A TEXTURAL AND CHEMICAL ANALYSIS
OF THE HANSON LAKE ORE DEPOSIT,
SASKATCHEWAN

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Submitted to the Faculty of Graduate Studies
in Partial Fulfilment of the Requirements
for the Degree of
Master of Science
in the Department of Geological Sciences
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by

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ABSTRACT

The Hanson Lake ore body was a small (156,000 tons), massive lens with sharp ore-wall rock contacts and a homogeneous mineralogy. The major sulfide minerals were sphalerite and galena.

Textures of the sulfide and gangue minerals indicate that the ore body had undergone deformation and recrystallization. Composition and gross features of the alteration envelope suggest that the deformation and recrystallization are a result of regional metamorphism and metasomatism during the Kenoran orogeny.

The relative age of the ore body in relation to metamorphism indicates the ore was deposited penecontemporaneously with the host, volcanic, rocks. The lack of a suitable magmatic source precludes a hydrothermal origin, and shearing within the ore precludes a metasomatic origin for the ore. However, Pb-Pb age of galena in the ore body is not consistent with the author's proposed volcanogenic origin for the ore.

The Hanson Lake and Flin Flon group of ore bodies differ in many respects, although they are similar, structurally, within metamorphosed volcanic rocks. The Hanson Lake deposit, with its lack of an extensive alteration zone and its distinctive mineralogy, occurs in older rocks than those of the Flin Flon deposits. The basic differences suggest that the Hanson Lake deposit should not be correlated regionally with the Flin Flon group of deposits, and may account for the lack of good correlation between Co:Ni ratios of pyrrhotite in the Hanson Lake deposit and in 'economic' deposits of the Flin Flon group.
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1. INTRODUCTION

1.1 Location and Access

The Hanson Lake lead-zinc ore body was located in northeastern Saskatchewan, 40 miles west of the town of Flin Flon, Manitoba (Figure 1). The mine site is situated on the west shore of Hanson Lake with the ore body 600 feet to the east under the lake (Figure 2). Co-ordinates of the ore body are 54° 70' 30" of north latitude and 102° 51' of west longitude.

The mine site is serviced by a seven-mile, all-weather road from mile 170.3 of the Hanson Lake highway (Highway 106). Float and ski-equipped aircraft were used extensively before the service road to the mine site was constructed.

1.2 History of Mine Development

The Hanson Lake ore body was discovered in 1957 by the Parrex Syndicate. The discovery was a result of routine drilling of a conductive geophysical anomaly which was parallel to and a short distance east of the ore body. After considerable diamond drilling, the property was optioned to Share Mines and Oils Limited during the winter of 1964-65. Surface diamond drilling indicated ore reserves of 250,000 tons. The ore body was mined by Western Nuclear Mines Limited from 1966 until reserves were depleted in 1969. The ore body contained only 156,000 tons of ore.

1.3 Acknowledgements

I wish to express sincerest thanks to Dr. John A. McDonald for
Figure 1

LOCATION MAP OF THE HANSON LAKE ORE BODY
(after consultant report to Share Mines and Oils Ltd.)
his valuable help throughout the preparation of this thesis. Western Nuclear Mines Limited was gracious in allowing the author to use drill hole core and logs and all other available mine information. I would also like to thank all of the mine staff at the Hanson Lake mine site who gave up so much of their time and energy to help me during my short stay at the mine site.

I would like to acknowledge and thank my wife, Valary, for her long hours spent typing and drafting.
2. PREVIOUS INVESTIGATIONS

The earliest geological map of the area was prepared by Wright and Stockwell (1934) on a scale of two miles to one inch. Byers (1957) mapped the Hanson Lake area on a scale of one-half mile to one inch. This report included a brief description of the ore and wall rock and of the development and history of the Hanson Lake lead-zinc prospect to 1957. A description of the ore from four primary exploration drill holes is given in an unpublished B.E. thesis (Gotts, 1958). Arnold (1967) included Hanson Lake pyrrhotite in his summary paper on the composition and structure of pyrrhotites from 82 deposits.

The most recent work has been an extensive geological and geochemical study of the Hanson Lake area by Coleman, Gasgarth and Smith (1970). The portion of the geological map from this report pertaining to the mine area is shown in Figure 3. Smith (ibid, p. 134-137) considered the possibility of the ore being a result of migration of ore-forming solutions towards a dilational shear zone during regional metasomatism. Coleman (ibid, p. 84) considered the possibility of a syngenetic origin for the ore body.

The host rocks of the ore body (Amisk-type volcanic rocks) have been dated by Rb-Sr isotope methods at 2521 ± 60 million years (Coleman, et al., 1970). Sinha (1970) gave a model Pb-Pb age of 1860 m.y. for the Hanson Lake ore body. Recent work on galena from the bottom level of the mine may indicate an age of 1790 m.y. (personal communication, D.F. Sangster).
3. PRESENT INVESTIGATIONS

3.1 Objectives

The study was undertaken to give as complete an analysis as possible of all pertinent aspects of the Hanson Lake ore body. All mineral phases were identified and many of their textural features were recorded on photomicrographs. The MnS and FeS contents of six mineralogical associations of sphalerite throughout the ore body were determined and related to the history of the ore and to other ore bodies in the Flin Flon area. The Co:Ni ratios of Hanson Lake pyrrhotites were compared to ratios in other ore bodies and to the ratios of the massive ore as a whole. Copper, lead, silver and zinc assay values were contoured on N-S longitudinal mine sections to determine any significant distribution patterns. Wall-rock alteration was studied to determine its relation to the massive sulfide lens. The gangue, composed mainly of inclusions, was compared to the wall rocks. All aspects of the ore body mentioned above, are discussed in relation to the history of the ore body and to ore genesis.

3.2 Methods

Approximately 100 polished sections and 50 thin section from 18 drill intersections of the ore body and 5 cross-sections sampled underground were used in the investigations. Diagnostic properties used for identification and textural relations were extracted from Moorehouse (1959), Ramdohr (1969), Short (1940), Schouten (1962) and Uytenboogaardt (1951). Grain textures in sphalerite, galena and pyrrhotite were
examined after immersion in a thiourea etchant solution*.

The electron microprobe was used for sphalerite and pyrrhotite analysis and, in conjunction with the non-dispersive spectrometer, for positive identification of sulfosalts and other minor phases. Drill hole assays from the Western Nuclear Mine site were utilized in the chemical studies.

3.3 Operation of the Non-dispersive Spectrometer

The non-dispersive spectrometer can simultaneously analyze the constituent elements in a sample. The sample, when excited by an electron beam from a source, emits characteristic x-rays for each element. The characteristic energy (KeV), rather than the wave length of the energy emitted from the sample, is measured in the non-dispersive system.

The instrument was used for qualitative and semiquantitative purposes in this study. Elements are listed on a chart according to channel number where each channel is the equivalent of a 50 eV increase in x-ray emission energy. Operation conditions of the microprobe for these purposes were a beam voltage of 25 KeV, a beam current of 100 micro-amps and a specimen current of 5 nano-amps (1 nano-amp = $1 \times 10^{-9}$ amps).

* Thiourea solution prepared from reagents in proportions given by Lyall and Paterson (1966).
4. REGIONAL GEOLOGY

The regional geology is based on the Saskatchewan Research Council report of the Hanson Lake area (Coleman et al., 1970). The ore body, in Precambrian rocks, is less than three miles north of the contact between the Precambrian Shield to the north and the Paleozoic rocks to the south. The four main types of Precambrian rocks are the Kisseynew-type rocks, Amisk-type rocks, intrusive rocks, and metasomatic rocks (Figure 3).

Kisseynew-type rocks are a group of gneissic, porphyroblastic, migmatitic and agmatitic rocks in which the granitoid components generally have a quartz-dioritic composition (Coleman et al., 1970). Amisk-type rocks are similar to the metavolcanic and metasedimentary rocks of the Amisk group in the Amisk Lake area as described by Byers and Dahlstrom (1954). These rocks consist of mafic to felsic fragmental rocks, tuffs, calc-silicate rocks and graywackes (Coleman et al., 1970). Intrusive rocks consist of several biotite granite bodies, three types of granitic pegmatites of which one is berylliferous, and a small discordant metapyroxenite body (ibid, p. 7).

Extensive deformation of the region has caused much folding and faulting. Coleman et al. (1970) considered the three directions of foliation to have resulted from one prolonged period of continuous folding; the major features being two south-plunging anticlines and two south-plunging synclines west of Hanson Lake. Gaskarth (1967) considered the Jackpine Lake anticline to be plunging 60° due south. A similar
attitude has been interpreted for the Hanson Lake syncline, although the Tulabi Lake syncline is considered to have a shallower plunge than the Jackpine Lake anticline (Byers, 1957). North-northeast- to north-northwest-striking faults and shear zones are common in the area. Some of the faults and shear zones west of Hanson Lake are considered to be part of the Tabernor Lake fault system that extends 170 miles to the north (Byers, 1962). Faults are considered to post-date the folds.

The area has been regionally metamorphosed to the amphibolite facies as defined by Turner (1968). Characteristic minerals of Amisk-type rocks for this grade of metamorphism are hornblende, plagioclase, garnet, biotite and epidote. Coleman et al. (1970) considers that the Amisk-type rocks have been affected by at least one period of bulk metasomatism which is characterized by segregations of pale green amphibole, shearing, and abundant garnets.
LONGITUDINAL PROJECTION OF ORE BODY
5. DESCRIPTIVE PETROLOGY

5.1 Mine geology

5.1.1 Wall rocks: The ore body is generally conformable with the litho-stratigraphic contact between felsic volcanic rocks and soda-rhyolite porphyry rocks*. Locally, the ore is totally within the soda-rhyolite porphyry unit and remnant plagioclase phenocrysts are found in the alteration zone. A horizontal projection of the ore body at the 200-foot level is shown in Figure 2. Three representative vertical cross-sections along the ore body show the wall-rock geology (Figures 5a, b and c), the locations of which are shown in Figures 2 and 4. These vertical sections are based on those prepared by the mining company. Hanging wall and footwall sections of drill holes 65-6, 65-10, and Par 13 were sampled and logged. The entire length of drill hole 65-3 was logged and sampled. The west side of the ore body is the structural and probably the stratigraphic, hanging wall.

The felsic volcanic rock unit consists of fragmental lavas, agglomerates and tuffs (Coleman et al., 1970). Near the mine, drill core specimens of this unit are predominantly tuff that is distinguished by very fine, even layering and well-defined biotite-muscovite schistosity. Very few fragments were found in core samples of this tuff. These rocks consist of fine-grained quartz and feldspar with 10 to 30 per cent biotite and muscovite. Biotite generally shows minor alteration to chlorite. Garnet is a common accessory and sericite, tremolite, hornblende,

* The nomenclature, soda-rhyolite porphyry and felsic volcanic rocks, of Coleman et al. (1970) has been accepted for this thesis.
sphene and calcite were observed in a few thin sections. Narrow bands, 
(<10 feet wide) similar in composition to the soda-rhyolite porphyry, 
are common in this unit.

The soda-rhyolite porphyry unit is characterized by many sub-
spherical, colourless to blue quartz, and white feldspar phenocrysts 
0.2 to 0.5 cm in length. Highly altered plagioclase, quartz, and a few 
K-feldspar phenocrysts constitute 10 to 40 volume per cent of the rock 
unit. Plagioclase, usually untwinned, is generally altered to sericite 
and some calcite. Grains that appear as quartz phenocrysts in hand 
specimens are revealed in thin section usually to be aggregates of large 
quartz grains. Biotite, muscovite and sericite, that are crudely fol- 
liated in thin section, make up less than 10 per cent of the rock. Minor 
alteration of biotite to chlorite is common. The remainder of the rock 
is fine-grained quartz and feldspar. Tuffaceous bands similar to the 
felsic volcanic rocks occur in this unit. One narrow, locally confor-
mable diorite band (5-6 feet wide), found in the ore zone in the southern 
portion of the ore body and 30 feet away from the ore body along the foot- 
wall to the north, is included in this unit.

Both of these units have been recrystallized and their volcanic 
identity is based on hand-specimen textures. Coleman et al. (1970) have 
suggested that the soda-rhyolite porphyry is probably ignimbrite flows and 
postulate the existence of a soda-rhyolite porphyry neck northeast of 
the ore body where this unit is thick and has concentric foliations.

Although sheared wall rocks, chloritization, and pyritization 
characterize the footwall of the ore, these features do not appear on
strike 1000 feet north of the ore body at the contact between the two rock units. They are, however, present at a depth of about 500 feet.

5.1.2 Gross features of the ore body: The ore body was essentially a steep, westerly dipping, irregular, conformable, undulating lens of massive lead-zinc-silver ore that was 1600 feet long, 400 feet deep, and up to 15 feet wide. Horizontally and vertically, the ore width was extremely variable. In many places, the ore decreased in width from 10 feet to 0.5 feet over a distance of less than 10 feet. The massive ore lies on the west side (hanging wall) of an envelope of silicification and shearing, although locally, the ore moves to the footwall side of this envelope. The maximum thickness of this alteration is 15 feet. Drill-hole information from below the ore body and from north and south of the ore body indicates rapid thinning of the alteration envelope with a decrease in width of massive ore. On surface, 1000 feet north of the ore body, there is no trace of shearing or mineralization at the stratigraphic contact, although at a depth of about 500 feet, minor lead-zinc mineralization has been found. Figure 6 is a three-dimensional sketch that shows the spatial relationship between the ore, alteration envelope and stratigraphy.

Vertically plunging folds ("rolls" in mine terminology) locally displace the ore as much as 10 feet laterally off strike of the ore body (personal communication, J. Donahague*). The author observed similar types of folds with an amplitude of less than 3 feet. Minor open folds and re-folded cylindrical isoclinal folds were observed in the wallrock at the bottom of the mine. These may correspond to F3 and F1 or F2 folds.

* Acting mine geologist at time of author's visit to the mine site.
THREE DIMENSIONAL SKETCH OF ORE BODY, ALTERATION & STRATIGRAPHY

Figure 6
respectively of Coleman et al. (1970). The contacts of soda-rhyolite porphyry, about 1 mile north of the ore body, have been found to be folded with F2 or F1 style folds (ibid, p. 66). The ore body has one major bifurcation and many minor bifurcations. Inclusions of wall rock up to two feet in length are common throughout the ore body. Some porous ore and vuggy wallrock were observed near the top of the ore body.

5.2 Ore Mineralogy

A typical ore section (Plate 1) consists of 70 to 80 volume per cent sulfides. The gangue consists of large quartz-muscovite wall-rock inclusions, quartz knots and minor amounts of carbonate, chlorite and muscovite. Locations of all specimens shown in the photomicrographs are listed in Table 4 in the Appendix.

5.2.1 Sphalerite: Sphalerite constitutes 70 to 80 volume per cent of the sulfides in the ore body (Plate 2a). Two major textural types of sphalerite as defined by grain size are present in the ore. The most abundant or normal type has a grain size (largest dimension measured) range of 0.02 mm to 0.3 mm (Plate 2b). Coherent twinning is ubiquitous in sphalerite of the normal grain size. Polygonalization is accentuated in some twin orientations (Plate 2c) and appears to control twinning in other sections (Plate 3a). The anomalously large sphalerite grains occur in a few galena deficient areas and where galena and sphalerite are segregated. The largest dimension of some of these grains exceeds 2.0 mm. (Plate 3b).

Individual sphalerite grains are common as inclusions in quartz (Plates 3c and 4a). These inclusions are generally well-rounded (Plate
Abbreviations used on all photomicrographs are as follows: sphalerite - sph, galena - gal, chalcopyrite - cpy, pyrite - py, pyrrhotite - po, marcasite - marc, arsenopyrite - aspy, sulfosalts - sf, bournonite - bourn, boulangerite - boul, and tetrahedrite - tet.

Plate 1 Specimen No. 1 Scale: 0.5x

A complete cross section of the ore. This narrow ore width is common in the mine. Note large siliceous inclusions. The narrow black line cutting the ore sample in two pieces is a fracture in the sample. H-1 to H-5 mark the locations of samples taken for chemical analysis.
Plate 2a  Specimen No. 2  Scale: 16x

Typical unetched ore: sphalerite, galena, pyrite, arsenopyrite, chalcopyrite, pyrrhotite, marcasite and sulfosalts in galena: unetched surface, plain reflected light.

Plate 2b  Specimen No. 3  Scale: 80x

Typical grain size for sphalerite, galena and pyrrhotite: thiourea etch, plain reflected light.

Plate 2c  Specimen No. 4  Scale: 250x

Polygonalization in sphalerite grains accentuated in certain twin orientations: thiourea etch, plain reflected light.
Plate 3a  Sample No. 5  Scale: 400x

Polygonalization in sphalerite grains appears to control twinning: thiourea etch, plain reflected light, oil immersion.

Plate 3b  Sample No. 6  Scale: 50x

Incoherent twins and irregular grain growth of large sphalerite grains in areas of low galena content: thiourea etch, plain reflected light.

Plate 3c  Sample No. 7  Scale: 100x

Typical single sphalerite grain in quartz. Note minute chalcopyrite grains about the sphalerite-silicate interface: thiourea etch, plain reflected light.
4a). Usually, these sphalerite grains have many minute chalcopyrite grains along the sphalerite-silicate interface (Plate 3c). Some brittle fractures in sphalerite are present throughout the ore body (Plate 4b). An abrupt decrease in grain size of sphalerite near wallrock inclusions in the ore is common (Plate 4c). Large sphalerite grains occur in embayments of inclusions (Plate 5a). Some arsenopyrite aggregates have a halo of coarse-grained sphalerite. Shear planes about these aggregates suggest that the arsenopyrite has been mechanically moved in sphalerite (Plate 5b).

5.2.2 Galena: Galena comprises 4 to 15 volume per cent of the sulfides in the ore body. Texturally, galena occurs as (a) grains with the maximum dimension between 0.04 mm and 0.3 mm (Plate 2b), (b) anomalously large grains with a maximum dimension 0.5 mm to 2.5 mm and (c) grains along sphalerite grain boundaries that are less than 0.04 mm long (Plate 2a). The first and third types are the most abundant. Large galena grains occur where galena is the dominant sulfide mineral such as in the hinge region of minor folds (Plate 15b), and where sphalerite and galena are segregated. Small galena grains (generally <0.04 mm long) usually outline sphalerite grains so that sphalerite grain size can be estimated without first etching the specimen (Plate 5c).

Sulfosalts are ubiquitous in all but the smallest galena grains (Plate 2a) although bournonite and tetrahedrite do occur as grains isolated from galena (Plates 10c and 11b). No silver was detected in galena by microprobe analyses.

5.2.3 Chalcopyrite: Chalcopyrite typically ranges between
Plate 4a  Specimen No. 8  Scale: 32x

Well-rounded to spherical sphalerite inclusions in quartz: unetched surface, plain reflected light.

Plate 4b  Specimen No. 9  Scale: 160x

Late fractures in sphalerite cut across grain and twin boundaries with no visible displacement: thiourea etch, plain reflected light.

Plate 4c  Specimen No. 6  Scale: 50x

Granulation of sphalerite about silicate inclusions. Abrupt decrease in grain size of sphalerite near inclusions is common: thiourea etch, plain reflected light.
Plate 5a  Specimen No. 10  Scale: 14x

Shearing in sphalerite can be seen by lines of small galena and pyrrhotite (black in photomicrograph) and granulation of sphalerite. Large sphalerite grains are found in embayment of silicate inclusions: thiourea etch, plain reflected light.

Plate 5b  Specimen No. 10  Scale: 32x

Halo effect about arsenopyrite aggregate. Shearing can be seen in sphalerite (grey) by shear planes of galena and pyrrhotite (black): thiourea etch, plain reflected light.

Plate 5c  Specimen No. 11  Scale: 40x

Small grains of galena occur as films on sphalerite grains allowing grain size estimations of sphalerite to be made: unetched specimen, plain reflected light.
zero and 3 volume per cent of the massive sulfides, although, in local areas of high silicate content, it may attain 20 volume per cent. Grain size is normally less than 0.1 mm (Plate 2a), although aggregates less than 1.0 mm in maximum length are common. Individual chalcopyrite grains occur mainly along sphalerite grain boundaries (Plate 3a) although large sphalerite grains contain structurally oriented exsolution lamellae of chalcopyrite along twin boundaries. Minute chalcopyrite grains (<0.05 mm) occur along the margins of rounded sphalerite inclusions in quartz (Plate 3c). Chalcopyrite also occurs in brittle fractures in pyrite (Plate 6a). The concentration of chalcopyrite on opposing sides of silicate grains suggests that chalcopyrite occurs as pressure shadows.

5.2.4 Arsenopyrite: The massive sulfide phase typically contains 3 to 7 volume per cent arsenopyrite. However, some local arsenopyrite-rich areas in the mine contain up to 50 per cent arsenopyrite. Arsenopyrite occurs as subhedral to euhedral grains with a size range of 0.01 mm to 1.3 mm (Plate 2a and 6c), while aggregates of small grains attain a maximum diameter of 1.5 cm (Plate 1 and 5b). Evidence of fracturing in some arsenopyrite grains is still preserved despite recrystallization of sphalerite that occupies the fracture (Plate 6b). Growth features are common within euhedral arsenopyrite grains (Plate 6c). In a paragenetic sequence, arsenopyrite is the only mineral that may be in its primordial form. Fractures with minor displacement appear to be the only metamorphic effect displayed by this mineral.
Plate 6a Specimen No. 11 Scale: 63x

Chalcopyrite, sphalerite and silicate minerals occupy fractures in pyrite: unetched surface, plain reflected light.

Plate 6b Specimen No. 12 Scale: 80x

Fractured euhedral arsenopyrite grain in a groundmass of sphalerite, galena and pyrrhotite: unetched surface, plain reflected light.

Plate 6c Specimen No. 13 Scale: 40x

Growth features in arsenopyrite: unetched surface, plain reflected light.
5.2.5 Pyrite: Pyrite constitutes less than 4 volume per cent of sulfides in the massive ore although massive and disseminated pyrite occurs throughout the alteration envelope. Pyrite in the massive ore is texturally different from wall-rock pyrite in that grains from the massive ore contains many inclusions while grains from the wall-rock pyrite contain very few.

Pyrite in the massive ore occurs as irregular anhedral grains with maximum dimensions ranging from 0.1 mm to 3.0 mm. Inclusions of silicate minerals, sphalerite, arsenopyrite, galena and chalcopyrite are almost ubiquitous (Plate 7a). Fractured pyrite grains are common (Plate 7a) and some smaller grains appear to be the result of granulation of larger grains. Marcasite and chalcopyrite occur along some pyrite fractures (Plates 6a and 7b) and, locally, pyrite shows an optically distinct "reaction rim", of some intermediate iron sulfide phase, along its contact with marcasite and chalcopyrite (Plate 7c). Microprobe analysis indicates similar amounts of iron and sulfur in the reaction rim, pyrite and pyrrhotite. No growth features in this pyrite were revealed by etching with either concentrated nitric acid or nitol (nitric acid + methyl alcohol).

Pyrite in the wall rock has a similar grain size to pyrite in the massive ore. Massive pyrite on the immediate hanging wall and footwall has been brecciated to the extent that any evidence of recrystallization has been obliterated (Plate 15a). A concentrated nitric acid solution emphasized faint concentric growth features on a few small wall-rock pyrite grains.

5.2.6 Pyrrhotite: Pyrrhotite content in the sulfides is generally less than 3 volume per cent, although it locally ranges from zero to 15
Plate 7a  Specimen No. 11  Scale: 35x

Pyrite porphyroblasts show inclusions of sphalerite, arsenopyrite, chalcopyrite and a silicate mineral. This porphyroblast is also fractured in two approximately orthogonal directions: unetched surface, plain reflected light.

Plate 7b  Specimen No. 11  Scale: 32x

Marcasite with minor chalcopyrite that occurs along fractures in pyrite: unetched surface, plain reflected light.

Plate 7c  Specimen No. 14  Scale: 50x

A distinct optical phase occurs as a reaction rim between pyrite and marcasite and chalcopyrite: unetched surface, reflected light, partially crossed nicols.
per cent.

The grain size of the longest dimension ranges from 0.01 to 0.10 mm. Pyrrhotite most commonly occurs as subhedral to euhedral laths that display the distinctive pyrrhotite (0001) cleavage (Plate 8a). Individual euhedral crystals within sphalerite grains and aggregates of anhedral grains are common.

Etched sections reveal the presence of both monoclinic and hexagonal pyrrhotite although Arnold (1969) reported only monoclinic pyrrhotite from this deposit. Monoclinic and hexagonal pyrrhotite rarely occur as intergrowths (Plate 8b). The two types of pyrrhotite occur generally as individual grains (Plate 8c). Identification of the two structural types of pyrrhotite was established by comparing diffraction lines for each type on x-ray photographs obtained from a 114.83 mm diameter powder camera. Hexagonal pyrrhotite has a single (10\(\overline{1}2\)) reflection at \(d = 2.06\) to \(2.10\) Å whereas a split reflection for (202) and (20\(\overline{2}\)) indicates monoclinic pyrrhotite (Haynes and Hill, 1970).

Pyrrhotite shows all degrees of alteration to marcasite. The progressive stages in this alteration are shown in Plates 9a, 9b and 9c.

5.2.7 Marcasite: Marcasite occurs as an alteration product of pyrrhotite and of some pyrite (Plates 7 and 9). It generally constitutes 3 to 10 volume per cent of the massive sulfides although locally marcasite content attains 25 per cent. The maximum dimension of the marcasite pseudomorphs of pyrrhotite ranges from 0.01 to 0.1 mm. Some
Plate 8a    Specimen No. 12    Scale: 160x

Diagnostic basal cleavage in pyrrhotite. Matrix is sphalerite and galena: unetched surface, plain reflected light.

Plate 8b    Specimen No. 15    Scale: 160x

Hexagonal pyrrhotite intergrowths in monoclinic pyrrhotite: thiourea etch, plain reflected light.

Plate 8c    Specimen No. 15    Scale: 160x

Hexagonal and monoclinic pyrrhotite grains in massive ore: thiourea etch, plain reflected light.
Plate 9a  Specimen No. 13  Scale: 250x

Typical pyrrhotite showing no alteration to marcasite. Pyrrhotite alteration begins with accentuation of basal cleavage: unetched surface, plain reflected light.

Plate 9b  Specimen No. 13  Scale: 200x

Partial alteration of pyrrhotite to marcasite: unetched surface, plain reflected light.

Plate 9c  Specimen No. 13  Scale: 160x

Pyrrhotite is completely altered to marcasite. Remnant basal cleavage of pyrrhotite is visible in marcasite: unetched surface, plain reflected light.
massive marcasite is present around pyrite. Relict pyrrhotite basal cleavage is common in marcasite (Plates 8b and 8c).

All marcasite is a result of either iron enrichment of pyrrhotite or minor alteration of pyrite. The alteration of pyrrhotite to pyrite involves a negative volume change of about 1 per cent (Yund and Hall, 1970). The transformation of marcasite to pyrite results in a volume reduction of about 2.1 per cent (Fleet, 1970). Using these values, the alteration of pyrrhotite to marcasite involves a positive volume change of about 1.1 per cent. The volume change would not be the controlling factor in this reaction. The alteration of pyrrhotite to marcasite begins with a marked accentuation of the basal cleavage of pyrrhotite (Vokes, 1963). Further alteration results in the appearance of marcasite. Conditions of low pH, low Eh and low temperature are conducive to this alteration of pyrrhotite (Ramdohr, 1969 and Vokes, 1963). The amount of alteration of pyrrhotite to marcasite has no apparent pattern throughout the ore body. Pyrite shows only minor alteration to marcasite along fractures.

5.2.8 Sulfosalts: Boulangerite, bournonite, and tetrahedrite are the sulfosalt minerals present in the ore. Sulfosalt content up to 3 volume per cent has been observed. The presence of sulfosalts in galena is a ubiquitous feature of this ore body (Plates 10a, 10b and 11a), although bournonite and tetrahedrite do occur as larger grains isolated from galena (Plates 10c and 11b). Boulangerite occurs exclusively in galena as anhedral grains less than 0.1 mm long. In galena, bournonite can be distinguished from boulangerite by its color, slightly lower
Plate 10a  Specimen No. 16  Scale: 63x

Sulfosalts (light grey) occur as irregular grains in galena (white) associated with granular sphalerite (medium grey): unetched surface, plain reflected light.

Plate 10b  Specimen No. 13  Scale: 250x

Tetrahedrite and minor bournonite or boulangerite occurs in galena. Sphalerite and pyrrhotite present: unetched surface, plain reflected light.

Plate 10c  Specimen No. 17  Scale: 50x

Single grain intergrowth of tetrahedrite and galena in a granular sphalerite and galena matrix. Note that galena in the intergrowth is in etch continuity: thiourea etch, plain reflected light.
Plate 11a Specimen No. 18 Scale: 100x

Diagnostic lamellar twinning of bournonite in galena: unetched surface, plain reflected light, partially crossed nicols.

Plate 11b Specimen No. 19 Scale: 100x

Bournonite grains with chalcopyrite. Note twinning in bournonite: thiourea etch, plain reflected light.

Plate 11c Specimen No. 13 Scale: 200x

Bournonite and galena occur with arsenopyrite aggregates: unetched surface, plain reflected light.
reflectivity and by its diagnostic lamellar twins (Plate 11a). Away from galena, bournonite is of sufficient grain size (up to 0.5 mm long) that positive optical identification can be made. Bournonite is an accessory mineral in chalcopyrite- and arsenopyrite-rich areas (Plate 11b and 11c). Tetrahedrite occurs as small grains (less than 0.05 mm long) in galena (Plate 10b) and as distinct intergrowths with 20 to 40 percent galena up to 0.8 mm long (Plate 10c).

By means of quick comparison with standards of known composition on the non-dispersive spectrometer, boulangerite was found to contain major quantities of sulfur, antimony and lead (Figure 7), while bournonite contains major quantities of sulfur antimony, copper and lead. At least some bournonite contains considerable iron (Figure 7). By comparison, tetrahedrite was found to contain major quantities of sulfur, antimony, silver, iron and copper (Figure 7).

5.2.9 Ilmenite: Ilmenite, containing minor amounts of manganese and chromium, was identified in one polished surface of a silicate-rich area in the ore body. Ilmenite shows replacement textures with sphene (Plate 12a) although it could not be determined which was the primary mineral. No magnetite was found with the ilmenite.

5.2.10 Gold: One grain of gold less than 0.05 mm long was identified in the ore. It occurs within a quartz grain of a small siliceous inclusion.

5.2.11 Gudmundite: Gudmundite was not identified with the microscope but three grains (<0.05 mm long) in close proximity to one another were found with the microprobe using the non-dispersive detector.
Identification of Minor Phases with Non-dispersive Spectrometer

**Figure 7**

Counts per channel (40 sec.)

**Energy (KeV)**

- **Bournonite**
  - Hanson Lake 65-3 399'
  - Standard

- **Tetrahedrite**
  - Hanson Lake 65-3 399'
  - Standard

- **Boulangerite**
  - Hanson Lake 65-3 401.5'
  - Standard

- **Gudmundite**
  - Hanson Lake 65-3 401.5'
  - Standard
Plate 12a  Specimen No. 17  Scale: 32x

Ilmenite and sphene show a replacement texture: un-etched surface, plain reflected light.

Plate 12b  Specimen No. 10  Scale: 1x

Large quartz-muscovite schist inclusion in massive ore. Also large quartz knot, arsenopyrite aggregate and small wall-rock inclusions.
Identification of this mineral is based on the element peaks given by the mineral (Figure 7) and by the reflectivity, color and polishing hardness as could be determined with the limited optics on the microprobe. The mineral occurs as distinct grains interstitial to sphalerite and galena.

5.3 Gangue

The massive ore has a near-constant gangue content (20 - 30 volume per cent) throughout, and local variations can be attributed to the frequency of generally large wall-rock inclusions (Plate 12b). The gangue consists of quartz knots (Plate 12b), muscovite, and quartz-muscovite-sericite knots (Plate 13a and 13b), some carbonate, and minor individual mica grains within massive sulfides. The quartz-muscovite schist inclusions range in size from 2 cm to 25 cm long (Plate 1 and 12b). Sericite and K-feldspar are common in the inclusions and the biotite content ranges from zero to 10 volume per cent. Schistocity in some inclusions near the wall rock has the same orientation as that of the wall rock although most have been mechanically rotated. The foliation in the smaller inclusions is typically bent along the margins of the inclusion or highly contorted throughout (Plate 13c). Plagioclase phenocrysts, highly altered to sericite and some calcite, have been noted in these inclusions. The similarity of these plagioclase phenocrysts to those of the soda-rhyolite porphyry rocks suggests that the inclusions were originally footwall rocks. There is no apparent sulfide enrichment in the larger inclusions. Quartz knots up to 4 cm long are common
Plate 13a  Specimen No. 9  Scale: 25x

Muscovite knot in massive sulfide ore (sulfides - black). Also typical quartz gangue: unetched surface, plain transmitted light.

Plate 13b  Specimen No. 14  Scale: 16x

Quartz-muscovite-sericite knot in massive sulfide ore (sulfides - black): unetched surface, plain transmitted light.

Plate 13c  Specimen No. 21  Scale: 10x

Contorted foliation in small quartz-muscovite inclusion: unetched surface, plain transmitted light.
throughout the ore. These knots consist of large recrystallized quartz grains (<5 mm) which show polygonal boundaries (Plate 14a). Major sulfide minerals occur as minor inclusions within these knots (Plate 4a). No quartz veins were observed in the ore body although local quartz-galena-rich areas occur throughout the ore. Carbonate minerals (calcite and minor siderite) are common interstitial gangue minerals. A vein of a carbonate mineral less than 1.0 mm wide cut the massive ore on one polished surface. Solitary muscovite grains are common within the massive sphalerite. The chlorite content of the gangue is similar to that of the whole Hanson Lake region. Normally, chlorite occurs as a trace mineral replacing biotite. Locally, chlorite content of the wall rock increases to 10 volume per cent.

Textural evidence of mechanical deformation of the gangue in the sulfide matrix is present in the ore. Sulfides (mainly galena) act as marker horizons for intricate minor folding in silicate inclusions (Plate 14b). Highly contorted swirl textures of muscovite, quartz and sulfide are common. In narrow ore sections, foliation of large inclusions of wall rock show all degrees of variation in orientation from that of the wall-rock foliation. Large, rounded quartz knots consisting of large polygonal grains indicate that at least the quartz gangue has been recrystallized (Plate 14a).

5.4 The Alteration Envelope

The alteration envelope is that portion of the wall rock about the ore body that differs from the regional country rock. The term
Plate 14a  Specimen No. 21  Scale: 10x

Large polygonal quartz grains in quartz knot. Half of quartz knot shown. (sulfides - black): unetched surface, transmitted light, partially crossed nicols.

Plate 14b  Specimen No. 17  Scale: 50x

Galena as marker bed for contorted deformation in gangue: unetched surface, plain reflected light.
Plate 14
envelope is used because of the general enveloping nature of the alteration that has been emphasized by drill-hole information below and to the north and south of the ore (Figure 6).

On the footwall, from country rock to the massive ore, the alteration is marked by a decreased number of phenocrysts (mainly plagioclase), an increased amount of muscovite, quartz, and sericite, and an increased amount of shearing. On the hanging wall, from country rock to the massive ore, the alteration is marked by an increased amount of muscovite which is usually in the form of segregated bands, and an increased amount of shearing.

Quartz-muscovite schist makes up most of the alteration which is generally confined to the footwall of the ore body. The schist is accompanied by considerable shearing and silicification. Biotite content of the alteration zone and of the country rocks is the same (<4%). Chloritization is absent from the alteration except as a minor replacement of biotite which is a regional feature of the area. Sericite is present throughout the wall rock although locally in the ore zone it attains 20 volume per cent. Plagioclase phenocrysts are highly altered to sericite and some calcite. Their similarity to those of the soda-rhyolite porphyry rocks suggest that the schist is altered soda-rhyolite porphyry rocks. Massive fuchsite lenses (<1 foot thick) that contain pyrite and galena along foliation planes occur intermittently along the immediate hanging wall and footwall. Minor fuchsite lenses are also found away from the ore in narrow shear zones. Individual fuchsite grains could not be identified from muscovite because of the subtle colour
difference between fuchsite and muscovite. Disseminated pyrite and a trace of chalcopyrite occur throughout the alteration. Garnet porphyroblasts similar to those of the country rocks occur up to the contact with the massive ore. Siderite and sphene have been noted within the alteration envelope. Narrow bands of highly contorted and brecciated massive pyrite (<1 foot wide) occur on the immediate hanging wall and footwall (Plate 15a). Vertical folds in the wall rock with an amplitude less than 10 feet have been reported. The author observed similar folds with an amplitude less than 3 feet in the wall of a mined-out stope. Minor folds with galena and arsenopyrite concentrated in the hinge region were observed near the ore (Plate 15b).
Plate 15a Specimen No. 22 Scale: 1x
Contorted and brecciated pyrite in the wall rock.

Plate 15b Specimen No. 23 Scale: 1x
Galena and arsenopyrite concentrated in the hinge region of small fold in wall rock.
A triple point measurement study was carried out on the ore body in order to add some understanding to the recrystallization of the ore for which there is much textural evidence. Most sphalerite shows deformation (coherent) twins (Plate 16a) and deformed twins (Plate 16a). The sphalerite grains show many signs of recovery from a state of high energy induced by the deformation. Some sphalerite grains show a progressive intensification of polygonization by growth of sub-grains that destroy twins (Plates 16b and 16c). Bent twins show formation of sub-grain boundaries at those intervals that are necessary to reduce the curvature of the strained twins (Plate 16a). "Foam structures" similar to those described by Stanton and Gorman (1968), which are indicative of fully annealed grains are found in galena and sphalerite (Plates 17a and 17b).

The study was carried out to determine the degree of mechanical equilibrium along the length and across the width of the ore body. Any consistent variation in mechanical equilibrium may be an expression of the deformation of the ore body such as shearing along one wall. For example, variations may indicate inhomogeneity of stress in the ore body. This inhomogeneity may be related to structural features within the ore. Mechanical equilibrium may be related to certain mineralogical associations, such as sphalerite in arsenopyrite-rich areas compared to typical sphalerite ore.

Sphalerite was chosen for this study because it is the major
Plate 16a  Specimen No. 26  Scale: 250x

Coherent twins in sphalerite. Note the beginning of formation of subgrain boundary at the most strained point in the grain: thiourea etch, plain reflected light.

Plate 16b  Specimen No. 26  Scale: 250x

Polygonization destroys twins in sphalerite: thiourea etch, plain reflected light.

Plate 16c  Specimen No. 26  Scale: 250x

Intensified polygonization results in the formation of subgrain boundaries which destroy twin structures. Note remnant twins in bottom left corner: thiourea etch, plain reflected light.
Plate 17a  Specimen No. 24  Scale: 250x

Sphalerite grains meet at triple points that measure approximately 120°: thiourea etch, plain reflected light.

Plate 17b  Specimen No. 25  Scale: 630x

Triple-point interfaces in sphalerite: thiourea etch, plain reflected light, oil immersion.

Plate 17c  Specimen No. 9  Scale: 160x

Chalcopyrite grains at sphalerite triple-point junction: thiourea etch, plain reflected light.
sulfide mineral of the massive ore. Sphalerite with normal grain size (<0.3 mm long) was used because it is the most abundant textural type. A total of 9 samples from 3 drill-core intersections were measured. Samples across the width of the ore body from drill hole 65-3 were measured to determine any variation from footwall to hanging wall. Samples from drill holes 65-29 and 65-13 were measured to indicate any longitudinal variations. The two samples from 65-13 represent forks of a bifurcation in the ore.

6.1 Surface Free Energy and Recrystallization

In general, grains meet at triple-point junctions. During grain growth and recrystallization, grain boundaries adjust to a configuration which minimizes surface free energy (Smith, 1964). The lowest surface free energy occurs when requirements for the following equation (according to Figure 8) are fulfilled,

\[
\frac{\gamma_1}{\sin \theta_1} = \frac{\gamma_2}{\sin \theta_2} = \frac{\gamma_3}{\sin \theta_3}
\]

where \(\gamma_1, \gamma_2\) and \(\gamma_3\) are interfacial free energies and \(\theta_1, \theta_2\) and \(\theta_3\), are the corresponding angles between grain boundaries (Stanton, 1964).

Figure 8. Relationship between interfacial free energies and triple points in a single phase matrix (after Stanton, 1964)
In a single phase system, \( Y_1 = Y_2 = Y_3 \) and equilibrium occurs when all interfacial angles are 120°. A random plane through an opaque aggregate of completely annealed grains will not always be normal to the plane of the triple junction. Stanton and Gorman (1968) expressed this error on a frequency distribution as a standard deviation of 9° about a sharp peak at 120°.

6.2 Analytical Method

Polished surfaces were etched by immersion in a thiourea solution for 40 seconds at 75° to 80° C. Following etching, some surfaces were buffed lightly on a cloth with 0.05 micron gamma alumina to remove any deposits that obscured the surface features. Statistical sampling of angles on a polished section was accomplished by measuring the angles in the field of view at x640 magnification along N - S traverses of the stage at 2 mm intervals. Sphalerite triple points are shown in Plates 16c and 17b. The relative states of equilibrium of each section measured is presented in the form of standard deviation from 120° (Table 1). By calculating the standard deviation for 180 interfacial angles at intervals of 30, it was found that the standard deviation for 120 angles was representative of the specimen. The small grain size of sphalerite and the high number of triple points containing galena and chalcopyrite grains (Plate 17c) greatly increased measurement time. Calculation time was greatly reduced by using a program for the WANG calculator that gave mean, variance, and standard deviation for each specimen.
<table>
<thead>
<tr>
<th>Drill Hole*</th>
<th>Sample Location</th>
<th>Standard Deviation from 120°</th>
<th>Sample Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>65-3</td>
<td>Footwall</td>
<td>18.1°</td>
<td>Typical ore sample (sph = 70%)</td>
</tr>
<tr>
<td></td>
<td>2' from footwall</td>
<td>18.3°</td>
<td>Typical ore sample (sph = 70%)</td>
</tr>
<tr>
<td></td>
<td>6' from footwall</td>
<td>13.6°</td>
<td>Typical ore sample (sph = 70%)</td>
</tr>
<tr>
<td></td>
<td>Hanging wall (8' from footwall)</td>
<td>16.1°</td>
<td>Typical ore sample (sph = 70%)</td>
</tr>
<tr>
<td>65-29</td>
<td>Footwall</td>
<td>12.8°</td>
<td>Typical ore sample (sph = 70%)</td>
</tr>
<tr>
<td></td>
<td>1.5' from footwall</td>
<td>12.9°</td>
<td>Typical ore sample (sph = 70%)</td>
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<tr>
<td></td>
<td>Hanging wall (3' from footwall)</td>
<td>15.5°</td>
<td>Lower sphalerite content and higher galena content than 65-3.</td>
</tr>
<tr>
<td>65-13</td>
<td>Footwall bifurcation</td>
<td>11.0°</td>
<td>Similar to 65-3</td>
</tr>
<tr>
<td></td>
<td>Hanging wall bifurcation</td>
<td>19.4°</td>
<td>Arsenopyrite-rich ore.</td>
</tr>
</tbody>
</table>

* Location of drill holes on Figure 4.
6.3 Results

Measurements of 9 samples show a variation in standard deviation from 11.0° to 19.4° (Table 1). Both extremities of the variation occur in the same drill-hole intersection. There is no apparent pattern to this variation either across the width or along the length of the ore. The standard deviation of 9°, for complete mechanical equilibrium given by Stanton and Gorman (1968), is for materials that on a microscopic scale were very pure. Small amounts of impurities localized at triple-point junctions are known to impede grain boundary movement on metals, and this undoubtedly holds for sulfides (*ibid*, p. 919). The specimens measured contained, at most, 70 per cent sphalerite. The large amount of impurities (galena, chalcopyrite, pyrrhotite, arsenopyrite, pyrite, marcasite, and wall-rock inclusions) would cause a variation from the equilibrium values for a single-phase matrix. The random variation in triple-point measurements may be a reflection of the amount of impurities in the polished surfaces although a direct correlation is not evident from the data in Table 1.

If there has been a plane of flattening in the sulfide aggregate, a variation in the range of triple-point values will occur with a change in orientation of the polished surface; the maximum range will occur on surfaces normal to the plane of flattening (Stanton and Gorman, 1968). If the ore body has been sheared, as the textural evidence indicates, then a variation in the triple-point values would be expected because the polished sections have an unknown but wide range of orientations.
7. MINERAL COMPOSITIONS

7.1 Analytical Techniques

7.1.1 Microprobe conditions: Quantitative analyses were carried out on a MS64 Electron Microprobe X-ray Analyzer. Probe conditions were a beam voltage of 25 KeV, a beam current of 100 microamps, and a specimen current, at all times, of 50 nano-amps (1 nano-amp = $1 \times 10^{-9}$ amp). Cobalt was detected on a $(1120)$ quartz crystal, manganese and nickel on a $(10\overline{1}1)$ quartz crystal and iron on a P.E.T. crystal.

7.1.2 Analytical technique for obtaining sphalerite data: The two standard curves of FeS and MnS contents of sphalerite were calibrated using natural standard samples supplied by Dr. R.G. Arnold of the Saskatchewan Research Council (Appendix, Table 5). To minimize the effects of unhomogeneity in the standards and scatter variations within individual probe readings, the following procedure was adopted: six grains on each standard, four points on each grain, and three replicate analyses at each point were obtained. The counting time for all analyses was 40 seconds except for background determinations which were taken from twelve 400-second counts on three standards. All pulse-count data was automatically recorded on computer cards. Calculations for the 12 standards were done using a computer program which corrected for drift from a monitor point run before and after each standard. The standard curves were plotted manually and the resulting slopes were used in the computer program which analyzed the Hanson Lake sphalerite.

Wherever possible, three replicate analyses for three points
on three grains were obtained for each mineralogical association of Hanson Lake sphalerite that was present on each of the analysed polished surfaces. A computer program (supplied by J.W.J. Smith of the Saskatchewan Research Council) executed the necessary calculation with data on computer cards to produce individual point analyses of weight per cent FeS and weight per cent MnS, grain averages, and polished surface averages for each mineralogical association of sphalerite. Corrections for drift were made for each polished surface from counts taken before and after each polished surface on the single monitor point used throughout the work. The monitor grain was run approximately every 90 minutes during operation of the microprobe. Standard deviation calculations for each mineralogical association of sphalerite on each polished section were also produced by the computer program. Apparent erroneous analyses (those with deviations greater than approximately 50% of average grain analyses in a section) were discarded during actual probe work and after computer calculations. Approximately 2 per cent of the analyses were discarded during the probe work and one analysis was discarded after computer calculations.

7.1.3 Analytical techniques for determination of Co:Ni ratios of pyrrhotite: A standard curve was calibrated using three natural standard specimens supplied by the Department of Geology, University of Saskatchewan, Saskatoon, Saskatchewan. Two replicate analyses for two points on two grains of each standard were sufficient to calibrate the curve. A counting time of 40 seconds was used for both the standards
and the samples. One 100-second count was made on each of two grains of each standard and on one Hanson Lake sample for calculating backgrounds. A monitor grain with 0.28 weight per cent nickel and 0.27 weight per cent cobalt was run before and after each standard to insure that relatively constant conditions were maintained. Subsequently, no correction was made for drift. Two replicate counts on one point from each of four grains were analyzed in each Hanson Lake sample. Only one point on each grain was analyzed because of the small grain size of pyrrhotite. All mathematical calculations were done with the help of a calculator and the standard curve was drawn manually.

7.1.4 Analytical technique for comparison of cobalt and nickel in pyrite: Two textural types of pyrite were analyzed for nickel and cobalt using the pyrrhotite standards. This method was satisfactory because only relative amounts of cobalt and nickel were needed to indicate possible chemical differences between the two types of pyrite.

7.1.5 Analytical techniques for determination of tetrahedrite composition: The Hanson Lake tetrahedrite was compared to a chemically analyzed sample of Keno Hill tetrahedrite by comparing net counts per second obtained from major element peaks. The analysis consisted of three replicate 40 second counts on three points on three grains of each sample. A good estimate of the copper, antimony, silver, iron, zinc, lead, and arsenic content of the Hanson Lake tetrahedrite was obtained by this method.
7.2 Results

7.2.1 Sphalerite composition: In order to determine any variation in sphalerite composition in the ore body, seven ore sections, four of which had hanging wall, center, and footwall samples, were analyzed. One sample was representative of a narrow massive ore section 600 feet north of the ore body proper. The following six mineralogical associations of sphalerite were analyzed for FeS and MnS content: 1) sphalerite with pyrrhotite dominant over marcasite on a polished surface, 2) massive sphalerite with marcasite dominant over pyrrhotite on the polished surface, 3) sphalerite grains completely enclosed in quartz, 4) sphalerite grains as inclusions in pyrite, 5) abnormally small sphalerite grains (<15 microns), and 6) abnormally large sphalerite grains (>200 microns).

There is no apparent spatial variation in FeS and MnS content of sphalerite throughout the ore body. Two mineralogical associations of sphalerite have chemical differences. The histogram of the weight per cent FeS of sphalerite shows a bimodal distribution with peaks corresponding to massive sphalerite with 9.5 to 10.0 weight per cent FeS and sphalerite inclusions in quartz with 12.0 to 12.5 weight per cent FeS (Figure 9). The standard deviation of the sphalerite inclusions (>0.5 and <2.5 wt. % FeS) is much higher than that of the massive sphalerite (<0.3 wt. % FeS). The high standard deviation of the sphalerite inclusions may be a result of some sphalerite that appears to be inclusions in two dimensions, actually are embayments in quartz in the third dimension or a result of sphalerite inclusions occurring along quartz grain
Total 408 grains

<table>
<thead>
<tr>
<th>No of samples</th>
<th>mean</th>
<th>var</th>
<th>std dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>272</td>
<td>10.06</td>
<td>1.70</td>
<td>0.41</td>
</tr>
<tr>
<td>83</td>
<td>11.65</td>
<td>0.90</td>
<td>0.95</td>
</tr>
<tr>
<td>53</td>
<td>12.17</td>
<td>0.66</td>
<td>0.81</td>
</tr>
</tbody>
</table>

- Massive sphalerite
- Sph. inclusions in quartz
- Sph. inclusions in pyrite

Weight per cent FeS in sphalerite
boundaries. The result would be a difference in FeS values similar to the maximum standard deviation for the sphalerite inclusions. An alternative cause would be the incorporation, and hence isolation, of sphalerite in quartz at different stages of ore emplacement of recrystallization. The result would be a wider range of FeS values in quartz inclusions than in the massive ore.

MnS content of sphalerite is uniform throughout the ore but is slightly higher in a narrow massive sulfide section 600 feet north of the ore body (Figure 10). The high MnS content coincides with the solitary observed occurrence of a Mn-rich carbonate.

The range of modes of FeS in sphalerite for 12 ore deposits in the Flin Flon and Lynn Lake area is three mole per cent to 15 mole per cent FeS (personal communications, S. Sangameshwar). This corresponds to a range of 2.8 weight per cent to 13.9 weight per cent. The mode of FeS content of Hanson Lake sphalerite occurs within this range (Figure 9).

7.2.2 Co:Ni ratios of pyrrhotites: Cobalt and nickel contents of pyrrhotite were measured on four representative samples of the ore body. Cobalt content ranges from 0.011 weight per cent to 0.024 weight per cent. Nickel ranges from undetectable amounts to 0.034 weight per cent. Co:Ni ratios for these samples range from 0.7 to greater than 1.57 (Table 2). Arnold (1968) analyzed Hanson Lake pyrrhotite with a Noralco vacuum-path x-ray spectrometer. His values (Co - 0.004 wt. % and Ni - 0.006 wt. %) give a Co:Ni ratio of 0.67.

The nickel values agree with the range of values given by
Total 408 grains

- Sph. in ore body
- Sph. 600' north of ore body

<table>
<thead>
<tr>
<th>mean</th>
<th>var</th>
<th>std dev</th>
<th>No of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.30</td>
<td>0.49</td>
<td>0.07</td>
<td>381</td>
</tr>
<tr>
<td>0.61</td>
<td>0.02</td>
<td>0.01</td>
<td>27</td>
</tr>
</tbody>
</table>

Figure 10

WEIGHT PER CENT MnS IN SPHALERITE
## PYRRHOTITE DATA

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Co Content Wt. %</th>
<th>Ni Content Wt. %</th>
<th>Co/Ni Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>65-3 396'</td>
<td>0.020</td>
<td>0.015</td>
<td>1.34</td>
</tr>
<tr>
<td>65-29 400'</td>
<td>0.011</td>
<td>0.015</td>
<td>0.73</td>
</tr>
<tr>
<td>65-10 235'</td>
<td>0.011</td>
<td>&lt;0.007</td>
<td>&gt;1.57</td>
</tr>
<tr>
<td>C - 5</td>
<td>0.024</td>
<td>0.034</td>
<td>0.71</td>
</tr>
</tbody>
</table>

## PYRITE DATA

<table>
<thead>
<tr>
<th>Pyrite in Massive Ore</th>
<th>Wall Rock Pyrite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample No.</td>
<td>Co* Ni*</td>
</tr>
<tr>
<td>C - 5</td>
<td>2.7 0</td>
</tr>
<tr>
<td>C - 2</td>
<td>2.3 0</td>
</tr>
</tbody>
</table>

Table 2  
COBALT AND NICKEL DATA FOR PYRITE AND PYRRHOTITE
Faulkner (1969) and Sangameshwar (1968) for 'economic' deposits in the Flin Flon area. The cobalt values are similar to those of the Flin Flon and Stall Lake mines but are much lower than those of the Coronation and Birch Lake mines (Faulkner, 1969). The Co:Ni ratios (although half are less than one) would place the ore body in the 'economic' deposits when compared with the ratios of the 'barren' deposits of Faulkner (1969) which are typically less than 0.5.

7.2.3 Relative cobalt and nickel contents of pyrite in massive ore and in wall rock: Pyrite porphyroblasts in the massive ore and massive pyrite on the wall rocks have similar nickel and cobalt contents (Table 2). The nickel content is probably in the same range as that of the pyrrhotite. Cobalt in either textural type of pyrite could not be detected with the probe (detection limit = 0.006 wt. % Co).

7.2.4 Tetrahedrite composition: The silver grade in the ore ranged from 2 to 56 ounces per ton with a normal range of 3 to 6 ounces. Tetrahedrite (freibergite, the silver-bearing variety) was the only silver-bearing mineral observed in the ore. The analyses indicate that the silver content of freibergite possibly exceeds 10 weight per cent (Table 3). Copper, antimony, iron, zinc, lead and arsenic contents are also compared to the Keno Hill standard (Table 3).

Silver was not detected in any of the other sulfosalts or in galena (detection limit = 0.01 wt. % Ag).
**MICROPROBE ANALYSIS OF HANSON LAKE TETRAHEDRITE**

<table>
<thead>
<tr>
<th>Elements</th>
<th>Standard*</th>
<th>Net Counts per Sec.</th>
<th>Analysis</th>
<th>Net Counts per Second Average Variations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu</td>
<td>1793</td>
<td>22.2%</td>
<td>1811</td>
<td>1846-1751</td>
</tr>
<tr>
<td>Sb</td>
<td>262</td>
<td>22.0%</td>
<td>263</td>
<td>267-257</td>
</tr>
<tr>
<td>Ag</td>
<td>213</td>
<td>19.6%</td>
<td>183</td>
<td>188-179</td>
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<tr>
<td>Fe</td>
<td>67</td>
<td>4.2%</td>
<td>82</td>
<td>83-78</td>
</tr>
<tr>
<td>Zn</td>
<td>22</td>
<td>2.0%</td>
<td>13</td>
<td>15-13</td>
</tr>
<tr>
<td>Pb</td>
<td>8</td>
<td>0.24%</td>
<td>12</td>
<td>13-11</td>
</tr>
<tr>
<td>As</td>
<td>1</td>
<td>0.12%</td>
<td>1</td>
<td>(0-2)°</td>
</tr>
</tbody>
</table>

* Standard from Keno Hill

° Average of each grain was 1 count per second, but point counts varied from 0 to 2.

Table 3
8. MAJOR ORE METAL VARIATIONS IN THE ORE

Copper, lead, zinc and silver contents of the massive ore were contoured on separate N-S longitudinal mine sections in order to define any significant metal distributions (Figures 11, 12, 13, 14, 15, and 16). Assay values of 28 drill intersections obtained from Western Nuclear Mines Ltd. as well as analyses of three underground sections were used for the contours. Twenty-three samples, representing three ore sections sampled underground by the author, and two ore intersections from Western Nuclear drill core, were assayed using atomic absorption methods by the Saskatchewan Research Council (Appendix, Table 5). The two drill core sections were sampled and analysed to check the validity of assay values as they were presented on drill-core logs. The 10 per cent difference between values is not unreasonable considering that representative core samples rather than chip samples of the whole intersections were analysed. However, the zinc value for one ore section was not used because it appeared to be anomalously high in comparison to a nearby core value.

The zinc contours show that the zinc content of the ore increases towards the center of the ore body (Figure 11). The lead contours show a similar pattern in the southern half of the ore body while lead content in the northern half increases with depth (Figure 12). Contours of the Zn:Pb ratios in the northern portion of the ore body run parallel to the plunge of regional structures (Figure 13). Silver contents of both the massive ore section and the total mineralized
LONGITUDINAL PROJECTION OF DISTRIBUTION OF ZINC IN ORE BODY
(average wt %/ft across width of massive ore)
LONGITUDINAL PROJECTION SHOWING DISTRIBUTION OF LEAD IN ORE BODY
(average wt %/ft across width of massive ore)
LONGITUDINAL PROJECTION SHOWING DISTRIBUTION OF Zn:Pb RATIOS IN ORE BODY

(average ratio over width of massive ore)
LONGITUDINAL PROJECTION SHOWING DISTRIBUTION OF SILVER IN ORE BODY
(average oz/ton/ft across width of massive ore)
LONGITUDINAL SECTION SHOWING CONTOURS OF SILVER IN ORE BODY
(oz/t/t/ton Ag over width of shear zone)
LONGITUDINAL PROJECTION SHOWING DISTRIBUTION OF COPPER IN ORE BODY
section (shear zone) were contoured (Figure 14 and 15). Both contour sections were deemed necessary to determine any variation that could result from possible silver enrichment in the wall rock. Some higher silver values over the total shear zone in the northern portion of the ore body indicate that silver occurs outside of the massive ore lens. Enrichment of silver in a diorite band in the southern portion of the ore body was reported but this feature does not show up on the contours. Both contour sections for silver show an alignment of contours with the plunge of regional structures (Figure 14 and 15). Copper content of the ore increases towards the center of the ore body (Figure 16). Analysis of the three handsampled ore sections show a concentration of copper on the hanging wall (Appendix, Table 6). This feature is not apparent in drill core assays.

The copper and, to some extent, the zinc contours show a correlation with thickness of the ore (Figures 11 and 16 and 17). No correlation is apparent on comparing the lead, silver, and zinc:lead ratio contour sections (Figures 12, 13, 14 and 15) with the isopach map (Figure 17).

The 23 ore samples were also assayed for manganese, cobalt, nickel, arsenic and cadmium (Appendix, Table 5). Manganese and cadmium show a complimentary relationship to zinc suggesting that these elements are bound up in the sphalerite structure. Arsenic shows a great variation (0.34 wt. % As - 17.0 wt. % As) because of the presence of numerous large aggregates of arsenopyrite throughout the ore (Plate 12b). The insoluble content of the assayed sections showed no preference for
Figure 17

ISOPACH MAP OF MASSIVE ORE

Legend:
- Drill core information
- Values from stope maps
- Contours (Contour interval = 2 ft)

Scale: 1" = 170'

Lake surface
Depth (ft)
0
100
200
300
400
500
600
hanging wall or footwall positions in the ore. The high insoluble frac-
tion in the hanging wall and/or footwall samples are probably a result
of samples having been taken too close to the wall rocks. Lead in all
assay data generally shows a gradational content towards the wall rock
but never consistently towards either the hanging wall or footwall.
Although silver-bearing tetrahedrite is associated with galena in the
ore, a comparison of contours in Figures 12, 14, and 15 indicates that
the relationship is not a quantitative one.

Cobalt and nickel contents of the massive ore samples assayed
are generally less than 0.01 weight per cent (Appendix, Table 6).
There is no correlation between the cobalt and arsenic contents of the
massive ore. The Co:Ni ratios range from less than 0.2 to 20. More
than half of the ratios are less than one. In massive sulfide deposits
where pyrite, pyrrhotite and chalcopyrite are the major sulfides, the
Co:Ni ratio of the ore body as a whole is usually greater than one
(Faulkner, 1969). The low Co:Ni ratios of the Hanson Lake ore body in
comparison to others in the Flin Flon area may be related to basic dif-
fences between the Hanson Lake deposit and the Flin Flon group of
deposits as discussed on pages 86 and 87.
9. DISCUSSION

9.1 Introduction

The Hanson Lake ore body is a small lens of massive, homogeneous sphalerite-galena ore. The ore body is conformable with lithology and with regional structural trends. The area has been metamorphosed to the amphibolite facies (Coleman et al., 1970) which caused recrystallization of the host rocks. Textural and chemical evidence of recrystallization and deformation in the ore indicates that the ore body had an extensive post-depositional history. Although much evidence of ore emplacement may have been obliterated, a determination of the relationship of the ore body to the structural history of the area may help to discriminate between several alternatives for the origin of the ore.

9.2 Textural and Chemical Features of the Hanson Lake Ore Deposit

9.2.1 Ore textures: Textural evidence of deformation is common in the ore. A decrease in grain size of sphalerite around silicate inclusions (Plate 3a) and the halo of sphalerite about arsenopyrite aggregates (Plate 5b) suggest that the ore has undergone deformation. Shear planes delineated by small galena and pyrrhotite grains (Plate 5a) are common with the above-mentioned features. The internal structure of sphalerite grains shows the results of strain. Deformation twins (Plates 16a and 16b) and deformed twins (Plate 16a) are common features of the ore. Polygonization (Plate 16b), formation of subgrain boundaries at sharp bends in twins (Plate 16a) and destruction of deformation twins by
growth of subgrains (Plate 16c) indicate that some lattice reorganization to reduce free energy has taken place in sphalerite.

Triple-point measurements indicate that the sphalerite grains are presently near mechanical equilibrium. The variation in the standard deviation values (11.0° - 19.4°) may be the result of the high number of impurities in sphalerite, or an effect of the random orientation of the polished surfaces. The random and small amount of variation in the values throughout the ore body, suggests that deformation and/or subsequent recrystallization in the ore was homogeneous.

Sphalerite and galena both occur in two grain-size ranges. There is no evidence in either phase to show that one grain-size type has grown at the expense of the other. There is, however, an apparent correlation between grain size and the amount of mixing of the two phases. Large sphalerite grains occur where galena is virtually absent and where the two phases are segregated. Large galena grains occur where the two phases are separate and where galena is the major sulfide phase such as in the hinge of minor folds (Plate 15b).

The grain growth process involves grain boundary migration (Smith, 1964). Grain growth would be most rapid in monomineralic matrices; increasing amounts of impurities (in the Hanson Lake deposit, small galena grains in a sphalerite matrix and vice versa) would hinder the process. The large grain size where sphalerite and galena are segregated would be expected during recrystallization of the ore. The large sphalerite grains within embayments of siliceous inclusions (Plate 5a) may be the result of relatively uninhibited recrystallization in areas
protected from the dynamic aspects of metamorphism.

Two textural types of pyrite exist in the ore body. The massive pyrite in the wall rock is brecciated, severely deformed and contains few, if any, inclusions (Plate 15a). Pyrite in the massive ore appears to be in the form of porphyroblasts. Evidence for the porphyroblastic character of this pyrite is the presence of inclusions of sphalerite, arsenopyrite and siliceous rock within grains and the irregular grain shape. Small pyrite grains in the massive ore scattered about larger grains, appear to be fragments broken off large pyrite porphyroblasts. The two types of pyrite contain similar amounts of cobalt and nickel and, therefore, probably reached chemical equilibrium under the same conditions. If so, recrystallization and brecciation in the wall-rock pyrite may have been paralleled by the growth of pyrite porphyroblasts in the massive ore. The massive wall-rock pyrite may also be in the form of porphyroblasts. Pyrite porphyroblasts in silicous rocks, and particularly in shales, are typically euhedral and contain few, if any, inclusions. Subsequent deformation and brecciation, as illustrated in Plate 15a, would have destroyed all euhedral character of these wall-rock porphyroblasts.

Chalcopyrite typically occurs as small grains along sphalerite grain boundaries and along some twin boundaries. Segregations of chalcopyrite at triple-point junctions, along grain boundaries, and along secondary twin boundaries are typical of deformed sulfides at Broken Hill, New South Wales (Richards, 1966).

Chalcopyrite occurs as pressure shadows about inclusions in
the Hanson Lake ore. McDonald (1967), in his discussion on the effects of metamorphism on sulfide assemblages, commented on the apparent relative ease with which copper can migrate. Walker and Buchanan (1969) found that in a fluid phase, at high temperatures, the relative mobility of sulfides was in the order of lead > zinc > copper. The apparent mobility of copper over lead and zinc in the Hanson Lake ore may indicate that chalcopyrite was involved in solid state transport to dilational features in the stress field set up during regional metamorphism. However, the necessity of conditions of low pH for the transformation of marcasite to pyrite indicates that some fluid phase existed in the ore body. The general lack of evidence for the existence of any appreciable volume of fluid may indicate that only small amounts of intergranular fluid was present in the ore at any time.

Marcasite in the ore forms by sulfur enrichment of pyrrhotite and by alteration of pyrite. Pseudomorphs of marcasite after pyrrhotite occur as bent laths about inclusions in the ore. Although no direct evidence of the mechanical behavior of marcasite is known, its behavior relative to pyrite and pyrrhotite may be gauged by their Vickers Hardness values. Hardness, a function of crystal structure, is the resistance of the structure to mechanical deformation (Berry and Mason, 1954). A quantitative measure of hardness is the Vicker's Hardness number. The value for pyrrhotite is 248 but the value for marcasite (1,113) is very similar to that of pyrite (Cameron, 1961). Pyrite acts in a very brittle manner while pyrrhotite is extremely ductile during deformation (Graf and Skinner, 1970). Because pyrite and marcasite have similar hardness values, they
probably respond in a similar fashion to deformation; therefore, the transformation of pyrrhotite to marcasite probably post-dates deformation of the ore body. This is consistent with Richards' (1966) statement that the formation of second and third generation minerals, such as marcasite and pyrite from pyrrhotite, is typical of metamorphosed and deformed sulfides.

Euhedral arsenopyrite grains have been fractured and displaced (Plate 6b). The interstitial sphalerite does not show any evidence of this fracturing. Richards (1966), in his description of fault zone sulfides at Broken Hill, New South Wales, considered that galena and sphalerite along fractures in brecciated arsenopyrite are indicative of microfractures healed by mechanical movement of sulfides.

9.2.2 FeS and MnS content of sphalerite: The iron and manganese contents of the Hanson Lake sphalerite are within the range of sphalerite compositions from eleven deposits in the Flin Flon and Lynn Lake areas (personal communication, S. Sangameshwar). There are no significant compositional variations of sphalerite with grain size in the Hanson Lake deposit (Table 5) with the exception of the higher iron content in coarse-grained sphalerite that occurs as inclusions in quartz gangue. This quartz gangue occurs as recrystallized knots rather than veins. The occurrence of the inclusions as single large sphalerite grains with chalcopyrite along the sphalerite-quartz interface (Plate 3c) indicates that the sphalerite, as well as the quartz, has been recrystallized, possibly with the expulsion of chalcopyrite from the sphalerite structure.
The two chemically different sphalerites may reflect two generations of mineralization, but considering the metamorphism, and recrystallization of the ore and quartz gangue, it is more likely that sphalerite inclusions in quartz have been shielded and prevented from reaching the same degree of chemical equilibration as unprotected sphalerite in the massive ore.

9.2.3 Cobalt:Nickel ratios of pyrrhotite: Sulfide deposits in the Flin Flon area have been divided into a "barren group", in which copper and zinc content rarely exceeds 0.5 per cent, and an "economic group" that contains relatively large amounts of chalcopyrite and sphalerite in addition to iron sulfides (Byers, Kirkland, and Pearson, 1965). The economic deposits typically have Co:Ni ratios greater than one while ratios of barren deposits are typically less than one (Faulkner, 1964). Cobalt : nickel ratios of Hanson Lake pyrrhotites range from 0.71 to more than 1.57 (Table 2). Bulk ore samples have a range of ratios from less than 0.02 to 20.0. Sixty per cent of the bulk sample ratios are less than one. The range of nickel content of Hanson Lake pyrrhotites is similar to those of the Birch Lake, Cuprus, Stall, Flin Flon and Coronation mines (Faulkner, 1969) and to that of the Osborne Lake mine (Sangameshwar, 1968). However, cobalt content is much lower than that of the other ore bodies cited.

Sangameshwar (1968) attributed the low cobalt content of some Osborne Lake pyrrhotites to the sponging effect of arsenopyrite for cobalt. The high arsenopyrite content (3 vol. % Aspy - 50 vol. % Aspy) of the Hanson Lake ore may be responsible for the low cobalt content and,
thus, for the low Co: Ni ratio of pyrrhotites. There is, however, no correlation between cobalt and arsenic contents of bulk samples (Appendix, Table 6). Faulkner (1969) states that economic deposits as a whole have Co: Ni ratios greater than one. This is not the case for bulk ore samples from Hanson Lake (Appendix, Table 5). It seems possible that a sponging effect of arsenopyrite for cobalt is not responsible for the low ratios of the Hanson Lake pyrrhotites. The economic barren sulfide classification (Byers et al., 1965) and the Co: Ni ratio work (Faulkner, 1964) were applied to deposits where pyrite, chalcopyrite and sphalerite are the major sulfides. Hanson Lake sulfide mineralogy (sphalerite - galena) is basically different and, therefore, may not fit into this classification of ore bodies in the Flin Flon area.

9.2.4 Metal contours: The zinc and copper contours (Figures 11 and 16) and, to some extent, the lead contours, (Figure 12) are generally concentric about the outline of the ore body and show an increasing grade towards the center of the deposit. This suggests that the ore body, despite its small size, is a unit and not an erosional remnant of a larger deposit. The silver contours, however, cut across the outline of the ore (Figures 14 and 15), but the correlation between these contour lines and the plunge of regional structures suggests that major redistribution of the silver within the ore occurred during regional metamorphism. The zinc and copper contours (Figures 11 and 16) show a complimentary relationship to thickness of the ore (Figure 17). This relationship is not apparent in contours of lead, silver, and zinc:lead ratio (Figures 12, 13, 14 and 15). There is, however a correlation between
the plunge of regional structures and contours of silver and lead:zinc ratio (Figures 13, 14, and 15). These contour lines in the northern half of the ore body have a trend that approximates the plunge of regional structures. This correlation suggests that the silver and zinc:lead distribution in the ore may be related to the major stress fields established during regional metamorphism as reflected by the plunge of regional structures. In light of the ore textures and conformable nature of the ore body, this relation appears to have been established as a result of chemical re-equilibration within the ore during metamorphism rather than caused by primary distribution of ore deposition. This may be a function of differential solid state movement of galena relative to sphalerite as, according to Richards (1966), galena is much more responsive to differential stress than sphalerite during deformation. The relationship between sphalerite and ore width may be a primary feature although a similar relationship for copper is probably not primary because of the apparent mobility of copper as shown by pressure shadows of chalcopyrite about inclusions in the ore and by the occurrence of chalcopyrite in fractures in pyrite.

Silver, as a minor element in the ore, is related to lead, a major element, by the typical textural association of tetrahedrite in galena (Plates 10a and 10b). The variation of silver with lead is not immediately evident on comparing the silver and lead contours (Figures 12 and 14 and 15). Silver enrichment in the wall rock is evident on comparing Figures 14 and 15. A diorite band that was in contact with the ore in the southern portion of the mine had a high silver content (<50 oz/ton).
Silver may not, therefore, be associated with the galena in all instances, although it appears so texturally, in the massive ore.

The silver in the Hanson Lake deposit appears to have been redistributed during the high grade (amphibolite facies) of regional metamorphism. The diorite band may have been a suitable trap rock for tetrahedrite and some galena during this redistribution. Henderson (1956) found a correlation between high silver: lead ratios and attenuated synclines at Broken Hill, Australia. McDonald (1967) considers Henderson's information to be indicative of the concentration of silver relative to lead in zones of high stress relief within areas of high deformation or high-grade regional metamorphism. Although it is possible that the silver is genetically related to the diorite band, it is unlikely because this narrow intermittent diorite band was deposited penecontemporaneously with the host rocks and it has no other major sulfide metals associated with it.

9.2.5 Alteration envelope: Mylonitization, development of muscovite, sericitization of feldspars, and silicification, which are all features of retrograde metamorphism and metasomatism, are common in sheared zones in the Hanson Lake area (Coleman et al., 1970). The alteration envelope about the ore body is delineated by similar features; shearing, complete sericitization of feldspar, development of muscovite, and silicification. Minor folds in the wall rocks, some of which contain galena and arsenopyrite (Plate 15b), are similar in style to minor F2 or F3 style folds described by Coleman et al., (1970) along the contact of the soda-rhyolite porphyry about two miles north of the ore body.
It is not known whether the vertical "rolls" fit any of the styles of folds described in the region.

The absence of hydrothermal alteration is a conspicuous feature of the alteration zone. The ore must have been emplaced with no development of ore channels from a source, unless regional metamorphism caused complete obliteration of all traces or such channels. However, even after metamorphism, a chloritic alteration zone, which is common about the recent Japanese deposits (Tatsumi, 1970), the Flin Flon deposits (Byers et al., 1965) and the Noranda deposits (Rosco, 1965), would retain a distinctive mineralogy. For example, the cordierite-anthophyllite rock in the Coronation mine is considered to be a metamorphosed chloritic wall rock alteration (Whitmore, 1969).

Considering the apparent limited extent (Figure 6) and composition of the alteration zone, the ore appears to have been affected by local shearing of the contact between two lithological units during metamorphism. Metasomatic fluids generated in the host rocks during regional metamorphism or solid-state transport in response to deformation may have taken part in the apparent redistribution of copper (chalcopyrite) and silver (tetrahedrite) and the concentration of galena and some arsenopyrite in the hinge regions of minor folds. Whatever transport mechanism was active, it must be consistent with the apparent mobility of copper and silver with respect to lead and zinc.

9.3 Geothermometry

Hexagonal and monoclinic structural forms of pyrrhotite are
present in the Hanson Lake deposit (Plates 8b and 8c). They occur typically as anhedral to subhedral grains along sphalerite grain boundaries although a few subhedral pyrrhotite laths cut across sphalerite and galena grain boundaries. The monoclinic and hexagonal forms usually occur as individual grains (Plate 8c) but hexagonal exsolution lamellae have been observed in a few monoclinic pyrrhotite grains (Plate 8b).

An abundance of natural monoclinic pyrrhotite associated with pyrite or with hexagonal pyrrhotite and pyrite is evidence for an ore deposit having been heated above 304 ± 6° C. (Arnold, 1969). This relationship assumes chemical equilibrium under hydrostatic pressure conditions. Monoclinic pyrrhotite is associated with pyrite in Hanson Lake ore, although in many places, only marcasite pseudo-morphs of pyrrhotite remain in contact with pyrite. This may indicate that at some time temperature within the ore exceeded 304 ± 6° C. Location of pyrrhotite grains along sphalerite grain boundaries is consistent with the apparent recrystallization of the ore. If regional metamorphism is responsible for deformation and recrystallization in the ore, then the pyrrhotite content may be a reflection of the temperature of metamorphism which, defined by Turner (1968, Figure 8-6, p. 366), was greater than 425° C.

The marcasite alteration may indicate temperatures lower than that of the thermal peak of metamorphism. Marcasite is slowly converted to pyrite above 350° C. (Allen et al., 1912, as cited by Ramdohr, 1969), and it has been obtained from controlled oxidation of cubanite by heating above 250° C. (Ramdohr, 1969). Marcasite can
form only under the special conditions of low pH and moderate temperatures (ibid, p. 827). The formation of marcasite postdates recrystallization and deformation of pyrrhotite and, therefore, probably formed at temperatures well below the thermal peak of metamorphism and within the range of temperature for known marcasite formation.

9.4 Post-depositional History of the Ore Body

The Hanson Lake area has undergone amphibolite regional metamorphism (Coleman et al., 1970). Sufficient thermal energy (>425° C.) and dynamic stresses would be placed on any existing ore body to cause recrystallization and obliteration of original ore features. Faults and shear zones in the area were formed during or after the last period of folding (ibid, p. 77). This suggests that the brittle deformation occurred late in the metamorphic event and probably post-dates the thermal peak of metamorphism. The result of this late stage shearing may be the prominence of brittle deformation textures in the ore such as shearing in sulfides about silicate inclusions.

The following are the post-depositional (metamorphic) events undergone by the ore body:

1) Recrystallization and redistribution of the ore during the major thermal and deformational (folding) aspects of the metamorphism: Much evidence of this event would have been destroyed by complete recrystallization of the ore. Some remaining indications are fractured arsenopyrite grains (Plate 6b), porphyroblastic pyrite (Plate 7a), galena and arsenopyrite that is concentrated in the hinges of minor folds
(Plate 15b), contorted sulfide bands in siliceous gangue material (Plate 14b), recrystallized quartz gangue (Plate 14a), muscovite knots in massive sulfide ore, and silver and zinc:lead ratio contours that have a similar trend to the plunge of regional structures (Figures 13, 14 and 15).

2) Late stage shearing probably responsible for the alteration envelope: Sharp ore contacts are a prominent feature of the ore body. McDonald (1967) considers that sharp massive ore contacts may indicate relative movement of the wall rocks and ore. The incorporation, and wide range of rotation, of wall-rock fragments in the massive ore that show no evidence of sulfide-silicate reactions, is consistent with the interpretation that the ore body has been sheared. Shear planes within sulfides adjacent to inclusions (Plate 5a) indicate deformation of the ore. The vertical "rolls" which displace the ore may be drag folds associated with deformation.

The pyrrhotite-to-marcasite alteration appears to post-date the major "kneading" of the sulfide body as shown by the bent marcasite pseudomorphs of pyrrhotite about inclusions. This alteration probably took place during a late stage in the metamorphism. The occurrence of chalcopyrite with marcasite along fractures in pyrite (Plate 6a) indicates that copper was mobile during the late stage in metamorphism. The occurrence of chalcopyrite along silicate-sphalerite interfaces (Plate 3c), and as pressure shadows, indicates that copper may have also been mobile throughout metamorphism.
9.5 Ore Genesis

Any theory of ore emplacement must be consistent with the shape and content of the alteration, sharpness of the ore-wall-rock interface, deformational history of the ore zone, composition of the ore, and relative and absolute ages of the ore body. Considering the deformational history of the ore, this deposit must be of syntectonic or pre-tectonic age. A discussion of the three possible origins which would be consistent with the deformation of the ore follows:

1) Hydrothermal origin (pretectonic or syntectonic): If a hydrothermal system was responsible for the formation of the ore body, virtually all evidence of hydrothermal activity has been obliterated by metamorphism. Silicification, shearing, and alteration of plagioclase to mica in the alteration envelope are similar to features ascribed by Coleman et al. (1970) to retrograde metamorphism and metasomatism localized along faults and shear zones. The amount of water necessary for development of the alteration about the ore body is not sufficient for the hydrothermal emplacement of the ore. The alteration, by its 'enveloping' nature, does not show any channelways which may lead to a source of metals. These ore channels could not have been destroyed by metamorphism as even a metamorphosed alteration zone would still have a recognizable mineralogy. It is difficult to find a suitable magmatic source for the necessary hydrothermal solutions. The diorite band (<6 feet wide) near the ore is too small to be a source for the volume of hydrothermal solutions needed to deposit the ore. The sill-like River Granite is
considered to be an orogenic intrusion associated with the Kenoran orogeny (Coleman et al., 1970). The nearest contact of this granite outcrop is one mile west of the ore body. It is improbable that the granite was a source unless some unknown subsurface channels exist between the ore and granite. The lack of a suitable magmatic source would preclude a hydrothermal origin for the ore.

2) Syntectonic metasomatic origin: Coleman et al. (1970) suggest that ore solutions may have migrated towards dilational shear zones during regional metasomatism. Deformation features would be present if the ore was deposited during an early stage in the metamorphic event. However, it is difficult to imagine the result of this process being a massive lens of sulfide with knife-sharp contacts and with virtually all of the lead, zinc, copper, and silver content within the lens. Analyses of core chips from both sides of the ore body show no gradation in lead, zinc, or copper towards the ore body (ibid, p. 137). Furthermore, as regional metasomatism postdates faulting (ibid, p. 81) deformation in the ore precludes a regional metasomatic origin for the ore.

The deformation in the ore, as discussed on pages 69 to 73, and the redistribution of zinc and copper, as discussed on pages 75 to 77, is considered, by the author, to have taken place during regional metamorphism. If fluid plase transport was active during the redistribution of metals in the ore body, then water necessary for metasomatism and retrograde metamorphism that is accentuated along faults may have been used in the fluid transport. Although regional metamorphism is not responsible for ore genesis, it may have caused concentration and remobilization as
well as deformation of the ore.

3) Syngenetic (volcanogenic) origin: Hutchison (1965) compared massive copper-zinc ore bodies in the Canadian Shield to massive pyrite deposits in the Cretaceous eugeosynclinal belt of Cyprus. The lack of post-volcanic orogenesis and igneous intrusion and the lack of deep burial is cited as evidence for precluding epigenetic hydrothermal solutions in the Cyprus deposits. These Cyprus deposits are stratigraphically conformable in volcanic sequences; they are typically lenticular or pod-like in shape, but display a wide range in size, have sharp hanging walls, have disseminated and stringer sulfides on the footwall, and show no recognizable structural control (ibid, p. 995-997). Similar field relations in Matagami sulfide masses led Sharpe (1965) to consider these ore bodies as having formed in shallow near-surface, physical and chemical traps in a volcanic pile. Roscoe (1965) considered the ore bodies in the Noranda and Matagami area to be related to Archean volcanism; he also places little genetic significance on morphological differences between individual deposits.

The occurrence of the ore body at the stratigraphic break in the volcanic sequence near a volcanic neck suggests that the ore body is genetically similar to the models proposed by Hutchison (1965), Roscoe (1965), and Sharpe (1965). The footwall of the Hanson Lake deposit, soda-rhyolite porphyry, may be near a volcanic neck (Coleman et al., 1970). Evidence for this is thickening of Amisk-type rocks in this area and a roughly concentric foliation in the soda-rhyolite porphyry (ibid, p. 77). The lack of a suitable magmatic source for ore solutions and the similar
relative structural ages of the ore and host rocks lend support to a volcanogenic origin for the ore body.

The Hanson Lake deposit differs from the given volcanogenic model. The deposit has a small alteration envelope with no apparent 'funnel' of disseminated sulfides on the footwall as described by Hutchison (1965) and Roscoe (1965). Furthermore, the mineralogy of the Hanson Lake ore body differs basically from volcanogenic ore deposits described in published literature (Hutchison, 1965, Roscoe, 1965, Sharpe, 1965, Tutsami, 1969). The Flin Flon and Noranda deposits, typical of this group, are pyrite-sphalerite-chalcopyrite ore bodies; the mineralogy of the Hanson Lake deposit is sphalerite-galena. The small alteration envelope, lack of abundant iron sulfides, and unique mineralogy indicates that the ore was deposited under unusual genetic conditions, although these could not be determined from the present work.

Coleman et al. (1970) consider the region to have undergone only the Kenoran orogeny. Deformation in the ore indicates a pre-Kenoran orogeny age, for the ore (2490 ± 100 m.y.). The ore would, therefore, be of similar age to the host Amisk-type volcanic rocks that are dated at 2521 ± 60 m.y. by Coleman (1970). The similar relative age of the ore and host volcanic rocks suggests that the ore body is a volcanogenic deposit.

The relative age of the ore is not, however, consistent with Pb-Pb ages of galena in the ore body (Sinha, 1970, and Sangster (personal communication). Discrepencies in the Pb-Pb ages may be the result of a decrease in non-radiogenic Pb$^{204}$ or in an increase in radiogenic Pb$^{206}$,
Pb\textsuperscript{207} and Pb \textsuperscript{208} during regional metasomatism.

9.6 Comparison of the Hanson Lake Deposit to the Flin Flon Group of Ore Bodies.

The Hanson Lake ore body is located 40 miles west of the Flin Flon ore bodies and a similar distance west-northwest of the Coronation, Birch Lake and Flexar deposits. Grouping ore bodies according to general stratigraphy and areal distribution would place the Hanson Lake deposit in the Flin Flon group.

The stratigraphic location of the Flin Flon and Hanson Lake ore bodies is similar. The Flin Flon ore bodies occur within a zone of shearing along a contact between competent quartz porphyry and lava flows and less competent pyroclastic rocks of the Amisk group (Byers \textit{et al.}, 1965). The Hanson Lake ore body occurs along the sheared contact between soda-rhyolite porphyry and felsic volcanic rocks of the Amisk-type group of rocks. These ore bodies are associated with N-S shear zones. Galena from all of these deposits give similar Pb-Pb age dates (Sinha, 1970).

There are considerable differences between the Hanson Lake ore body and the Flin Flon group of deposits. Hanson Lake ore is a massive homogeneous lens of sphalerite-galena ore. The homogeneity is such that one grab sample of the ore is generally representative of the whole ore body (Plate 1 and 12b). However, qualifications extend to small-scale, local variations such as quartz-galena-rich areas and arsenopyrite-rich areas. Ore bodies in the Flin Flon group are all pyrite-chalcopyrite-sphalerite ore bodies with considerable disseminated ore as well as
massive ore. Ore contacts in the Flin Flon deposits are not as sharp as those at Hanson Lake. The length-to-depth ratio of the Hanson Lake deposit exceeds 4:1. Ore bodies in the Flin Flon group all have length-to-depth ratios which are less than one; the two ore lenses of the Coronation mine have length to depth ratios of 0.6 (Cairns, 1969), six ore bodies in the Flin Flon mine have ratios of approximately 0.4 (Byers et al., 1965), the Schist lake, Mandy, Birch Lake, and Flexar deposits are of similar shape but much smaller (ibid, p. 79). The host rocks, although of similar lithology, are of greatly different ages. The Amisk group near Flin Flon have been dated at 1775 ± 89 m.y. using Rb/Sr methods (Mukherjee, Stauffer, and Baadsgaard, 1971) while Hanson Lake Amisk-type rocks have been dated at 2521 ± 100 m.y. (Coleman et al., 1970). This structural interpretation places the Hanson Lake ore body in an entirely different structural province from the Flin Flon ore bodies.

The many differences between the Hanson Lake ore body and the Flin Flon group of deposits, despite stratigraphic similarities and areal proximity, suggests that the Hanson Lake ore body should not be included with those of the Flin Flon group for regional correlations or consideration of ore genesis.
The Hanson Lake ore body should not be considered as a deposit in the Flin Flon group of ore bodies. It is found in older host rocks, has a totally different physiognomy, and has different basic mineralogy.

The ore body has undergone a period of metamorphism. The main event resulted in kneading, shearing and recrystallization of the massive sulfide lens, accompanied by a redistribution of the minor metals, copper and silver. Brittle fracturing and alteration of pyrrhotite and pyrite to marcasite is a late stage of the metamorphism although the alteration of pyrrhotite and pyrite to marcasite may be a post-tectonic event. Subsequent surface leaching has affected the upper portions of the ore.

Gross geological features and textures of the ore, gangue, and wall-rock minerals indicate that the ore is of syngenetic origin. Lead-lead age dates of ore samples indicate that the ore is of post-tectonic epigenetic origin. More weight should be placed on the geological and textural features of the ore than on the age dates because regional metamorphism and metasomatism may have reset the isotope clocks. This is emphasized by the relative age of the ore body in relation to metamorphism and to the host rocks. The Pb-Pb age of the ore is not consistent with a syngenetic origin for the ore. However, the author chose to accept the textural evidence in the ore body over the Pb-Pb age in defining an origin for the ore body.
11. REFERENCES


_______, 1969, Pyrrhotite phase relations below 304 ± 6° C. at <1 atm total pressure: Ec. Geol., v. 64, p. 405-419.


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* Drill hole number followed by core footage or underground sample section followed by identification number (Figure 4). Note -- location numbers, in full, on back of polished surfaces.

LOCATION OF SPECIMENS IN PHOTOMICROGRAPHS

Table 4
### FeS AND MnS CONTENTS OF SPHALERITE

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\* Locations as on Figure 4.
\* Mineral associations as listed on page 52 (1- pyrrhotite dominant on polished surface; 2- marcasite dominant on polished surface; 3- inclusion in quartz; 4- inclusion in pyrite; 5- grain size >200 microns; and 6- grain size <15 microns.
\* Standard deviation in wt. %.
\* Conversion factors for calculating mole % were obtained from the straight line relationship of wt. % and mole % shown by the standard samples.
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<th>Mole %</th>
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Chemical Analysis

The analyses were carried out, using an atomic absorption spectrometer, by G.L. Smithson, chemist, at the Saskatchewan Research Council. The samples were crushed to -200 mesh by the author before the chemical analysis.

Copper, zinc, manganese, nickel, cobalt, arsenic and cadmium contents were determined by atomic absorption analysis of bromine-bromide digestions.

A separate bromine-bromide digestion was used to determine lead and insoluble contents. After excess bromine was removed with nitric acid, the solution was treated with acetic acid and hydrochloric acid until all soluble material (PbSO₄) was back in solution. The insoluble fraction was filtered off, washed, dried and weighed. The solution was then diluted for the determination of lead by atomic absorption methods.
CHEMICAL ANALYSES OF DRILL CORE SAMPLES AND ORE SECTIONS SAMPLED UNDERGROUND

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<th>Wt. % Zn</th>
<th>Wt. % Mn</th>
<th>Wt. % Cd</th>
<th>Wt. % As</th>
<th>Insol.</th>
<th>Wt. % Co</th>
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<td>26.3</td>
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<td>0.04</td>
<td>1.9</td>
<td>14.8</td>
<td>0.002</td>
<td>0.005</td>
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</table>

- Drill hole number or intersection number (Figure 4) followed by core footage and/or location with respect to the hanging wall and footwall of the ore.
- Location of H-1 to H-6 shown in Plate 1.
Figure 18

The natural sphalerite standards were analysed by R.G. Arnold at the Saskatchewan Research Council.
STANDARD CURVE FOR FeS CONTENT IN SPHALERITE

Figure 18

Net Counts per Seconds

Weight % FeS
Figure 19

The sphalerite standards are natural grains analysed by R.G. Arnold at the Saskatchewan Research Council.
STANDARD CURVE FOR MnS CONTENT IN SPHALERITE
The natural pyrrhotite standards are the property of the Department of Geology, University of Saskatchewan, Saskatoon, Saskatchewan.
STANDARD CURVES FOR DETERMINATION OF COBALT & NICKEL CONTENTS IN PYRRHOTITE

Figure 20

Net Counts per Second

Weight % Cobalt

Weight % Nickel

0.00 0.01 0.02 0.03 0.04

0.0 0.1 0.2 0.3 0.4 0.5 1.0

0.00 0.01 0.02 0.03 0.04

S-1

S-2

S-1

S-2
LEGEND

Projection of ore body from 200' level to surface

Mine shaft

Shore line

Reference grid for cross-sections

Figure 2
LOCATION OF ORE BODY UNDER HANSON LAKE
Figure 5a
Cross-section of the Massive Ore Body

LEGEND
- Soda-rhyolite porphyry
- Felsic volcanic rocks
- Projected outline of massive ore
- Diamond drill hole
- Alteration envelope and other shear zones

Legend scale:
0' 50'
Figure 5c
Cross-section of the Massive Ore Body
128 N

LEGEND
- Soda-rhyolite porphyry
- Felsic volcanic rocks
- Projected outline of massive ore
- Diamond drill hole
- Alteration envelope and other shear zones

0' 50'