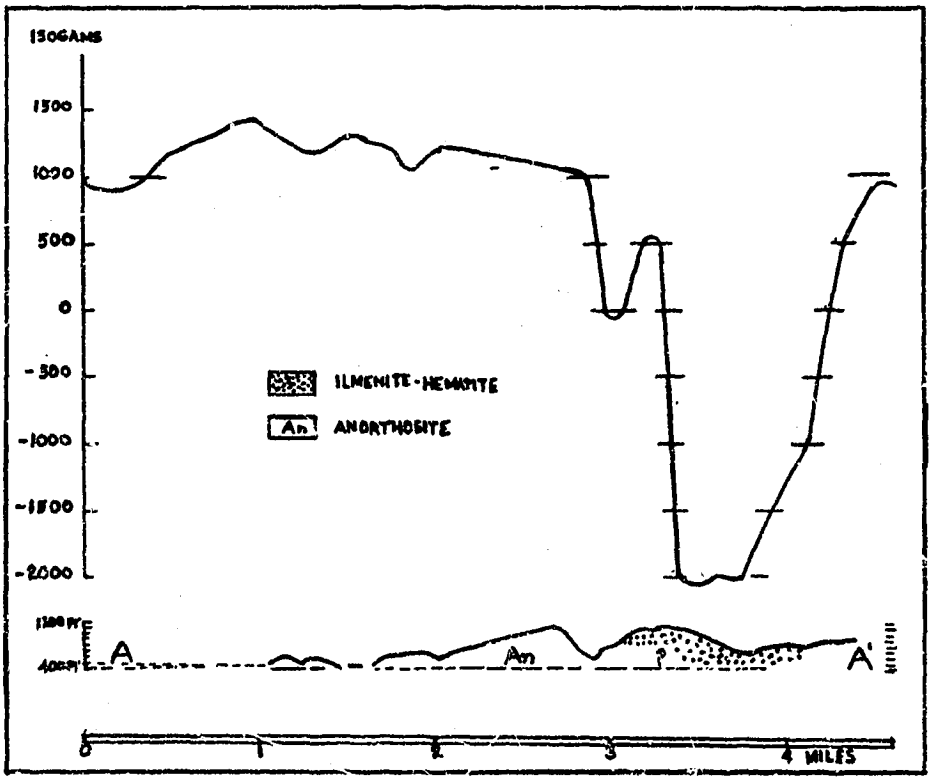


Figure 8. Aeromagnetic profile of Lac Tio ilmenite ore body. (Bourret, 1949)

-Continued-

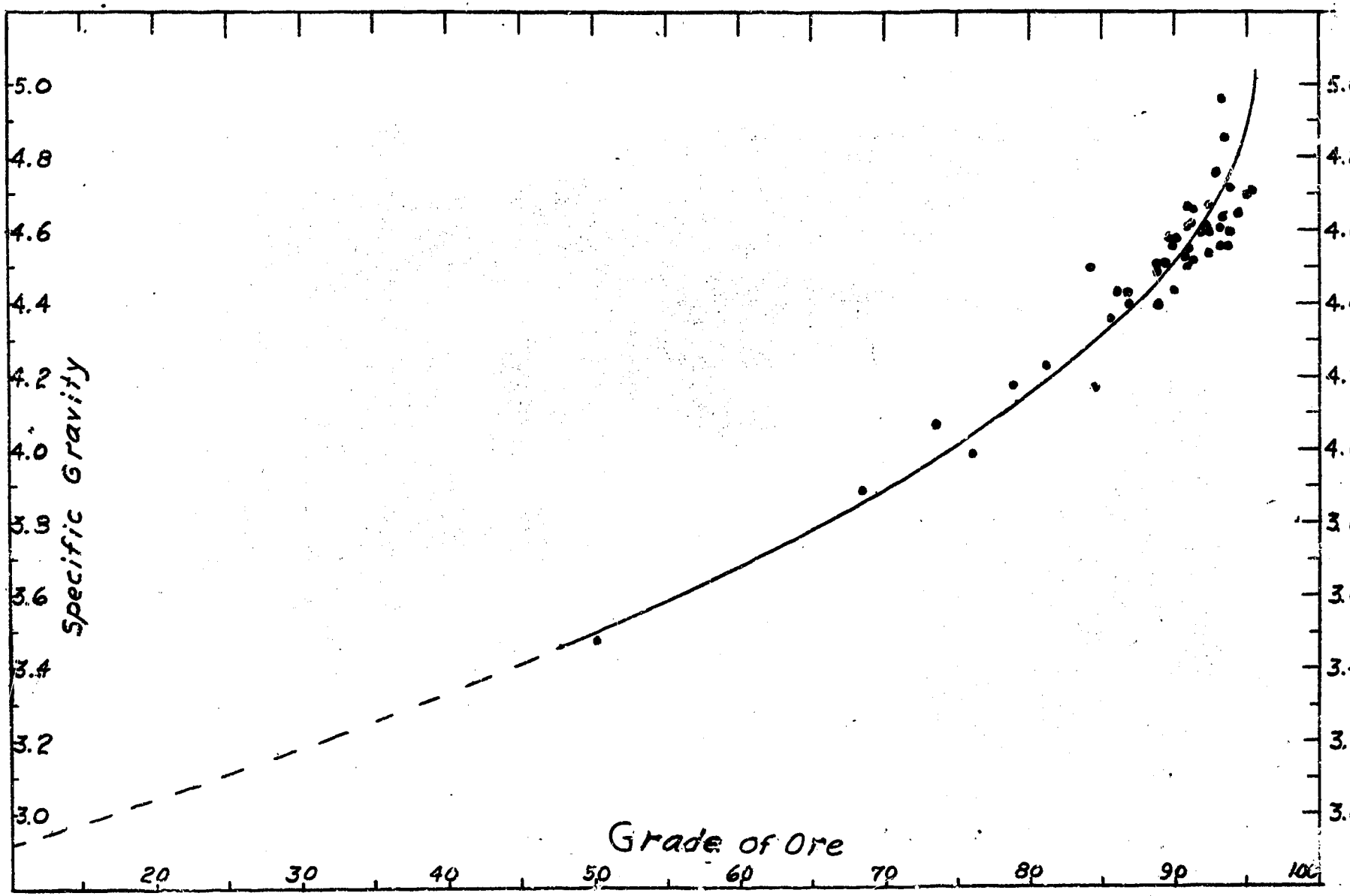


Figure 9. Specific gravity vs. grade of Petit Pas drill cores. (New Jersey Zinc).

-Continued-

LAC TIO ILMENITE ORE

General Physical Properties (Hammond, 1949)

For convenience, Allard Lake ore is usually referred to as ilmenite, whereas it is actually ilmenite-hematite. The ore is dense black, mostly coarse-grained, and is made up of thick tabular crystals. The specific gravity of the material classed as ore ranges from 4.46 to 4.9. Figure 9 shows the relation between the grade and the specific gravity of the ore.

Chemistry (Q.I.T.), (N.J.Z.), (Lister, 1966)

Table IV is a typical analysis of an 87 percent grade ore.

Table IV

Analysis of Allard Lake Ore

TiO_2	34.2%	MnO	0.16%
FeO	27.5%	S	0.3%
Fe_2O_3	25.2%	Na_2O and K_2O	0.35%
SiO_2	4.3%	P_2O_5	0.015%
Al_2O_3	3.5%	Cu	0.023%
CaO	0.9%	Ni	0.027%
MgO	3.1%	Ga	0.004%
Cr_2O_3	0.10%	Co	0.03% (?)
V_2O_5	0.27%		

-Continued-

Ilmenite crystals from the deposit contains about 43% Fe and 38% TiO_2. According to Lister no regular variation in the ratio of Fe and TiO_2 in the ilmenite crystals was observed in the deposit. In the massive ilmenite portion of the deposit, the amount of Cr and V seems to decrease upwards and the amoung of Mg increases upwards. These trends apparently do not continue into the layered section of the sheet. The Mn content of ilmenite throughout the deposit is unusually low. The chemical composition of the ilmenite crystals corresponds to about 30 percent hematite and 70 percent magnesian ilmenite. The lowest amounts of Mg and the highest amounts of (Fe + Ti) were found in ilmenites from the upper part of the layered section of the sheet.

Compared with the ilmenite found in the deposit, the ilmenite from the anorthosite, which forms the host rock of the deposit, has a lower minor element content with the exception of manganese.

Figure 10 shows the relations between the grade and the amount of SiO_2 and Al_2O_3 in Allard Lake ore. It is interesting to note that the SiO_2 values extrapolate to zero at the maximum grade ore while the alumina values extrapolate to about one percent. This is interpreted to mean that the feldspar (silicate) content of a high grade material ore may approach zero but its spinel content ($(Fe,Mg)O.Al_2O_3$) may be as high as 2%.

-Continued-

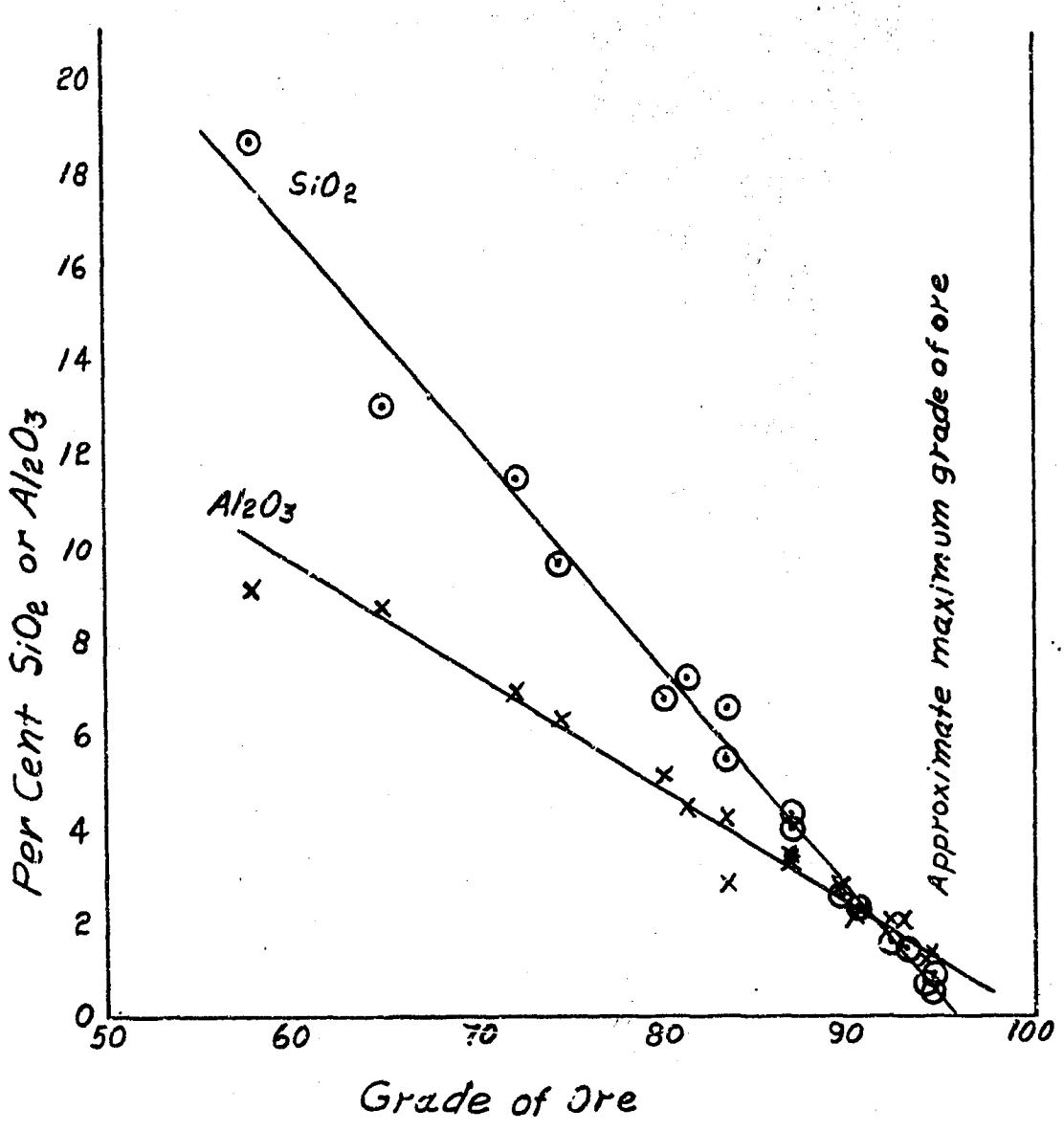


Figure 10. Relation between the grade and the amount of SiO_2 and Al_2O_3 (New Jersey Zinc).

-Continued-

Mineralogical Components (N. J. Z.) (Bergeron)

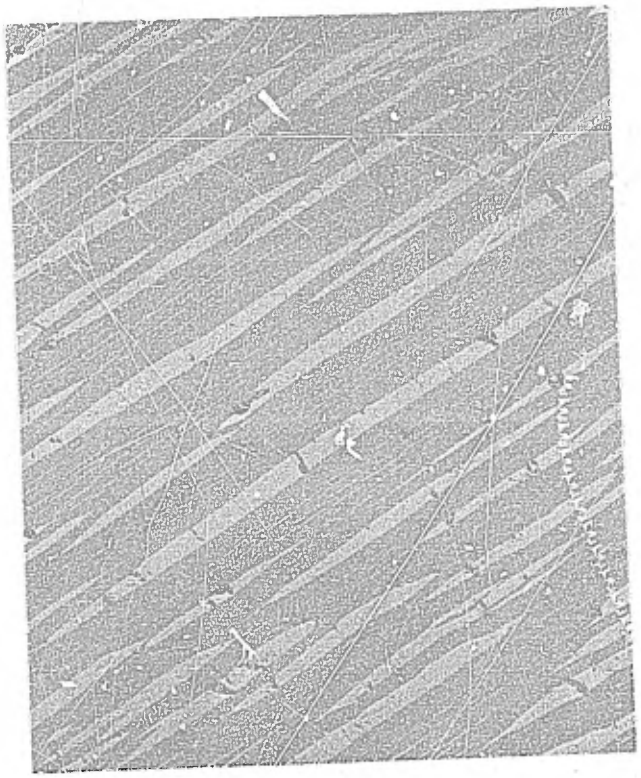
In addition to ilmenite and hematite which exist in the ratio of 2:1, we find minerals such as plagioclase, pyrite, spinel, biotite, magnetite, and hypersthene. Other minerals such as chalchopyrite, millerite, zircon, corundum and anatase have also been reported but these are present in very small amounts. More information on the nature and abundance of these minerals is given below.

Ilmenite and Hematite

The two main minerals in Allard Lake ore are ilmenite ($FeO.TiO_2$) and hematite (Fe_2O_3). Both occur in the same crystal, ilmenite forming the groundmass and hematite forming groups of exsolution lamellae. The crystal has an overall specific gravity of 4.8. Figure 11 is a microphotograph of a section of a crystal which has been cut parallel to its c axis. This photograph shows that the ilmen-hematite lamellae fall into two distinct size ranges, one of large and some intermediate lamellae, and the other of very small lamellae. The large and intermediate lamellae range in length from 1 to 10 millimeters and in thickness from 0.005 to 0.004 millimeters. The small lamellae are roughly 5 to 10 microns long, 0.2 to 1 micron thick.

When the crystal is cut perpendicular to the c axis (Figure 12), the hematite phase appears as small circular discs. From microscopic observations, it is evident that the hematite phase has exsolved in the basal plane of the crystal. Intergrowth of this type appears to be the result of unmixing of a solid solution since the crystal may be rendered homogeneous by heating it to a high temperature. Some small exsolution ilmenite lamellae are also present in the hematite phase.

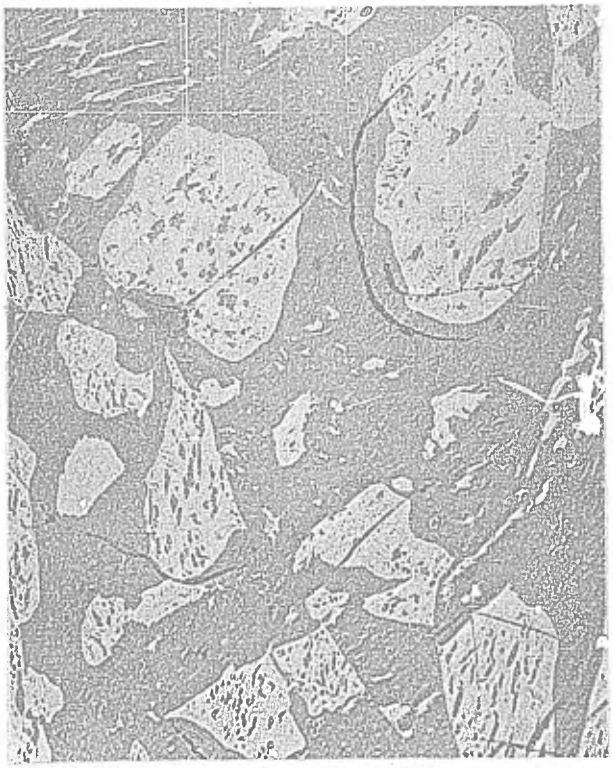
-Continued-



X 100

Figure 11. Polished section of an ilmenite crystal which has been cut parallel to its c-axis.
White = hematite phases.
Grey = ilmenite phases.

-Continued-



x 100

Figure 12. Polished section of an ilmenite crystal which has been cut perpendicular to its c-axis.
White = hematite phases
Grey = ilmenite phases

-Continued-

Plagioclase Feldspar (N. J. Z.) (Bergeron)

An appreciable quantity of plagioclase feldspars can be found in Allard Lake ore. The mineral which has a density of 2.7 is the principal gangue constituent in the ore.

The refractive index (1.524) and maximum extinction angles on albite twins indicate that the Allard Lake feldspar contains about 46 weight percent anorthite ($CaAl_2Si_2O_8$) and 54 weight percent albite ($NaAlSi_3O_8$). Table V gives the chemical composition corresponding to a feldspar containing 46% anorthite. In this table only the main constituents are considered.

Table V

Analysis of Allard Lake Plagioclase

(Bergeron)

Oxide	% by Weight
CaO	9.3 ± 0.2%
$Na_2O + K_2O$	6.4 ± 0.2%
Al_2O_3	27.3 ± 0.1%
SiO_2	57.0 ± 0.3%

Usually about 0.4% K_2O is present with these plagioclases. Since K_2O can substitute for Na_2O, we must substract this amount to the value of 6.4 percent. Therefore the Allard Lake feldspar must contain around 6.0% Na_2O and 0.4% K_2O.

Pyrite (N. J. Z.) (Mariano, 1970)

Interstitial pyrite, FeS_2, is the principal sulfide mineral in Allard Lake ore. The mineral which represents about 0.6% of the ore has a density of 5.02. It is often associated in the ore with magnetite (Fe_3O_4) and chalcopyrite ($CuFeS_2$). From an analysis of isolated grains of pyrite carried out by Dr. Mariano(Kennecott Copper, Ledgemont Laboratory), minor amounts of copper, nickel and cobalt were found. These elements probably occur as substitutional elements in the pyrite structure since the cell edge of Allard Lake pyrite is 0.0041 Angstroms longer than that of synthetic pyrite which is 5.4171 ± .0001 Angstroms. According to Lister,

-Continued-

sulfides are slightly more abundant in the low grade ore.

Spinel (N. J. Z.)

A small amount of interstitial pleonaste spinel $(Mg, Fe)O.Al_2O_3$ is present in the ore. It apparently does not increase with other gangue minerals in low grade ore. Spinel is probably present to an extent of one or two percent in the ore. The mineral which has a density of 3.8 is green in thin section, black in mass and has a refractive index of 1.77.

Biotite Mica (N. J. Z.)

Minor amounts of biotite mica, $K(Mg, Fe)_3 AlSi_3O_{10}(OH)_2$, with a specific gravity between 2.8 and 3.2 were found. Very little data are available on the amount of mica present. Unlike the spinel, it probably increases as the grade of the ore is dropped and is not likely to be much over one percent, even in the low grade (80%) material.

Magnetite (N. J. Z.)

Magnetite, Fe_3O_4, with a specific gravity of 5.2 is known to be present in various amounts, probably not exceeding about five percent. Magnetic measurements made on three miscellaneous samples of Petit Pas ore (N. J. Z. memorandum M-451) indicate that a high grade ore may contain about four percent magnetite. Microscopic study has indicated an association between the magnetite and the sulfides.

Hypersthene, Pyroxene (N. J. Z.)

Hypersthene, $(Mg, Fe)_2 Si_2O_6$, with a specific gravity around 3.4 was found in small amounts in some portions of the ore body. The mineral is dark in color and is difficult to detect without a detailed examination.

-Continued-

Miscellaneous (N. J. Z.) (Mines Branch Ottawa) (Lister) (Bergeron) (Retty)

No discreet chromium, vanadium and manganese bearing minerals were found associated with the ore. Chlorite and rutile are generally evident in widths of a few inches where the steep faults cut the ore sheet. Before the discovery of the Allard Lake deposit, Dr. Retty has observed in other ilmenite localities some quartz included in the feldspar (myrmekite structure). It is reasonable to believe that the same phenomenon exists at Lac Tio. The amount of quartz present in this form in the ore would probably be extremely small ($< 1\%$).

Crystallographic Properties of Ilmenite Crystals (Bergeron) (Lindsley) (Carmichael) (Osborne)

Pure hematite contains 70% Fe and 30% O and pure ilmenite, 36.8% Fe, 31.6% Ti and 31.6% O. These two oxides crystallize in the rhombohedral class of the hexagonal system. The cell parameters of ilmenite and hematite are similar and their crystal angles are almost identical. Both phases are strongly anisotropic and can easily be distinguished from magnetite under crossed nicols.

Solid solutions of hematite and ilmenite are generally encountered in nature. The basis for x-ray diffraction analysis of these solid solutions is the regular variation of crystal lattice parameters, for an isomosphous series, between the values for the two end members of the series. Figure 13 shows two curves relating the 2θ diffraction angle off the (116) and the (024) planes with the composition of the hematite-ilmenite solid solution. These curves, determined by Lindsley in 1962, are the ones generally used by the author.

Many samples of Allard Lake ore have been analysed by the author on the basis of the curves shown in Figure 11. It was found that the large hematite lamellae contain on the average 14% ilmenite and 86% hematite, and the ilmenite groundmass 8% hematite and 92% ilmenite. The small hematite lamellae have not been analysed at Q. I. T., but Carmichael who carried out some studies on the remanent magnetism of the ilmenite crystals has reported a composition of 7% ilmenite and 93% hematite for the small hematite lamellae.

-Continued-

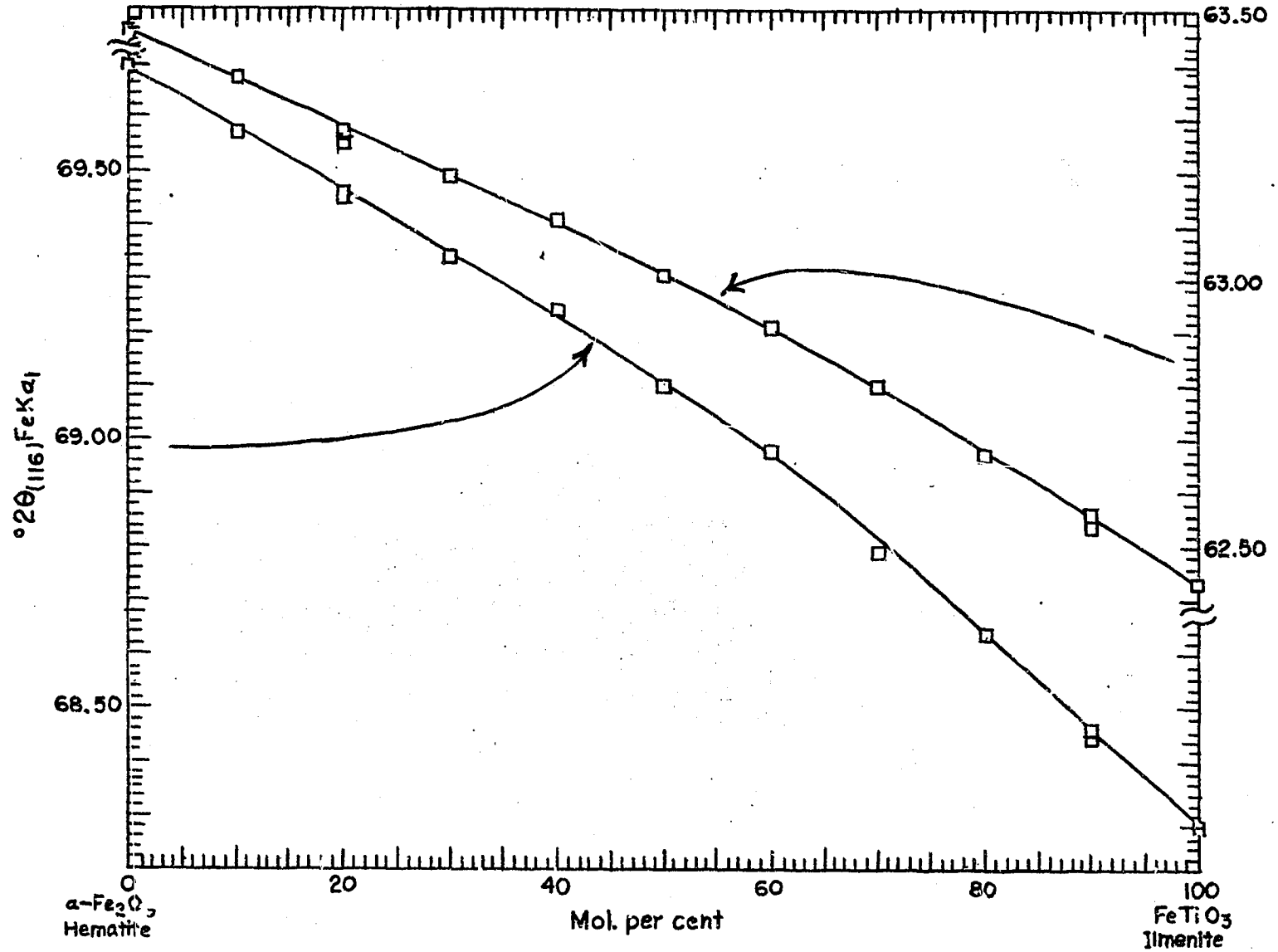


Figure 13. Lindsley's curves relating the 2θ diffraction angles of the (116) and (024) planes with the composition of the hematite-ilmenite solid solution. (Lindsley, 1962).

-Continued-

(Lindsley, 1962)

Origin of Allard Lake Ore (Hammond, 1952) (Lister, 1968) (Hargraves, 1962)

All known ilmenite deposits in the area occur in association with gabbro and anorthosite rocks in which ilmenite is found as an accessory mineral. Thus there is a genetic relationship between ilmenite and rocks of this composition. There is, however, no general agreement on their precise relationship, nor indeed on the origin of anorthosite itself.

Hammond and Lister suggested that the Allard Lake deposit was formed from an ore magma and that hydrothermal activity was not the major process involved. Their conclusion was based on the following observations:

1. The presence of sharp contacts between massive ilmenite and unaltered pure anorthosite.

2. The presence of unsupported inclusions of unaltered anorthosite within the massive ilmenite.

3. The general lack of minerals such as garnet, tremolite and muscovite which are commonly associated with hydrothermal deposits.

4. The uniformity of mineralization which suggests an approach to equilibrium conditions.

5. The orientation of platy ilmenite crystals parallel to the attitude of the ore sheet, suggesting crystals settling in a liquid.

6. The decrease in the amount of vanadium and chromium and the increase in the amount of magnesium upwards in the massive section of the sheet, suggesting crystallization from a magma.

7. The manganese content which is much lower than would be expected for a hydrothermal deposit.

-Continued-

The oxide minerals in the host rock contain less vanadium, chromium and aluminum and more manganese than do the oxide minerals of the deposit. This indicates that the liquid ore was not derived by filter pressing of the anorthosite in this part of the pluton. The liquid ore probably originated from the same parent magma as the anorthosite but the evidence available does not establish the mechanism of collection of the liquid ore before its injection into the hot crystallized anorthosite rock.

After the liquid ore had been injected into a zone of dilation in a gently-dipping sineous shear zone in hot anorthosite, the hemo-ilmenite melt solidified into crystals of homogeneous composition. During cooling the crystals have separated by exsolution into an ilmenite-rich phase and a hematite-rich phase. The hematite-rich phase has exsolved in the form of thin discontinuous lamellae with their long and intermediate axes in the basal plane of the rhombohedral host-crystal. The hematite lamellae have exsolved in two distinct size ranges as shown in Figure 11. The simplest explanation for this is that there are two plateaux in the cooling curve of the deposit: a long period of fairly constant temperature during which the large hematite lamellae exsolved, followed by a relatively rapid drop in temperature, and then a second constant temperature period during which the small lamellae were formed. Unfortunately, the steep sides of the hematite-ilmenite solvus curve shown in Figure 14 make it difficult to fix the temperature plateaux accurately. From the composition of the two main ilmenite-hematite solid solutions it seems that the first plateau in the cooling period would probably occur around 600°C. The temperature of the second plateau is probably around 300°C.

To summarize, we can say that the Allard Lake ilmenite deposit is thought to have been formed by the injection of a liquid ore of essentially the same composition as the overall composition of an ilmenite crystal in a shear zone of hot solid anorthosite. In the upper portion of the ore sheet the liquid ore has invaded closely spaced sheat planes and permeated fractures in the crushed anorthosite to produce banded and disseminated mineralization. During slow cooling the crystals have separated by exsolution to form two main groups of hematite lamellae and a group of small ilmenite lamellae within the large hematite discs.

-Continued-

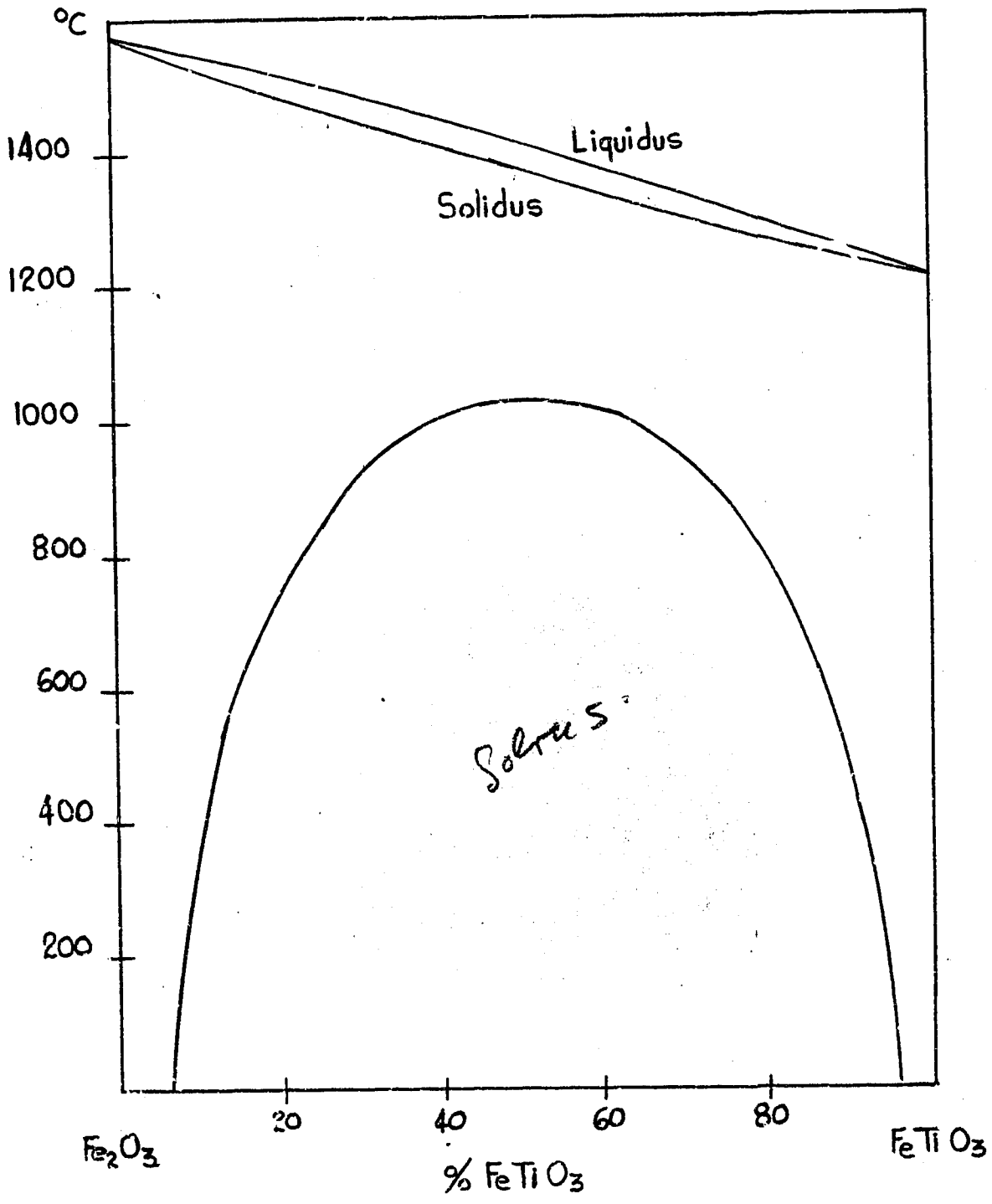


Figure 14. Hematite-ilmenite solvus curve(Carmichael, 1961).

-Continued-

REFERENCES

Archambault, M., Claisse, F., and East F., 1953, Hematization de l'ilménite: Quebec Department of Mines, Preliminary Report associated with the Research Project No. 59.

Bergeron, M. and Rigaud, M., 1968, Allard Lake Ore and the Fe-Ti-O system: Q. I. T. Internal Report No. 38-68

Bosschart, R. A., 1966, Report on a Gravity Survey, Tio Mine Property, Allard Lake District Quebec: Q. I. T. file.

Bourret, W., 1949, Aeromagnetic Survey of the Allard Lake District, Quebec, Economic Geology Vol. 44, no. 8, pp. 732-740.

Carmichael, C. M., 1959, Remanent Magnetism of the Allard Lake Ilmenites: Nature, Vol. 183, pp. 1239-1241.

Carmichael, C. M., 1961, The Magnetic Properties of Ilmenite-Hematite Crystals: Proceedings of Royal Society, London, Vol. 263, ser. A, pp. 508-530.

Dearden, E. O., 1958, Compilation of Lac Tio Geological Data: Kennco Explorations Limited, Internal Report.

Dearden, E. O., 1961, An Evaluation of Q. I. T.'s Non-Contiguous Claim groups Kennco Explorations Limited.

Fleming, H. W., 1966, Report on the Gravity Survey, Lac Tio Ilmenite Deposit, District of Saguenay: Report from Kennco Explorations Limited.

Fleming, H. W., 1961, A Preliminary Geophysical Assessment of Portions of Q. I. T.'s Properties: Kennco Explorations Limited.

Goode, J. D., 1958, Field Trip to Lac Ellen and Lac Grader: Q. I. T. file.

Guimond, R., 1964, Titanium and Q. I. T.: Mining in Canada Journal, November 1964.

-Continued-

Hammond, Paul, 1949, Petrology of Allard Lake Ilmenite Deposits: Canadian Mining and Metallurgical Bulletin, March 1949.

Hammond, Paul, 1952, Allard Lake Ilmenite Deposits: Economic Geology, Vol. 47, pp. 634-649.

Hargraves, R. B., 1959, Petrology of the Allard Lake Anorthosite Suite and Paleomagnetism of the Ilmenite Deposits: PhD. Thesis, Princeton, May, 1959.

Hargraves, R. B., 1962, Petrology of the Allard Lake Anorthosite Suite, Quebec: Reprint of a Volume Titled "Petrologic Studies", pp. 163-189.

Hughson, M. R. and Kaiman, S., 1961, A Mineralogical Report on Ilmenite Hematite Ore from Q. L. T., Allard Lake, Quebec: Mines Branch Investigation Report IR 61-60.

Lindsley, D. H., 1959, Magnetic Anisotropy and Remanent Magnetism in Homo-Ilmenite from Ore Deposits at Allard Lake, Quebec: Journal of Geophysical Research, Vol. 64, No. 10, pp. 1565-1578.

Lindsley, D. H., 1962, Fe-Ti Oxides in Rocks as Thermometers and Oxygen Barometers: Carnegie Institution of Washington, Annual Report 1962-63, pp. 60-66.

Lister, G. F., 1966, The Composition and Origin of Selected Iron-Titanium Deposits: Economic Geology, vol. 61, pp. 275-310.

Lister, G. F., 1968, Lac Tio 1966-67 Drilling Program, Tio Mine, Parket TWP. Quebec: Kennco Explorations Limited, Internal Report.

Longley, W. W., 1944, North Shore of the St-Lawrence Mingan to Aguanish: Preliminary Report, Quebec Department of Mines.

Mariano, A. N., Pojasek, W. J., White, P. F., 1970, Some Mineralogical Analyses of Allard Lake Ilmenite-Hematite Ore: Kennecott Copper Corporation Internal Report.

Mines Branch, Ottawa, 1955, Sulphur Elimination and Beneficiation Tests on the Ilmenite-Hematite Ore and Minus 14 mesh Fines from the Quebec Iron and Titanium Corporation, Sorel, Quebec: Department of Mines and Technical Surveys, Mines Branch, Canada, Report Investigation No. MD 3024.

-Continued-

Osborne, F. F., 1944, The Microtextures of Certain Quebec Iron Ores: Quebec Bureau of Mines Preliminary Report 186.

Quebec Department of Mines and Technical Surveys, 1959, Granularity Differences in Titanium Ore from Allard Lake: Mineral Sciences Division, Test Report M-59-3.

Retty, J. A., 1942, Lower Romaine River Area, Saguenay Country Dept. of Mines, Quebec Preliminary Report No. 171.

Retty, J. A., 1944, Region de la Rivière Romaine Inférieure: Quebec Department of Mines, Geological Report No. 19.

Rodda, J. L. and Tennant, C. B., 1952, Magnetic Estimation of Gangue in 89% and 93% Grade Allard Ores: New Jersey Zinc Report No. 1840.

Rodda, J. L., 1945, Magnetic Properties of Some Samples of Allard Lake Type Titanium Ores: New Jersey Zinc Memorandum M-435.

Rodda, J. L., 1947, Chemical and Mineralogical Composition of Petit Pas Ore, New Jersey Zinc Report No. 1298.

Rodda, J. L., 1947, Grade of Ore in the Cliff Ore Body, Petit Pas Area: New Jersey Zinc Memorandum, M-514.

Rodda, J. L., 1947, Specific Gravity of Petit Pas Drill Cores: New Jersey Zinc Report No. 1252.

Rodda, J. L., 1947, Petit Pas Ore Beneficiation: New Jersey Zinc Report No. 1268.

Rodda, J. L., 1948, Beneficiation of Petit Pas Iron-Titanium Ore by Milling: New Jersey Zinc Report No. 1338.

Rodda, J. L., 1948, Distribution of Copper, Nickel, Cobalt and Sulphur in Magnetically Separated Petit Pas Titanium Ore: New Jersey Zinc Report No. 1434.

Rodda, J. L., 1948, Copper Content of Petit Pas Ore: New Jersey Zinc Memorandum M-558.

Rodda, J. L., 1949, Gallium Content of Petit Pas Titanium Ore: New Jersey Zinc Memorandum 679.

-Continued-

SUBJECT INDEX

Allard Lake ore, origin, 42
Alumina vs. ore content, 33, 34
Alumina oxide in plagioclase, 38
Amphibolite, 10
Anorthosite, 11
Anorthosite with pyroxene crystal, 11
Anorthosite, ilmenite rich, 13
Anorthosite, dykes, 13
Biotite, 39
Bronzite crystal, composition, 12
Calcium oxide in plagioclase, 38
Cataclasis, evidence, 11
Chalcopyrite, 38
Champlain sea deposit, 16
Chromium, variation, 33
Chromium, mineral, 40
Chlorite, 24, 40
Claiming of property, 2
Cliff ore body, 21, 23
Cobalt, 38
Crystallographic prop. of hemo-ilmen. crystal, 40
Diorite, 15
Drainage of Allard Lake region, 7
Exsolution of hematite, 43, 35, 36, 37
Faulting, Lac Tio, 17, 21, 23
Faulting, regional, 17
Gabbro, 15
Geology, regional, 8
Geology, sections, 24
Glacial erosion, 7
Glaciation, regional, 18
Gneisses, 10
Gneisses Hornblende, 10
Gneisses Biotite, 10
Gneisses Injection, 10
Gneisses Garnettiferous, 10
Grade of ore vs specific gravity, 32
Grader Lake deposit, 6
Granitic rocks, 14
Grenville Series, 10
Greywache, 10
Hematite, Fe_2O_3, 35
Hematite, exsolution, 35, 36, 37, 43
Hematite-ilmenite phase diagram, 44
Hematite-ilmenite, solid solution, 40
Hematite lamellae, description, 35
Hematite phases, composition, 40, 43
Hematite phase, microphotograph, 36, 37
Hemo-ilmenite in anorthosite, composition, 33
Hemo-ilmenite crystal, composition, 33
Hemo-ilmenite crystal, crystallographic prop., 40
Hemo-ilmenite S. S., Determination of, 40, 41
Hemo-ilmenite, specific gravity, 35
History, 2
Hypersthene, pyroxene, 39
Ilmenite, 35
Ilmenite deposits, subdivision, 19
Ilmenite, nature of ore, 31
Ilmenite occurrences, 2, 4
Ilmenite occurrences, analysis of samples, 19
Ilmenite phase, composition, 40
Ilmenite phase, microphotograph, 36, 37
Kennco's explorations, 2
Lac Tio deposit, aeromagnetic profile, 30
Lac Tio deposit, aeromagnetic survey, 29
Lac Tio deposit, description, 21
Lac Tio deposit, discovery, 5
Lac Tio deposit, dip section, 27, 24
-Continued-

Lac Tio deposit, geological sections, 26, 27
Lac Tio deposit, location of drill holes, 25
Lac Tio deposit, nature of ore, 31
Lac Tio deposit, strike section, 24, 26
Lac Tio deposit, subdivision, 21
Lac Tio deposit, surface outline, 22
Location of Tio deposit, 2
Location map, Tio deposit, 3
Main ore body, 21
Magnesium, variation, 33
Magnetic property Lac Tio ore, 27
Magnetite, 39
Magnetometer survey, 5, 20
Manganese, 33, 40
Metagabbro, 15
Mica, 39
Migmatite, 10
Mineralogical components of Allard Lake ore, 35
Mining, beginning of, 6
Morin series, 11
Nature of ilmenite ore, 31
Nickel, 38
Nortwest orebody, 21
Ore, chemical analysis, 31
Ore, content vs SiO_2 and Al_2O_3, 33, 34
Ore, nature of ilmenite, 31
Ore, physical properties, 31
Precambrian rocks, 8
Petrology, regional, 8
Plagioclase, 38
Plagioclase, density, 38
Plagioclase, composition, 38
Pliestocene and recent, 16
Potassium oxide in plagioclase, 38
Pyrite, 38
Pyroxene, 39
Quartz, 40
Quartzite, 10
Railroad, construction, 6
Rock units in the area, 9
Rutile, 22, 40
Schist, 11
Silica vs. ore content, 33, 34
Sodium oxide in plagioclase, 38
Specific gravity vs. ore grade, 32
Spinel, 39
Structural geology, regional, 17
Syenite, 14
Topography, regional, 7
Vanadium, mineral, 40
Vanadium variation, 33