THE SOUTH HENINGA LAKE COPPER-ZINC DEPOSIT

DISTRICT OF KEEWATIN, N.W.T.

A Thesis
Presented To
The Faculty of Graduate Studies
University of Manitoba

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

by

Sidney R. Leggett

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ABSTRACT

The stratigraphy of the southern part of the Heninga Lake map sheet can be divided into two formational units, here informally called Formation A and Formation B. Formation A is the oldest and is composed primarily of intermediate and less amounts of felsic tephra. Formation B overlies Formation A and is composed primarily of intermediate and mafic tephra and flows. Features in these formations suggest that the source for most of the flows and tephra was a volcanic vent to the west of the deposit, and that the volcanic rock was deposited in a subaqueous environment.

The deposit occurs in the upper part of Formation A in intermediate and some felsic ash tuffs and lapillistones. The interbedded, conformable relationship of the massive sulphides with respect to the ash tuffs, and primary features in the sulphide minerals suggest that the deposit is syngenetic.

Three massive sulphide zones are present in the deposit. Two of these occur over discordant zones of stringer sulphides which may represent source conduits for the mineralized fluids from which precipitated the two proximal sulphide zones. The third sulphide zone probably represents distal sulphides deposited from mineralizing fluids derived from these or other source conduits.

The percolation of the mineralizing fluids through the conduits removed silica and calcium from the rocks in

that area and added iron and magnesium. This is now seen as an area of chloritic alteration in the immediate area of the sulphide zones. The silica and calcium moved outward from the chloritic alteration producing an extensive halo of silica and calcium enrichment around the deposit, in the form of quartz-sericite-carbonate-pyrite alteration. Introduction of this silica and calcium into the subaqueous environment resulted in the precipitation and deposition of chert nodules and beds, and thin carbonate beds with the volcanic ash and lapilli.

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CHAPTER I

INTRODUCTION

Statement of Problem

The Rankin-Ennadai greenstone belt is a major Archean greenstone belt stretching southwest 380 km from just south of the settlement of Rankin Inlet, to the weather station at Ennadai, District of Keewatin, Northwest Territories. There has been considerable interest in this belt by industry for many years, particularly in its potential for massive volcanogenic sulphide deposits. This study of the South Heninga Lake deposit, which is the largest known Cu-Zn occurrence in the belt, is an outgrowth of this interest. The objectives of this study are:

1. to document the geological setting of the (South Heninga Lake) deposit,
2. to outline the character of the mineralization within the deposit, and
3. to interpret the genesis of the mineralization.

Location and Access

The South Heninga Lake deposit is located 260 km southwest of Rankin Inlet, N.W.T., and 26 km southeast of the abandoned settlement of Padlei, N.W.T. (Figures 1 and 2). Access to the area is possible by charter flights either from Churchill, Manitoba; Rankin Inlet, N.W.T.; or Baker Lake, N.W.T.

Previous Geological Mapping

Initial reconnaissance mapping (1:1,000,000) of the geology of the Southern District of Keewatin was carried out in 1952 (Lord, 1953; and Wright, 1967). This work defined the Rankin-Ennadai greenstone belt as it is represented in Figure 2.

In 1968, mapping (1:250,000) of the NTS 65H, Henik Lakes map sheet, was completed (Bell, 1968, 1971). At the same time, Davidson (1970a, b) was responsible for proposing the name Kaminak Group for the Archean volcanic rocks in the area immediately east of the Henik Lakes area.

An extensive stratigraphic correlation of the eastern half of the Rankin-Ennadai greenstone belt was completed by Ridler (1971a, b, 1972, 1973a, b, 1974) and Ridler and Schilts (1974a, b). This correlation included the north end of the Heninga Lake map sheet, but did not include the South Heninga Lake deposit.

Between 1975 and 1977, most of the Heninga Lake map sheet (NTS 65H16) and parts of the adjacent map sheets

Figure 1: Location of the Heninga Lake Project area (shaded area marked Heninga Lake Project Area shows location of Figure 3).

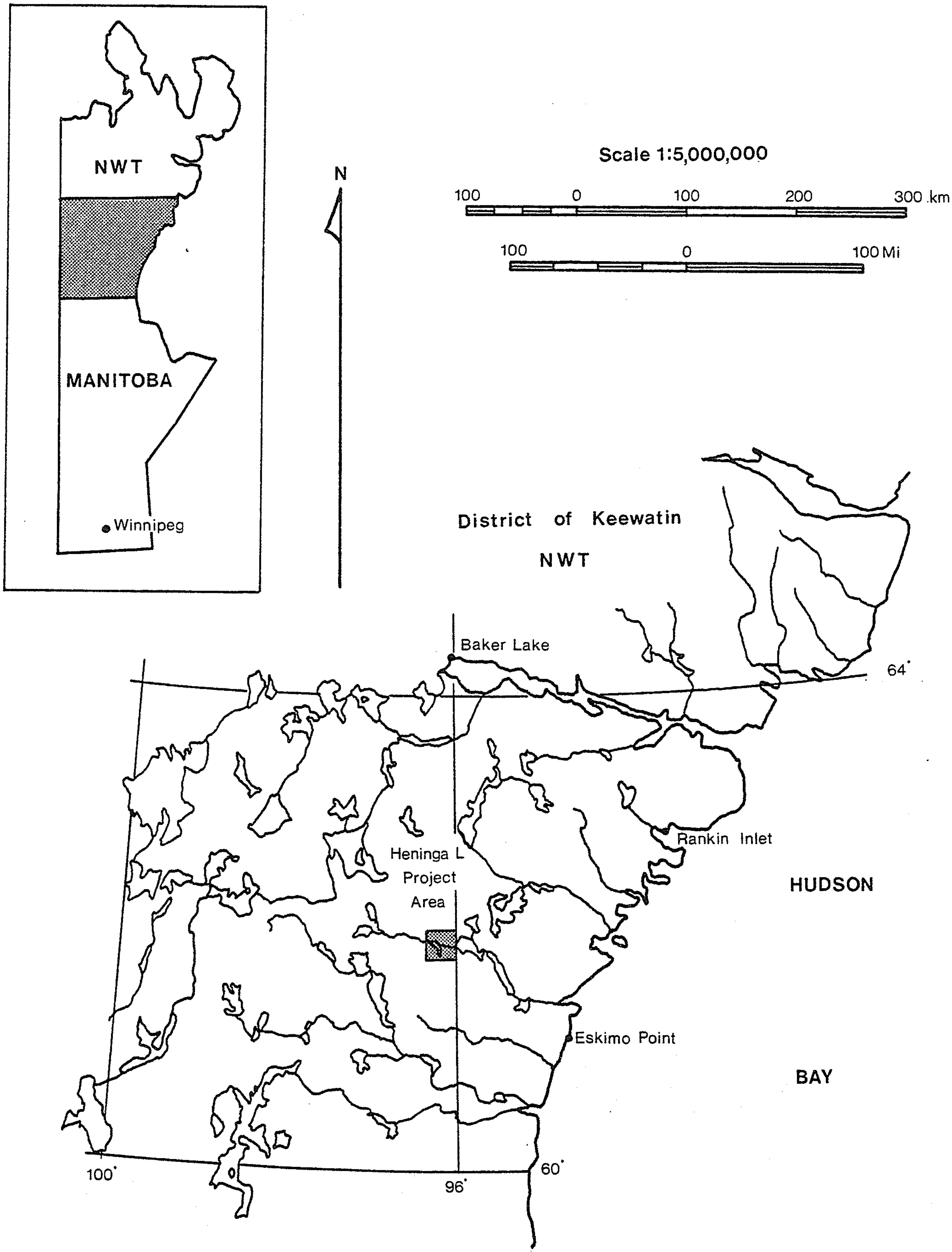
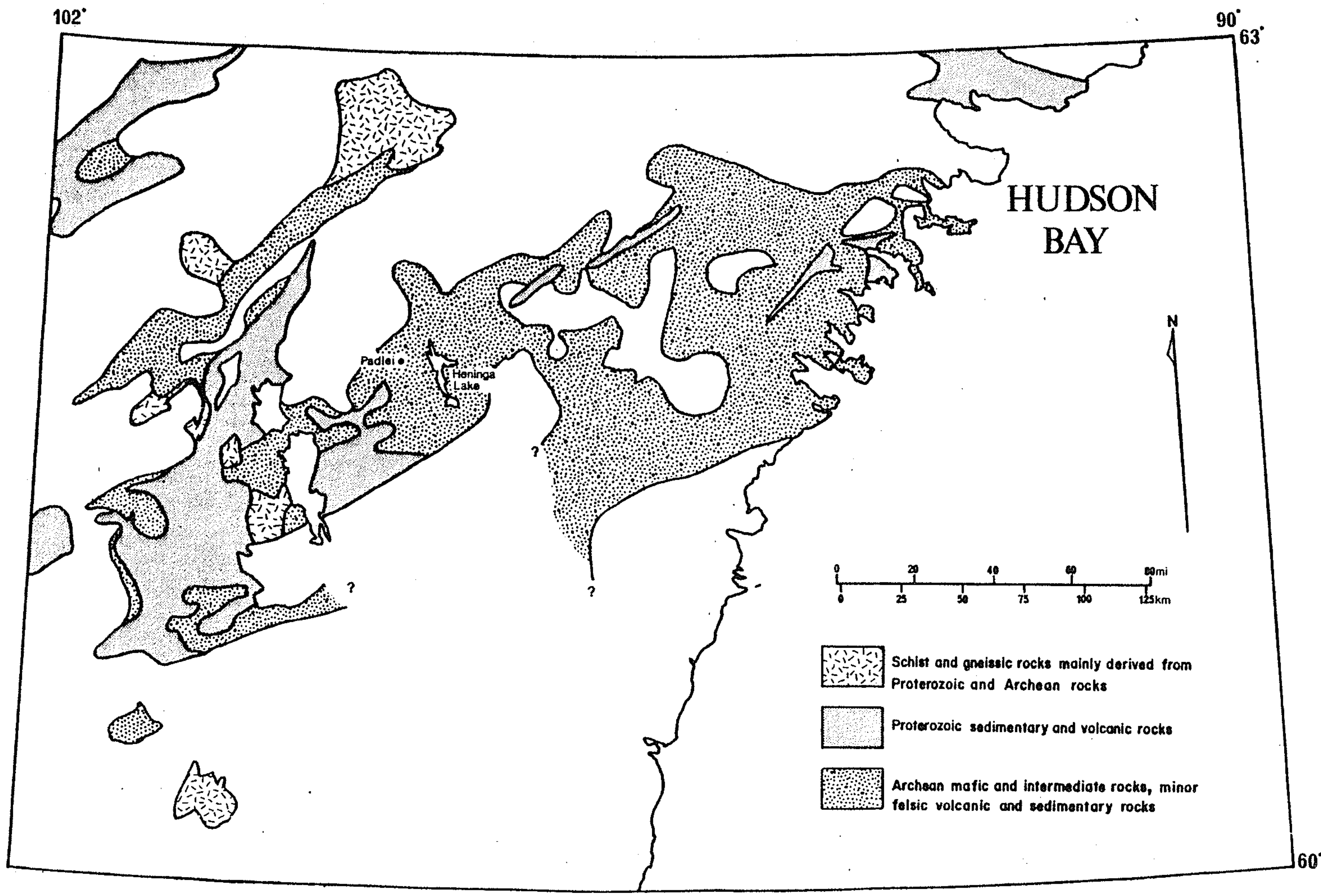

NWT
MANITOBA
Winnipeg
N
Scale 1:5,000,000
100 0 100 200 300 km
100 0 100 Mi
District of Keewatin
NWT
Baker Lake
64°
Rankin Inlet
Heninga L
Project
Area
HUDSON
BAY
Eskimo Point
100°
96°
60°

Figure 2. The Rankin-Ennadai greenstone belt (after Wright, 1967).


102°
90°
63°
60°
HUDSON
BAY
N
Padlei
Heninga
Lake
?
0 20 40 60 80mi
0 25 50 75 100 125km
Schist and gneissic rocks mainly derived from Proterozoic and Archean rocks
Proterozoic sedimentary and volcanic rocks
Archean mafic and intermediate rocks, minor felsic volcanic and sedimentary rocks

to the east, northeast, and north (NTS 55E13, 55L4, and 65I1 respectively) were mapped at a scale of 1:31,680. The area immediately east of the South Heninga Lake deposit was intensively sampled geochemically in 1975, revealing high background values of both copper and zinc in soils and rocks (Schilts and Delabrio, personal communication, 1976). An extensive stratigraphic and structural analysis of parts of the Heninga Lake and adjacent map sheet to the northeast was carried out by Barrett (personal communication, 1979).

Previous Work on the South Heninga Lake Deposit

The South Heninga Lake deposit was first staked as the TOWER claims in 1948 by Hudson Bay Mining and Smelting Co. Ltd. Sixteen diamond drillholes were drilled in the deposit the same year. The drilling showed significant sulphide mineralization but the results were inconclusive due to poor core recovery.

The deposit was acquired by Hewbet Mines Ltd. as the SKIM, URP, and DOE claims in 1971-1972. Boulder tracing done in 1972 suggested that there was more mineralization under Heninga Lake to the west of the property. Following the liquidation of Hewbet Mines Ltd., Gemex Minerals Inc. took over the property in 1974. Seven diamond drillholes were drilled in 1974 and a geophysical survey was completed.

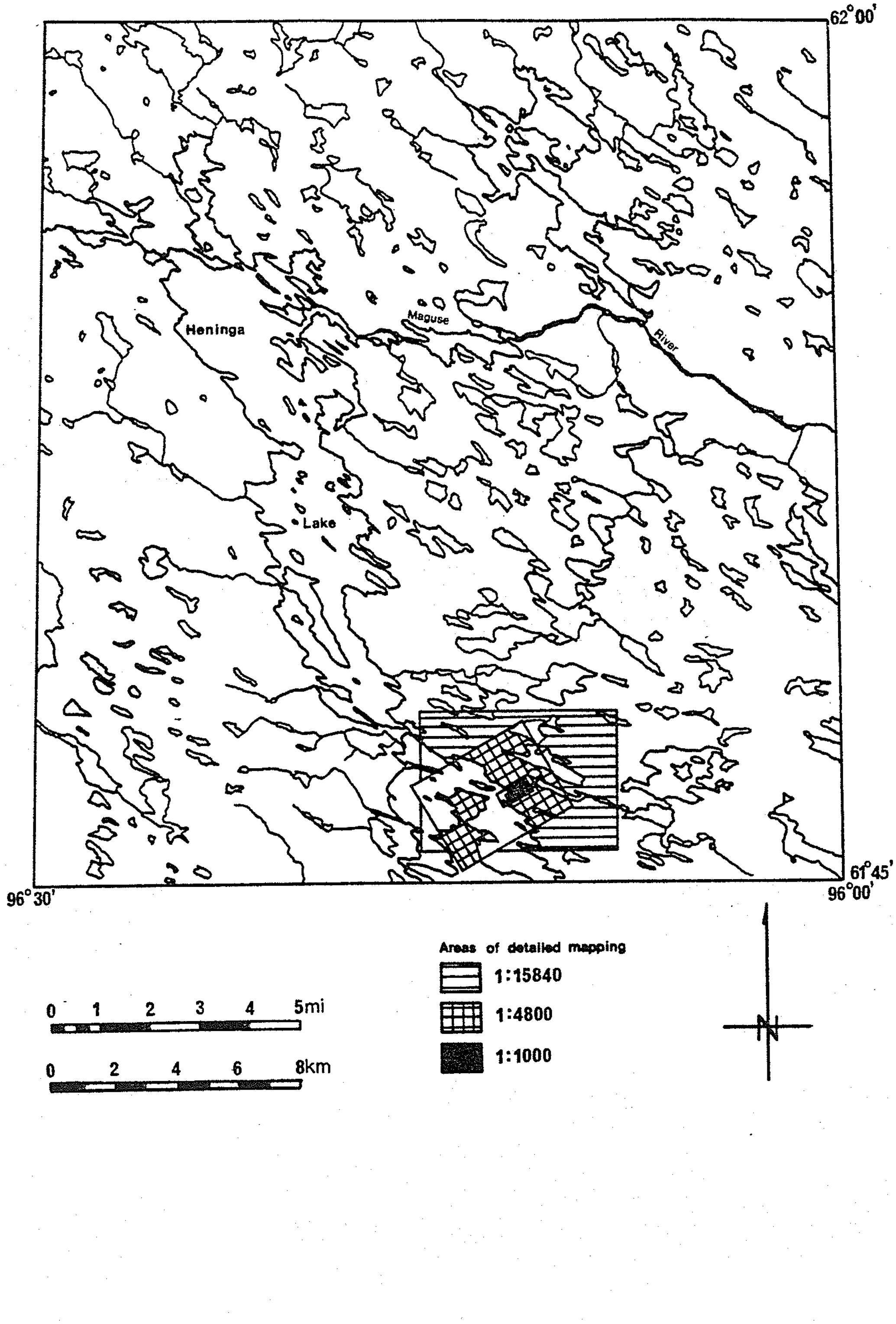
The drillholes indicated the presence of extensive Cu-Zn mineralization and the geophysics suggested that the mineralized zone extended to the west under Heninga Lake.

On the basis of this work, the property was optioned to St. Joseph Explorations Ltd. late in 1974. In 1975, concurrent with this study, St. Joseph Explorations did extensive geophysics, geochemistry, and geological mapping. Nine drillholes were also drilled into the deposit by St. Joseph Explorations. Seven additional drillholes were completed and more geophysics was done in 1976 by the same company.

Present Work

Fieldwork for the present study was done during the summer of 1975 and 1976 in conjunction with the 1:31,680 scale mapping done by D.I.A.N.D. of the Heninga Lake (NTS 65H16) and adjacent map sheets (parts of NTS 65I1, 55L4, and 55E13). During 1975, initial reconnaissance (1:15,840 scale) mapping was done around the area of the property and the drillcore from the Gemex Minerals Inc. and St. Joseph Explorations Ltd. drilling was logged and sampled. In 1976, the geological mapping at the scale of 1:15,840 was finished and detailed mapping at 1:4800 and 1:1000 scales was completed on the area immediately around the showing (Figure 3).

Figure 3. Index maps showing the location of, and the scales of mapping for the South Heninga Lake project area.



62°00'
Heninga
Lake
Maguse
River
61°45'
96°30'
96°00'
Areas of detailed mapping
1:15840
1:4800
1:1000
0 1 2 3 4 5mi
0 2 4 6 8km
N

A total of 137 thin sections, 20 polished sections, and three polished thin sections were prepared from samples and were studied.

Acknowledgements

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Dr. W.C. Brisbin gave guidance and supervision throughout the initiation and completion of this study. The author also gratefully acknowledges the help of P.J. Laporte (District Geologist, D.I.A.N.D.), Leo King (St. Joseph Explorations Ltd.), Dr. L.D. Ayers (University of Manitoba), and the technical staff of the Department of Earth Sciences, University of Manitoba.

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CHAPTER II

GENERAL GEOLOGY OF THE CENTRAL RANKIN-ENNADAI GREENSTONE BELT AND OF THE HENINGA LAKE MAP SHEET

Introduction

The South Heninga Lake Cu-Zn deposit is within the Kaminak subprovince of the Churchill structural province of the Canadian Precambrian shield. The Kaminak subprovince is dominated by the Archean Rankin-Ennadai greenstone belt, a 380 km long northeasterly trending metavolcanic-metasedimentary sequence, bordered by granitic batholiths, gneisses, and migmatites (Figure 2). Proterozoic volcanic and sedimentary rocks, largely of the Aphebian Montgomery Lake and Hurwitz Groups, unconformably overlie Archean rocks and are preserved locally in downfaulted blocks.

Regional Stratigraphy and Structure of the Central Rankin-Ennadai Belt

A table of formations for the central Rankin-Ennadai belt, based on mapping by Bell (1971), Beavon (1976), Davidson (1970 a, b, 1972), and Eade (1974) is illustrated in Table I. Extensive tholeiitic mafic flows are the oldest rocks in the greenstone belt and form the base for the Archean volcanic pile. These are followed by thick

Table I: Table of Formations, Central Rankin-Ennadai Greenstone Belt (after Bell, 1971, Beavon, 1976, Davidson, 1970a,b, 1972, and Eade, 1974).

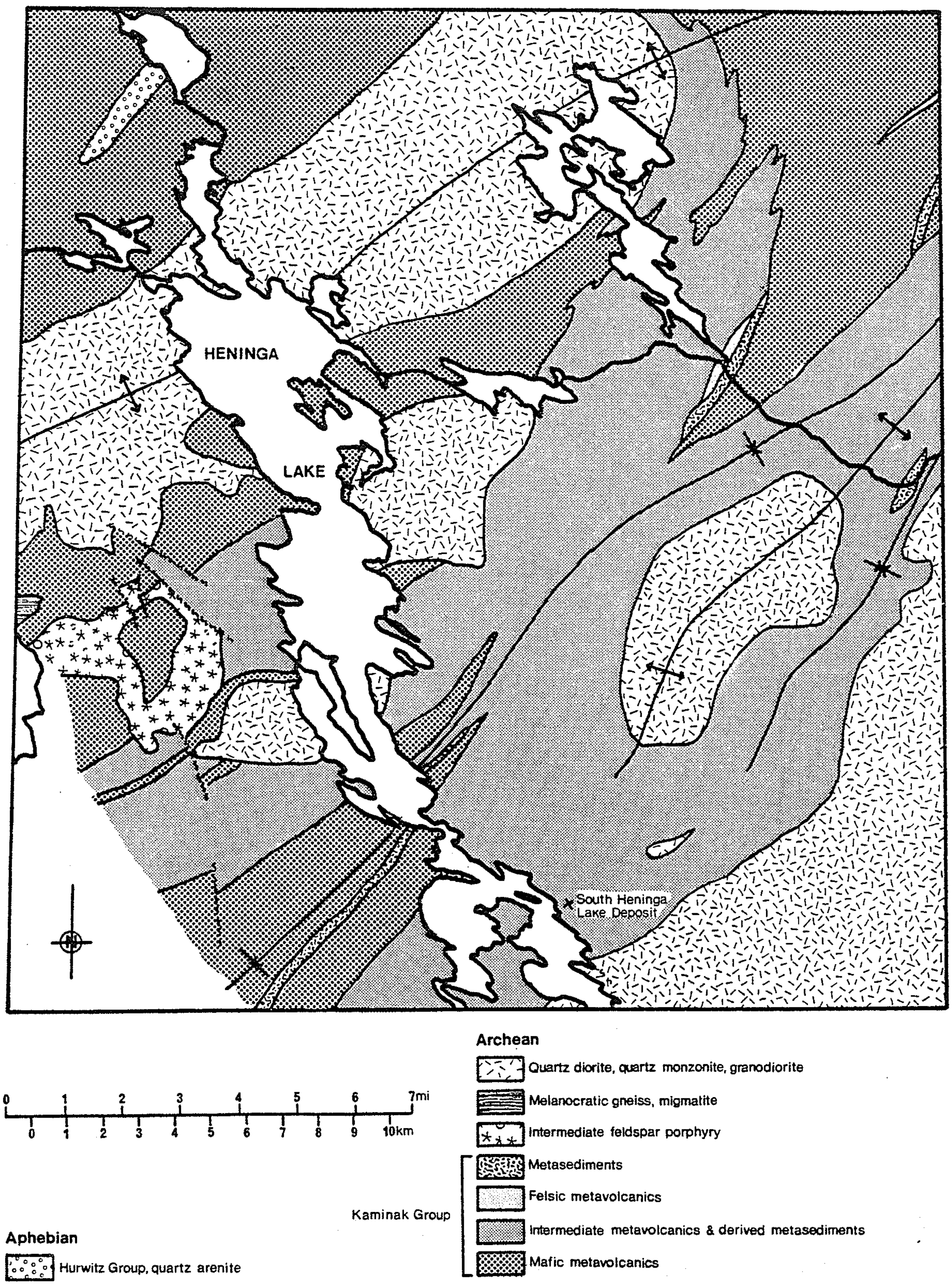
Age	Group	Lithology
Helikian		Diabase dykes, biotite lamprophyre sills
		Intrusive Contact
Aphebian		Granite, pegmatite, migmatite
		Intrusive Contact
	Hurwitz Group	
	Ameto Formation	Mudstone, siltstone, slate, argillite, greywacke
	Kinga Formation	Quartz arenite
	Padlei Formation	Paraconglomerate, mudstone
		Unconformity
	Montgomery Lake Group	Quartz arenite, grit, siltstone, conglomerate
		Porphyritic basalt flows; related diabase intrusives
		Unconformity
Archean		Quartz monzonite, granodiorite, Quartz diorite, meta-gabbro, diorite
		Intrusive Contact
	Kaminak Group	Shale, greywacke, siltstone, tuff, iron formation, chert; derived slate, phyllite, pelitic schist, gneiss
		Dacite, rhyolite, agglomerate, tuff, breccia, quartz-feldspar porphyry; derived phyllonite, quartzofeldspathic sericite schist, gneiss
		Andesite, basalt, minor mafic tuff, agglomerate, flow breccia; gabbro sills and dykes; derived amphibolite, amphibolite schist, hornblende plagioclase gneiss.

sequences of calc-alkaline intermediate and felsic flows and volcaniclastic sediments (Davidson, 1972, and Ridler and Schilts, 1974). Davidson (1970a) has classified these Archean volcanic and sedimentary rocks in the Kaminak Lake area of the central Rankin-Ennadai belt as the Kaminak Group. During the late Archean, the belt was deformed by the intrusion of extensive quartz diorite to granodiorite batholiths and stocks resulting in the current southwest-northeast orientation of the belt as is illustrated in Figure 4.

Numerous northeast trending Kaminak mafic dykes and related flows were extruded within the belt during the early part of the Aphebian (Beavon, 1976). During or shortly after the deposition of these flows and emplacement of these intrusions, a succession of coarse clastic sediments was deposited in discontinuous basins on the maturely eroded Archean terrain. These sediments have been classified as the Montgomery Lake Group by Bell (1971).

The Montgomery Lake Group was gently folded before a sequence of clastic sediments and minor mafic flows called the Hurwitz Group (Bell, 1971) were deposited. Bell (1971) has suggested that the Hurwitz Group represents a change from a continental to a deep marine depositional environment which forecasted a series of events during the

Figure 4: Geology of NTS 65H16, Heninga Lake map sheet (after Barrett et al, 1976, and Barrett, personal communication, 1979).


HENINGA
LAKE
South Heninga
Lake Deposit
N
0 1 2 3 4 5 6 7mi
0 1 2 3 4 5 6 7 8 9 10km
Archean
Quartz diorite, quartz monzonite, granodiorite
Melanocratic gneiss, migmatite
Intermediate feldspar porphyry
Kaminak Group
Metasediments
Felsic metavolcanics
Intermediate metavolcanics & derived metasediments
Mafic metavolcanics
Aphebian
Hurwitz Group, quartz arenite

middle and late Aphebian called the Hudsonian Orogeny. Along the edges of the Rankin-Ennadai belt, the Aphebian and Archean rocks were deformed and metamorphosed into extensive areas of gneiss and migmatite during the Hudsonian Orogeny. However, the central part of the belt including the Heninga Lake area was relatively unaffected except for minor faulting and folding.

After the Hudsonian Orogeny, thin biotite lamprophyre dykes dated at 1700 Ma were intruded throughout the subprovince (Davidson, 1972).

Stratigraphy of the Heninga Lake Map Sheet

The NTS 65H16 map sheet which covers the Heninga Lake area, was mapped at a scale of 1:31,680 (Figure 4) by Barrett, Leggett, and Laporte (1976) and Barrett (personal communication, 1979).

The oldest unit within the Heninga Lake area consists of mafic volcanic rocks which outcrop in the northwest and west part of the NTS 65H16 area and which represent part of the oldest unit of the Kaminak Group. These rocks are massive and pillowed basalt flows with some minor mafic tuff and flow breccia, cherts, and cherty iron formation. This mafic pile has been intruded by large gabbroic intrusions which were probably synvolcanic in origin.

Overlying and interfingering with the top of the mafic volcanic rocks is a thick unit of largely intermediate volcanic rocks which occur in a northeast-southwest belt across the center of the Heninga Lake area. This unit is composed mostly of intermediate flows, flow breccia, tephra, and volcaniclastic sedimentary material. This intermediate volcanic rock is associated with some felsic flows, flow breccia and tephra, occasional mafic flows, and some sediments: conglomerate, quartz arenites, greywacke, and iron formation. This intermediate unit has been interpreted by Barrett (personal communication, 1979) as a largely subaqueous and locally subaerial stratovolcano. It is part of the Archean Kaminak Group and the South Heninga Lake deposit.

The Archean metavolcanic rocks to the west of the Heninga Lake area have been intruded by a large intermediate feldspar porphyry intrusion, followed by the intrusion of several quartz diorite, quartz monzonite, and granodiorite batholiths and stocks throughout the Heninga Lake area. In the northwest corner of the Heninga Lake area, there is a small outcrop of quartz arenite which probably belongs to the Aphebian Hurwitz Group.

Structure and Metamorphism of the Heninga Lake Map Sheet

The structure in the Heninga Lake area is dominated by northeast trending isoclinal folds and a related slaty cleavage produced by the diapiric intrusion of the Archean granitic batholiths and stocks (Figure 4). Overprinted on the Archean slaty cleavage is a younger, weak, north-northeast trending crenulation cleavage produced by the late Aphebian Hudsonian Orogeny. The metamorphic grade of the rocks in the Heninga Lake area is low to middle greenschist occassionally upgraded to lower amphibolite near the granitic batholiths (Bell, 1971, and Davidson, 1970b).

CHAPTER III

GEOLOGY OF THE SOUTH HENINGA LAKE AREA

General Statement

The South Heninga Lake mineralization occurs within an interbedded sequence of Archean intermediate and some mafic volcanic breccias, flows, and tuffs; and minor felsic tuffs and volcaniclastic sedimentary rocks. The entire sequence is part of the northern overturned limb of a large northeast trending anticline. This anticline was probably produced by the updoming of the metavolcanic rock by the intrusion of a late Archean granitic batholith to the south of the deposit (Figure 5). Several Aphebian diabase dykes and sills, and a small younger lamprophyre stock have intruded the Archean rocks.

Stratigraphy

The geology of the South Heninga Lake area is illustrated in Figures 5, and 6 (in pocket). A generalized stratigraphic section derived from these maps is shown in Figure 7. The detailed stratigraphy for the South Heninga Lake deposit area is shown in Figure 8 (in pocket).

The Archean stratigraphy in the South Heninga Lake area has been divided into two formations, here informally named Formation A and Formation B. Formation A predates and is in conformable contact with Formation B. The base of Formation A has been cut off by a granitic intrusion.

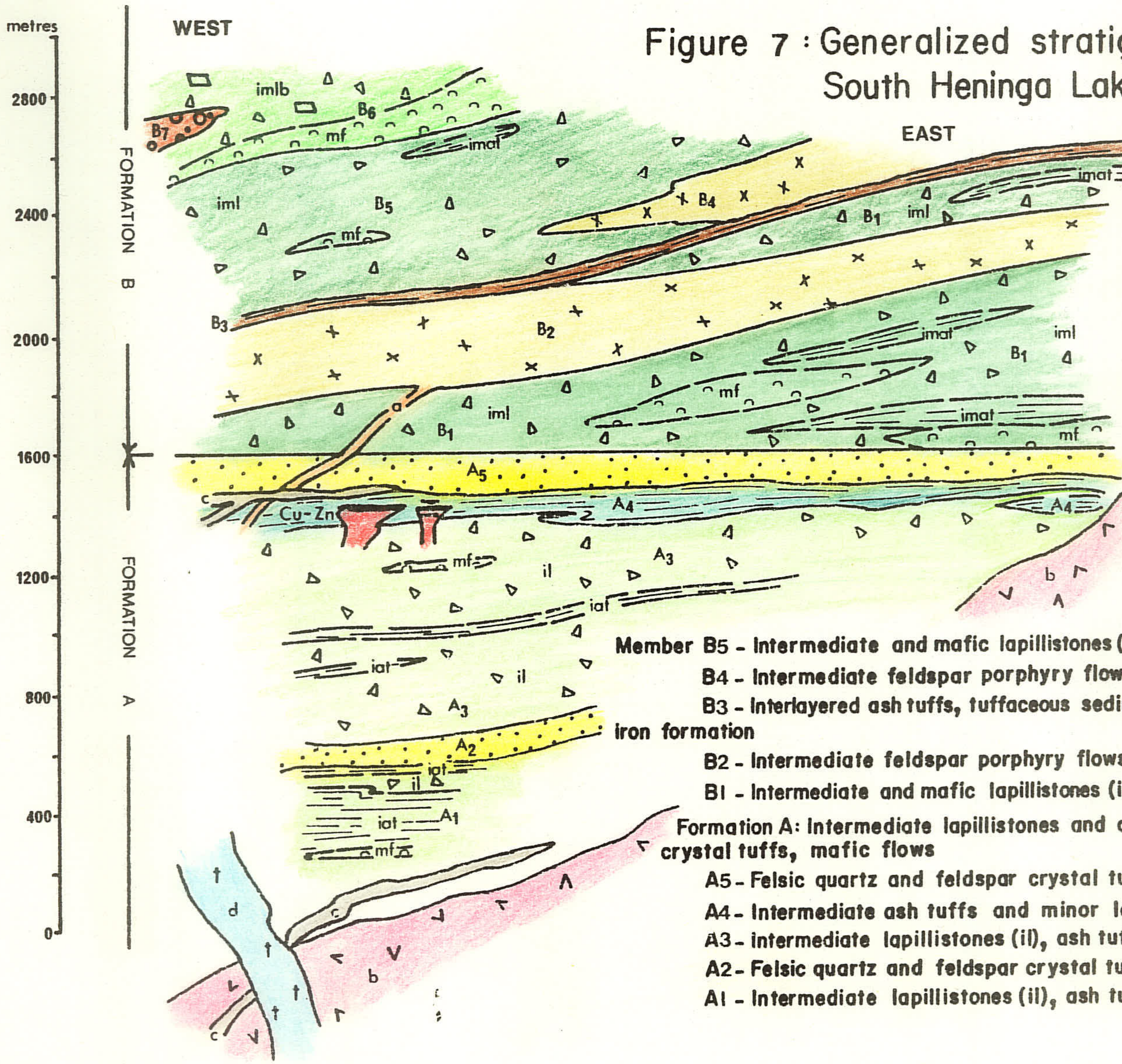


Figure 7 : Generalized stratigraphic section for the South Heninga Lake area

LEGEND

Intrusive Rocks

- d Aphebian or Helikian camptonite lamprophyre stock
- c Aphebian Kaminak diabase sills and dykes
- b Archean granitic intrusives
- a Archean intermediate dykes and sills

Archean Kaminak Group

Formation B: Intermediate and mafic lapillistones, breccias, ash tuffs and flows; minor jasper – magnetite iron formation and volcaniclastic sediments

Member B7 - Volcaniclastic sediments

B6 - Intermediate and mafic lapillistones and breccia (imlb), and mafic flows (mf)

Member B5 - Intermediate and mafic lapillistones (iml) and ash tuffs (imat), mafic flows (mf)

B4 - Intermediate feldspar porphyry flows

B3 - Interlayered ash tuffs, tuffaceous sediments, cherts and jasper-magnetite iron formation

B2 - Intermediate feldspar porphyry flows

B1 - Intermediate and mafic lapillistones (iml) and ash tuffs (imat), mafic flows (mf)

Formation A: Intermediate lapillistones and ash tuffs, felsic quartz and feldspar crystal tuffs, mafic flows

A5 - Felsic quartz and feldspar crystal tuffs

A4 - Intermediate ash tuffs and minor lapillistones

A3 - intermediate lapillistones (il), ash tuffs (iat) and mafic flows (mf)

A2 - Felsic quartz and feldspar crystal tuffs

A1 - Intermediate lapillistones (il), ash tuffs (iat) and mafic flows (mf)

The upper (northern) contact of Formation B was not defined within the limits of the geological mapping done in the South Heninga Lake area. Formation A is composed mainly of intermediate and some felsic tephra, and is host for the Heninga Lake deposit. Formation B is composed of intermediate and mafic tephra and flows, and is unmineralized. Both formations have been subdivided into members on the basis of lithological character, members A_1 to A_5 for Formation A and members B_1 to B_7 for Formation B. Each of these members is described below. Four different intrusions of Archean to middle Proterozoic age, here labelled a, b, c, and d, have been intruded into the metavolcanic and metasedimentary rock. All intrusive rocks are described separately under the subheading, Intrusive Rocks.

Formation A

Formation A is a 1600 m thick interlayered sequence of intermediate and minor felsic lapillistones, delicately layered fine grained ash tuffs, and volcaniclastic sediments, felsic quartz and feldspar crystal tuffs and mafic flows or sills. Sulphide mineralization occurs throughout Formation A in association with the ash tuffs. The upper contact for Formation A is defined as the upper (northern) contact of member A_5, a quartz and feldspar crystal tuff. The lower contact of this formation in the South Heninga Lake area cannot be defined as a result of the late Archean granitic batholith at the extreme southern end of Heninga Lake which cuts across the natural stratigraphic succession.

Formation A is subdivided into five members (A_1, A_2, A_3, A_4, and A_5) on the basis of lithologic character and position in the stratigraphic succession. Member A_1 is the oldest. It is followed in succession by members A_2 to A_5, with member A_5 being the youngest member in Formation A. These members are described in detail below beginning with member A_1.

<u>Member A_1</u>: Member A_1 consists of a 500 m thick sequence of interbedded intermediate lapillistone (il)* and ash tuff (iat) which is exposed in several outcrops near the southeast end of Heninga Lake. A small outcrop of what is believed to be a small mafic flow (mf) occurs at the extreme southern exposure of the member. The initial 200 m of the stratigraphic section between the edge of the granitic batholith and the initial exposure of member A_1 is covered.

The lapillistones (il) of member A_1 are composed of volcanic fragments (85%) from about 0.5 to about 4 cm in size, and usually no more than 15% fine grained ash matrix. Some of the fragments and all of the matrix has been recrystallized to fine grained plagioclase, chlorite, sericite, and quartz. The identifiable lapilli fragments are heterolithic and are composed of both essential and accidental fragments. The

*abbreviations for rock types shown on Figures 5, 6, 7, 8, and 9.

majority of the fragments are accidental and appear to have been derived from pre-existing intermediate flows. These fragments usually have a relict trachytic texture, often are amygdaloidal, and sometimes are microporphyritic. The balance of the lapilli are essential fragments of partially preserved devitrified intermediate pumice and scoria. These have undergone partial recrystallization to fine grained plagioclase, chlorite, sericite, and quartz. The matrix is interpreted as fine grained vitric ash which has devitrified and recrystallized.

The ash tuff (iat) is medium grey-brown to light brown in colour and shows a delicate compositional layering. Except for the occasional coarser fragment, the ash tuffs have altered to a fine grained intergrowth of chlorite, sericite, quartz, epidote, and minor albite and potassium feldspar. The composition and the fine grain size of the secondary minerals suggest that the tuff was probably fine grained, intermediate, and vitric. The delicate 0.5 to 5 cm thick layering in the tuffs is produced by a variation in the concentration of chlorite, sericite, and quartz, and appears to reflect a primary variation in the composition of the ash. Up to 5% quartz and feldspar crystals are found in the ash tuff in the upper 75 m of member A_1. Occasional intermediate lapilli fragments similar to those already described are scattered throughout the ash tuff.

Rust weathering, 3 cm thick, pyritic, ash tuff beds occur throughout the member. The ash tuff surrounding these rusty beds is siliceous and often cherty. Approximately 60 m from the top of the member, chalcopyrite occurs with the pyrite.

The small mafic flow at the extreme southern exposure of the member is similar to mafic flows found in member B_1.

Member A_2: The ash tuff of the upper part of member A_1 grades upward into a 20 m thick, light brown-grey to grey weathering felsic quartz and feldspar crystal tuff. The most recognizable feature of the member are quartz and feldspar crystals up to 5 mm in diameter which make up about 20% of the member. About 75% of the member is composed of essential and accessory tuffaceous fragments from about 1 mm to 10 mm in diameter. These fragments were originally vitric, but have been devitrified and recrystallized and are now composed of a fine grained intergrowth of sericite, chlorite, biotite, epidote, quartz, and albite. Alteration rinds on many of the larger essential fragments are preserved as thin rinds of chlorite. The accessory fragments may have a relict trachytic texture and may contain quartz and feldspar microphenocrysts.

Larger lapilli fragments, 2 to 3 cm in diameter, are scattered throughout the member. For the most part, these are felsic, essential, and contain quartz and feldspar crystals similar to the smaller fragments. There are however, with the fragments, a small number of accidental intermediate lapilli fragments similar to those already described in member A_1.

Member A_3: A 600 to 700 m thick section composed of intermediate lapillistones (il), several thin beds of layered ash tuffs (iat), and two small mafic flows or intrusions (mf) overlies member A_2. The stratigraphy of member A_3 is only sporadically exposed in outcrop along the southeast shore of Heninga Lake and immediately inland from that shore. The contact between member A_3 and the underlying member A_2 is not exposed.

The lapillistones, ash tuffs, and mafic flows are similar to those already described in member A_1. The lapillistones of member A_3 are intermediate in composition and are heterolithic. Eighty percent of the lapilli fragments are medium brown-grey in colour while 20% are medium to light grey-brown. The ash tuff is delicately layered, often cherty, and not mineralized. Two small mafic bodies occur within this member immediately below (to the south of) the deposit. These bodies may be either flows or intrusions.

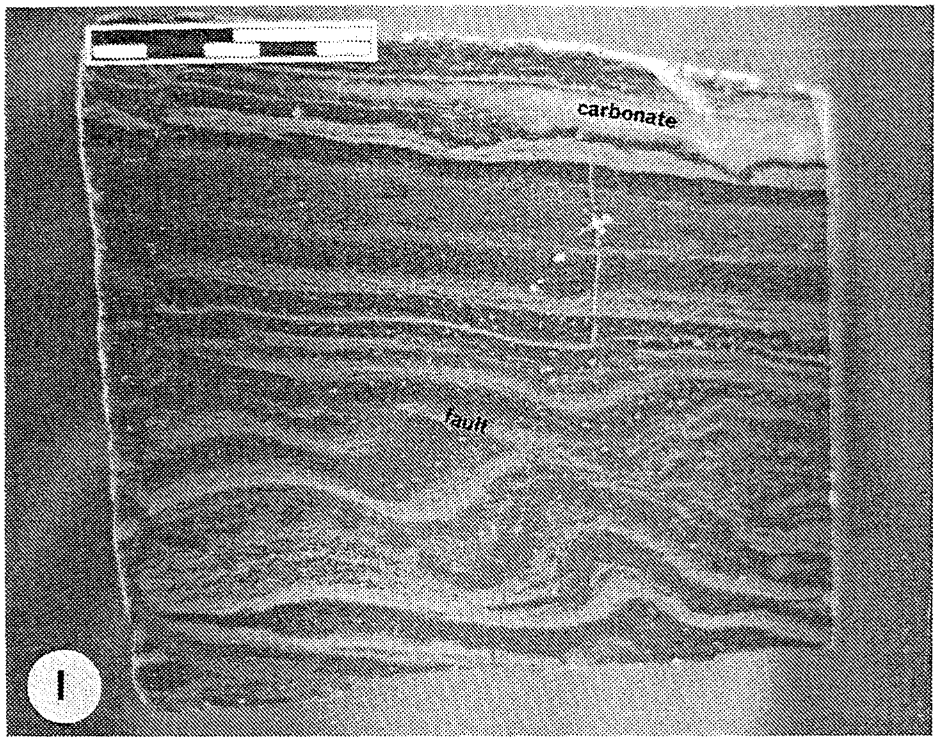
Member A_4: Member A_4 is a 50 to 150 m thick sequence of intermediate and felsic ash tuff (ifat) and lapillistone (ifl), and some tuffaceous sediments and cherts (ch). The base of this sequence of tuffs interfingers with the underlying lapillistones of member A_3. The South Heninga Lake deposit occurs within member A_4.

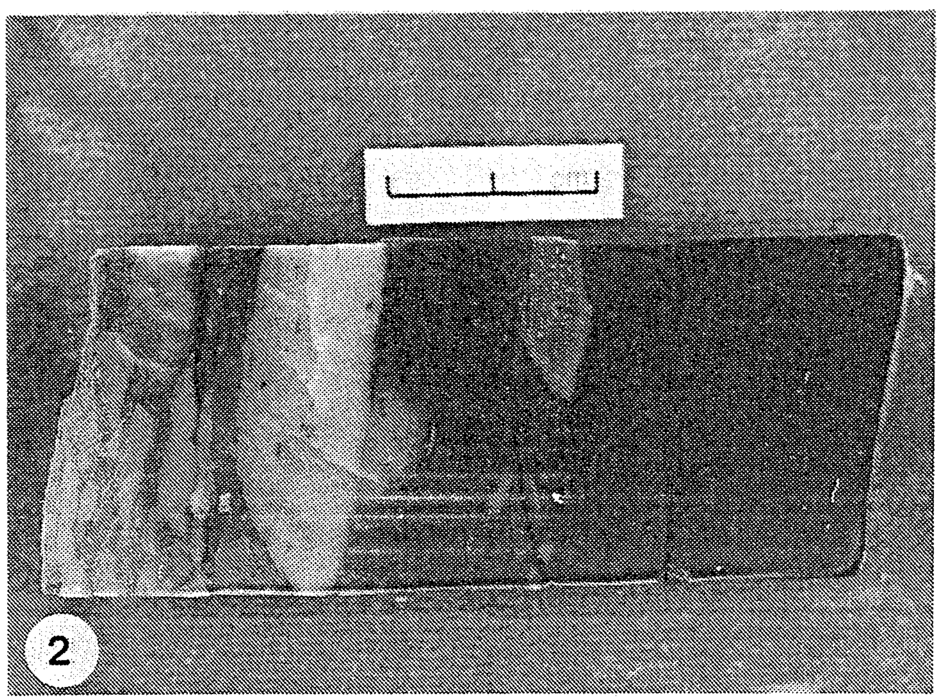
The principal component of member A_4 is delicately layered, light grey to grey-brown, intermediate to felsic ash tuff (ifat--Plate 1) similar to that found in member A_1. The ash has altered to a fine grained intergrowth of quartz, sericite, chlorite, and minor albite, potassium feldspar, and carbonate. Variations in the concentrations of the quartz, sericite, and chlorite define the delicate layers in the tuff. The individual layers are from 1 mm to 3 m thick but average from 1 to 2 cm thick. The layers are traceable for at least 10 m. Microscours and some small crossbeds in some of the ash beds demonstrate that there has been some sedimentary reworking of the ash into a tuffaceous sediment. Load structures also occur within some of the ash beds. Occasional quartz and feldspar crystals are scattered throughout the ash tuff of this member. One 3 m thick bed of felsic quartz and feldspar crystal tuff (fct) similar to the crystal tuffs of members A_2 and A_5, outcrops to the east and below the sulphide occurrence. Two 3 to 4 cm thick beds composed of about 90% carbonate and 10% quartz and chlorite also occur within the ash tuff (Plate 1).

Pinkish-white chert nodules and beds are characteristic of member A_4 in the South Heninga Lake area.

Plate 1: Delicately layered beds of ash tuff and carbonate. A low angle normal fault crosscuts the sample.

Plate 2: Lapilli fragments sandwiched between layers of ash tuff. From DDH SJ-5-75, 125.40-.46 m.


carbonate
fault
1


2

The chert nodules are lense shaped, up to 8 cm in diameter, and usually occur in groups. The chert beds are from 5 cm to 1 m thick and are usually about 10 m in length before they pinch out. Several large massive pods of slightly recrystallized white chert also occur just to the south of the main showing (Figure 8).

Lapilli up to 5 cm in diameter comprise about 45% of member A_4 at the South Heninga Lake deposit. The percentage of fragments decreases to about 15% of this member approximately 4 km to the east of the deposit. For the most part, the fragments are scattered throughout the ash tuff (Plate 2), although occasionally they are abundant enough to form lenses of lapilli tuff and lapilli breccia. Similar to members A_1 and A_3, most of the lapilli fragments are predominantly lithic and accidental, having been derived from pre-existing intermediate volcanic rock. Some essential, intermediate, vitric fragments and a few fragments of felsic volcanic rock and of pinkish-white chert, also occur with the ash tuffs.

Rust weathering gossans (g) have formed throughout the member in areas where the mineralization process has altered the rock. Within these alteration zones, primary textures have been almost entirely obliterated. These zones are approximately stratiform although they are quite variable in size and extent.

<u>Member A_5</u>: Member A_5 is a felsic, quartz and feldspar crystal tuff similar to the crystal tuff of member A_2. The contact between member A_5 and the underlying member A_4 is gradational. The contact between the overlying Formation B and member A_5 is covered. Member A_5 has been traced continuously from immediately above the South Heninga Lake deposit, to the eastern edge of the mapped area, and is approximately 120 m thick.

Approximately 90% of the tuffaceous fragments in member A_5 are less than 1 cm in diameter. The remaining 10% of the tuffaceous fragments are from 2 to 3 cm in diameter. These larger fragments are usually scattered among the smaller fragments although they occasionally form distinct lenses of coarse lapilli tuff and lapilli breccia.

Quartz and feldspar crystals averaging 1.0 to 1.5 mm in diameter account for up to 40% of the rock, although near the base of the member, the crystals may only make up to 1 to 2% of the tuff. The only difference between members A_5 and A_2 is the occurrence of occasional pyroxene crystals with the quartz and feldspar crystals in member A_5. These pyroxene crystals have been pseudomorphically replaced by chlorite.

<u>Formation B</u>

Formation B is an interlayered sequence of intermediate and mafic flows, flow breccia, ash tuffs, lapillistones, breccia, some volcaniclastic sediments, and minor jasper-magnetite iron formation. Formation B is at least 1400 m thick. No upper contact for Formation B was defined within the limits of the detailed mapping in the South Heninga Lake area. The lower contact with member A_5 is covered.

Within the area mapped, Formation B is subdivided into seven members (B_1, B_2, B_3, B_4, B_5, B_6, and B_7). Member B_1 is the oldest member of Formation B. It is overlain by members B_2 to B_7 which generally represent successively younger members in the formation. Several members (B_2, B_4, and B_7) however, appear to extend only partly across the stratigraphic succession in the South Heninga Lake area and are surrounded on three sides by another member (e.g. member B_7 is surrounded on the north, south, and east sides by member B_6). The members in Formation B are described below.

Member B_1: Member B_1 is composed of intermediate and mafic ash tuff (imat), intermediate and mafic lapillistones (iml), and several mafic flows (mf). The member is exposed in outcrop within the eastern part of the South Heninga Lake area only. It is suggested that this member may extend to the west of the known exposures and may occur between members A_5 and B_2 immediately above the deposit as it is illustrated in Figure 5. Although member B_1 is similar to members A_1 and A_3 which have been described, member B_1 has a large percentage of mafic fragments in the tuffs and is unmineralized.

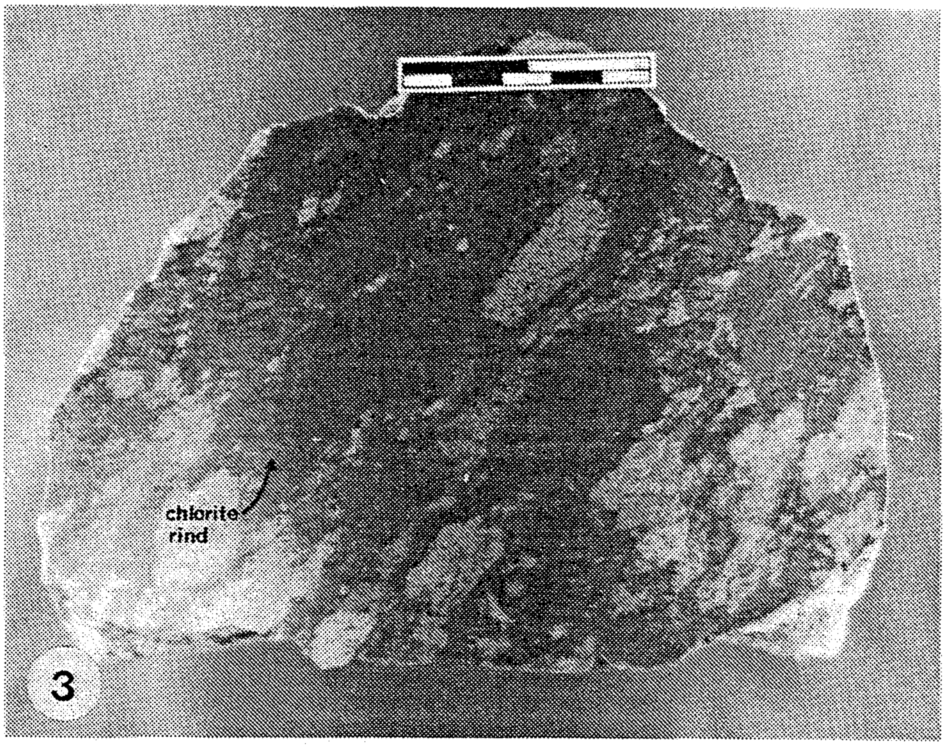
The lapillistones (iml) are composed of 30 to 50% essential and accessory mafic fragments and 50 to 70% accidental intermediate fragments. The mafic fragments have been altered to a secondary mineral assemblage composed of fine grained albite, chlorite, sericite, saussurite, and minor quartz. In the cores of the fragments, the albite, which has pseudomorphically replaced the original plagioclase laths, still exhibits the primary trachytic texture. The cores of the fragments are surrounded by a 0.5 cm thick glassy rind which has now altered to chlorite (Plate 3).

The intermediate lapilli fragments are heterolithic and accidental, and have been derived from older intermediate volcanic rock. These intermediate fragments often show various primary textures from the older volcanic rock such as amygdules and microphenocrysts.

The ash tuffs of member B_1 are slightly more mafic than the ash tuffs of Formation A. Occasional mafic and intermediate lapilli fragments are scattered throughout the tuff. Unlike the ash tuff of Formation A, none of the ash tuff of member B_1 is cherty or mineralized.

Two small aphyric mafic flows are partly exposed in the member. These flows appear to be lenticular in shape and from 30 to 40 m thick. The upper 2 to 3 m of each flow is usually brecciated, probably due to autobrecciation during extrusion. The flows are composed

Plate 3: Heterolithic mafic and intermediate lapilli fragments of member B_5. Mafic fragments have a thin chloritic rind.


chlorite
rind
3

of about 60 to 70% felted, tabular, plagioclase crystals. These crystals are from 0.3 to 1.0 mm in diameter and have been replaced by albite, and minor saussurite, biotite, and carbonate. The balance of the rock has been altered to a fine grained intergrowth of biotite, actinolite, saussurite, and carbonate.

Member B_2: A sequence of intermediate feldspar porphyry flows forms member B_2. The member extends across the South Heninga Lake area but thins from 280 m thick on the west to 160 m thick on the east side of the South Heninga Lake area (Figure 5) and probably grades laterally into member B_1 to the east of the area mapped. It is underlain to the south and overlain to the northeast by parts of member B_1, and is overlain to the northwest by member B_3. Contacts with members B_1 and B_3 are sharp.

The member is best exposed just to the north of the deposit along the shore of Heninga Lake where there are three flows each of which are 60 to 80 m thick. Autobrecciation of the flows has produced a 30 to 40 m thick layer of flow breccia (ifb) on top of the flows, and several small isolated pods of breccia within each flow. The flows are mostly porphyritic (ifpf) but may have a 5 to 10 m thick aphyric core (if) near the centre of the flow.

The plagioclase phenocrysts within the porphyritic parts of the flows are from 2 to 7 mm in diameter and have been replaced by pseudomorphs of albite, chlorite, carbonate, and saussurite. Occasional smaller quartz phenocrysts, 0.3 to 0.4 mm in diameter, occur with the feldspar phenocrysts. The groundmass for the flows has recrystallized to a fine grained (less than 0.1 mm) intergrowth of albite, quartz, chlorite, saussurite, and minor sericite and carbonate.

Between the top of the first flow and the base of the second flow is a 10 m thick layer of ash tuff (iat) similar to that found in member B_1.

<u>Member B_3</u>: Member B_3 comprises a 25 m thick sequence of interlayered ash tuff, tuffaceous sediments, cherts, and oxide iron formation. The member is exposed across the entire South Heninga Lake area and has sharp upper and lower contacts.

The identifying feature of this member is several beds of thinly layered oxide iron formation. On the east side of the South Heninga Lake area, total thickness of each of the several beds of interlayered magnetite and white chert is about 0.5 m. On the west side, near the eastern shore of Heninga Lake, each of the beds have thickened to 2 to 4 m and are composed of interlayered magnetite, jasper, and minor white chert. The magnetite and cherts of the iron formation have recrystallized to magnetite cubes and octahedrons 0.1 to 0.2 mm in diameter and to quartz grains 0.1 to 0.15 mm in diameter.

Interbedded with the iron formation are ash tuffs and tuffaceous sediments. Similar to ash tuffs elsewhere in the section, those of member B_3 have altered to a fine grained intergrowth of quartz, chlorite, carbonate, and plagioclase. The tuffaceous sediments show considerable evidence of reworking in the form of abundant micro-crossbedding, scours, and soft sediment slumps, but are otherwise similar to the ash tuffs. These sediments are suggested to have resulted from the reworking of the fine grained ash deposits.

Member B_4: Several intermediate feldspar porphyry flows similar to those of member B_2 occur in the northeast corner of the South Heninga Lake area. The lower contact of member B_4 with member B_3 is sharp. The upper contact was not defined within the area mapped. To the west, member B_4 grades laterally into member B_5. The flows are locally amygdaloidal and contain up to 10% plagioclase phenocrysts, 2 to 3 mm in diameter. Several pods of flow breccia were exposed, however, outcrop exposure is insufficient to outline individual flows.

Member B_5: Immediately above member B_3 along the east side of Heninga Lake is an interlayered sequence of volcanic rocks consisting of approximately 75% mafic and intermediate lapillistones (iml), 5% ash tuffs (imat), and 20% mafic flows (mf). The lapillistones are heterolithic and are usually amygdaloidal. Occasional breccia sized fragments occur with the lapilli tuffs and lapilli breccias. Several thin beds of delicately layered ash were deposited with the lapilli tuffs and lapilli breccia. Two small 20 m thick aphyric mafic flows were extruded during the deposition of the tuffaceous sequence.

Member B_6: Member B_6 comprises mafic flows (mf) and flow breccia (mfb), and mafic and intermediate lapillistone and breccia (imlb). It is exposed along the shores and on several islands in Heninga Lake.

The lappillistone and breccia are similar to the volcaniclastic rocks of members B_1 and B_4, however, the fragment size is coarser and about 80% of the fragments are mafic. Fragment size varies from 1 to 30 cm in diameter but averages about 3 to 6 cm. The breccias and lapillistones are clast supported with about 90% carbonate and 10% ash matrix. The mafic fragments are essential and accessory in origin. The occasional accidental intermediate fragment occurs with the mafic fragments. Approximately 40% of the member is composed of mafic flows. These flows are usually pillowed and are frequently amygdaloidal, but are otherwise lithologically similar to the other mafic flows in the section.

Member B_7: A wedge of volcaniclastic sediments surrounded by the flows and lapillistones of member B_6 outcrops on a small island and a peninsula on the west side of the South Heninga Lake area.

Beds from 10 to 30 cm thick of sandstones, grit-stones, pebbly sandstones, and cobble and boulder conglomerate separate 1 to 2 m thick beds of pebble conglomerate. The pebbles, cobbles, and boulders are subangular to subrounded. The volcaniclastic rocks which make up the member were derived from intermediate and, to a lesser extent, mafic flows and pyroclastic rock.

Intrusive Rocks

This section describes all intrusive rocks encountered in the South Heninga Lake area. With the possible exception of several small, probably Archean, intermediate dykes, all the intrusions postdate Formations A and B.

(a) Archean Intermediate Dykes: Small discontinuous intermediate dykes up to 10 m in width occur throughout the South Heninga Lake area. The dykes are occasionally aphyric but usually are porphyritic. Plagioclase phenocrysts up to 2.0 mm in diameter form up to 40% of the dyke. The phenocrysts have been replaced by pseudomorphs of albite and minor sericite, chlorite, and carbonate. One intrusion also contained 10% quartz phenocrysts, 0.4 mm in diameter. The aphyric dykes and the groundmass of the porphyritic dykes have altered to a fine grained intergrowth of quartz, untwinned albite, sericite, carbonate, and chlorite.

The presence of the strong northeast trending slaty cleavage in these intrusive rocks suggests that the age of the dykes is older than that of the schistosity which is probably of late Archean age. The close similarity between the petrology of the dykes and the Archean feldspar porphyry flows of members B_2 and B_4 suggests that the dykes may be part of the feeder system for the flows, and that the dykes are of Archean age.

(b) Granitic Intrusions: Two quartz monzonite to quartz diorite intrusions of late Archean age (Bell, 1971) have intruded the metavolcanic and metasedimentary sequence. A large granitic batholith occurs on the extreme south end of Heninga Lake and there is a small granitic stock on the east side of the South Heninga Lake area. The stock is thought to slightly postdate the batholith.

(c) Kaminak Diabase Dykes and Sills: Diabase dykes and sills up to 50 m in width are best exposed in the southern part of the South Heninga Lake area. The diabases usually form sills rather than dykes since they have a tendency to intrude along the late Archean northeast trending slaty cleavage, which approximately parallels the bedding of the volcanic sequence.

The identifying feature of these Kaminak diabases is the occasional accumulations of large plagioclase phenocrysts. The Kaminak diabase sills and dykes have been described elsewhere in the Rankin-Ennadai belt by Beavon (1976) and Christie et al. (1975), and were dated at 2370 Ma (early Aphebian) by Wanless et al. (1973).

The plagioclase phenocrysts are up to 5 cm in size and are equant or tabular in shape. These phenocrysts have been replaced by pseudomorphs composed of albite, epidote, chlorite, and minor sericite, during metamorphism resulting from the late Aphebian Hudsonian Orogeny. Plagioclase laths with interstitial pyroxene in the groundmass have altered to albite, epidote, chlorite, and sericite, with interstitial chlorite, biotite, iron-titanium oxides, and uralite. Small amounts of fine grained quartz, pyrite, magnetite and pyrrhotite also occur in the groundmass. About 5% coarse, euhedral pyrite crystals have formed along the chilled margins of the diabase intrusions.

(d) Lamprophyre: The granitic batholith at the extreme south end of Heninga Lake (Figure 5) has been intruded by a small lamprophyre stock.

Altered mafic phenocrysts from 0.7 to 5 mm in diameter account for approximately 40 to 50% of the lamprophyre rock. About 30 to 40% of these phenocrysts are equant pseudomorphs of tremolite-actinolite which have replaced titaniferous augite. Subsequently, biotite has formed along the cleavage planes of the amphibole. There are minor amounts of calcite in the center of the phenocrysts along with moderate amounts of disseminated sphene. The balance of the phenocrysts are generally 1 to 2 mm in diameter and are tabular in shape. They have altered to fibrous chlorite, and minor biotite and uralite. These phenocrysts are interpreted as altered hornblende.

The matrix is a fine grained intergrowth of uralite, tremolite-actinolite, sphene, chlorite, biotite, and relict lathes of oligoclase-andesine plagioclase. A chemical analysis (Table II, p. 44) on this rock showed very high MgO (12.80%) and FeO (6.10%), similar to most lamprophyres as described by Turner and Verhoogen (1960), and Carmichael, Turner, and Verhoogen (1974), but had somewhat higher SiO_2, lower volatiles, and lower alkali content. This lower alkali content with respect to silica placed the overall composition of the lamprophyre in the subalkaline field rather than the alkaline field where most lamprophyres occur (Turner and Verhoogen, 1960).

The criteria for classification of lamprophyres however, is not defined precisely chemically. The term "lamprophyre" applies only to a group of dark coloured hypabyssal igneous rocks characterized by a high percentage of mafic phenocrysts in a fine grained matrix (Gary et al., 1974). According to the classification scheme of Turner and Verhoogen (1960), this stock is an altered camptonite lamprophyre.

The intrusion of the lamprophyre stock into the Archean granitic batholith indicates that the stock is post-Archean. The altered assemblage is of similar metamorphic grade to that found in the Kaminak diabase intrusions and probably results from metamorphism related to the late Aphebian Hudsonian Orogeny. It is suggested that the lamprophyre stock was intruded late in the Aphebian or early in the Helikian towards the end of the Hudsonian Orogeny, and is genetically related to that event. The stock may be related to the minette lamprophyres which occur elsewhere in the Rankin-Ennadai belt and have been dated at 1700 Ma

(Davidson, 1972).

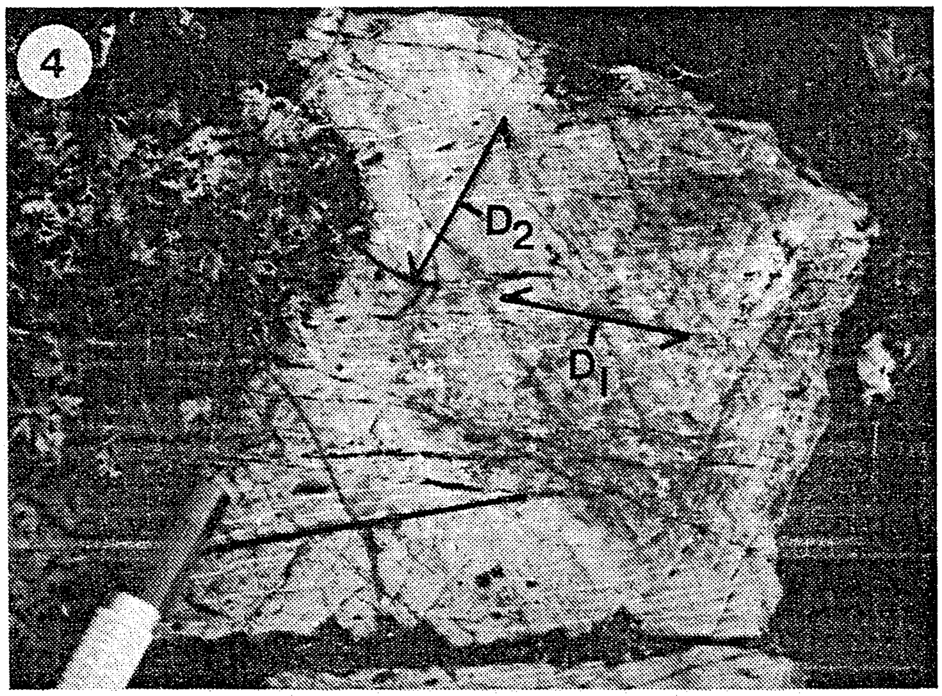
Structure

In the South Heninga Lake area, the bedding trends northeast, parallel to the contact between the metavolcanic sequence and the granitic batholith to the south of the deposit. The beds are overturned, dipping steeply to the south with the tops to the north. Along the extreme southwest part of the South Heninga Lake area (Figure 5), the strike of the bedding changes from northeast to north-northeast as the beds begin to bend around the nose of the anticline to the south of the area. A northwest trending fault in the Archean metavolcanic rock was interpreted on the basis of an offset in the stratigraphy along the southeast shore of Heninga Lake.

Two deformational events have been interpreted in the study area. The first event, D_1, produced a strong slaty cleavage and elongation of the volcaniclastic fragments in a northeast direction, approximately parallel to the bedding strike. The second event, D_2, resulted in a weak, north-northeast trending crenulation cleavage overprinted on the first D_1 cleavage. The second cleavage is usually present only in the phyllosilicate rich rocks such as the ash tuffs. Both the D_1 slaty cleavage and the D_2 crenulation cleavage are illustrated in layered ash tuffs in Plate 4.

The axis of the anticline to the south of the

Plate 4: Younger crenulation cleavage (D_2) overprinting older slaty cleavage (D_1) in layered ash tuff.


4
D2
D1

Heninga Lake area is located approximately at the center of the granitic batholith (Figure 5). The emplacement of the batholith may have resulted in the updoming of the Archean metavolcanic rock into an anticline. The similarity of attitude between the D_1 slaty cleavage and the axial surface of the anticline to the south of Heninga Lake suggests that the stress generated by the intrusion and the folding may have been responsible for the D_1 cleavage.

The small granitic stock on the northeast side of the South Heninga Lake area is illustrated in the map by Barrett et al. (1976) as strongly elongated in a northeast direction. It appears to postdate the D_1 event and is concordant with the D_1 foliation. This stock may have been passively emplaced along the plane of weakness represented by the bedding and the D_1 slaty cleavage. This plane of weakness may have been produced by dilatant processes related to the intrusion of the batholith and the folding of the metavolcanic sequence. Emplacement by these processes resulted in the elongation of the stock in a northeast direction.

The second D_2 crenulation cleavage was produced possibly during the late Aphebian Hudsonian Orogeny. Davidson (1970b) recognizes a weak Hudsonian schistosity which has a similar north-northeast orientation immediately to the east of Heninga Lake.

Metamorphism

The metamorphic grade of the Archean rocks in the South Heninga Lake area is low to middle greenschist. The metamorphic assemblage is of the quartz-albite-muscovite-chlorite subfacies, sporadically upgraded to the quartz-albite-epidote-biotite subfacies. Within areas that have undergone regional metamorphism to the quartz-albite-muscovite-chlorite subfacies, the plagioclase has altered to albite with the release of calcium producing calcite. The plagioclase may also have a fine dusting of sericite and chlorite. All ferromagnesian minerals have been replaced by chlorite.

In areas of quartz-albite-epidote-biotite subfacies metamorphism, the chlorite and sericite of the quartz-albite-muscovite-chlorite subfacies are replaced by biotite and saussurite. Locally, patches of tremolite-actinolite also form in the centers of the coarser feldspar grains. This metamorphism has been interpreted as being of late Archean age.

The Aphebian Kaminak diabase dykes and the camptonite lamprophyre stock have also been metamorphosed to the quartz-albite-epidote-biotite subfacies of the middle greenschist facies during the late Aphebian Hudsonian Orogeny. The effects of this second late Aphebian metamorphic overprinting is almost undetectable in the surrounding Archean rocks which can be assumed to have undergone the same metamorphic event (Eade, 1978).

Chemistry

Whole rock chemical analyses were completed on eight samples taken from fine grained, massive, largely nonporphyritic flows and intrusive rocks. One porphyritic sample from the camptonite lamprophyre stock was analyzed. The locations of these samples are shown in Figure 6.

C.I.P.W. normative compositions were calculated according to Irvine and Baragar (1971), based on the chemical analyses adjusted to 100% without H_2O. The upper limit on Fe_2O_3 was set at $\%Fe_2O_3 = \%TiO_2 + 1.5\%$, with the excess Fe_2O_3 being converted to FeO. Four samples were rejected as probably altered according to the criteria set by Gelinas et al. (1972). The remaining four samples were classified on the AFM, $Na_2O + K_2O/SiO_2$ and normative colour index/normative plagioclase plots of Irvine and Baragar (1971). These four chemical analyses and their normative compositions are shown in Table II.

All samples analyzed were calc-alkaline. The three samples from flows were basaltic to andesitic in composition. The lamprophyre sample plotted in the high magnesium field of the AFM plot.

Interpretation of Volcanic History

The volcanic stratigraphy in the South Heninga Lake area resulted from two different periods of volcanic activity. The initial volcanism was generally moderately to very explo-

Table II: Chemical Analyses from the South Heninga Lake Area
For sample locations, see Figure 6.

Chemical Analyses					C.I.P.W. Norms--% Cation Equivalents				
Sample	1	2	5	8		1	2	5	8
SiO_2	52.50	59.60	53.90	50.10%	Qtz	2.698	16.060	10.988	-- %
Al_2O_3	15.60	15.81	14.08	11.62%	Or	2.442	1.770	0.192	8.617%
Fe_2O_3	2.24	3.25	2.05	2.57%	Ab	33.365	32.234	30.584	23.799%
FeO	7.98	3.52	6.12	6.10%	An	26.048	27.516	26.301	15.879%
MgO	7.07	3.00	5.83	12.80%	Di	1.155	6.183	4.006	15.621%
CaO	5.76	8.16	6.40	8.16%	He	0.583	3.999	1.833	3.337%
Na_2O	3.60	3.48	3.14	2.62%	En	19.571	5.138	15.458	10.515%
K_2O	0.40	0.29	0.03	1.44%	Fs	9.879	3.016	7.073	2.246%
TiO_2	0.85	0.61	0.64	0.74%	Fo	--	--	--	13.069%
P_2O_5	0.19	0.11	0.12	0.21%	Fa	--	--	--	2.792%
MnO	0.15	0.10	0.13	0.15%	Mt	2.418	2.276	3.215	2.369%
CO_2	0.16	0.05	4.00	0.21%	Il	1.222	0.877	1.315	1.043%
H_2O	3.52	1.90	3.75	2.93%	Ap	0.411	0.238	0.301	0.445%
Total	100.02	99.88	100.19	99.65%	Cc	0.418	0.130	--	0.537%

sive and produced the extensive deposits of intermediate and felsic tephra which has been classified as Formation A. A large part of Formation A is made up of the intermediate heterolithic lapillistones of members A_1 and A_3. These two members were formed predominantly from lapilli sized accidental fragments derived from older intermediate rock, and a small amount of intermediate essential and accessory fragments. Deposition of these rocks could only have taken place during very explosive volcanism which blasted out large amounts of older solidified rocks along with a small amount of essential and accessory tephra. The coarseness and angularity of most of the volcanic fragments suggests that they underwent little if any secondary reworking before lithification. Separating these periods of very explosive volcanism were short periods of quieter volcanic activity during which thinly bedded, largely essential, intermediate ash tuffs were deposited. These sheets of ash tuff occur in members A_1 and A_3, sandwiched between the thick sequences of lapillistone. They also make up most of member A_4. Only small amounts of coarser accidental intermediate volcanic rock were deposited with the ash tuffs. In member A_4, however, the percentage of ash in the member decreases and the percentage of coarser lapilli increases from east to west. Since tephra typically tends to get coarser towards the vent source for the tephra, this would suggest that the vent source for this tephra in member A_4, is to the west of Heninga Lake. Small scale sedimentary structures in the ash tuffs of members A_1, A_3, and A_4 suggests deposition in a subaqueous environment and some sedimentary reworking.

Intermediate ash tuffs at the tops of member A_1 and member A_4 grade upward into the essential, felsic, quartz and feldspar crystal tuffs of members A_2 and A_5. The coarse ash to fine grained lapilli fragment size of the crystal tuffs suggests an intermediate intensity of explosive volcanism.

Three small mafic flows in members A_1 and A_3 represent the only volcanic flows observed in Formation A. The lack of similarity between these flows and any of the tephra suggests that there is probably a different source for the flows than for the tephra.

After the explosive intermediate and felsic volcanism of Formation A, a gradual change occurred resulting in intermediate and mafic effusive and explosive volcanism. This activity deposited the tephra and flows of Formation B. Several thick accumulations of tephra (members B_1, B_5, and to a lesser extent, B_6) were produced during the explosive volcanism. These are primarily heterolithic lapillistones, minor breccias, and some layered ash tuffs. They are similar to the tephra of Formation A, but have a large (30 to 70%) percentage of essential and accessory mafic fragments. The breccias of member B_6 on the extreme west side of South Heninga Lake are sufficiently coarse (up to 30 cm in diameter) as to be a proximal vent facies. As in Formation A, evidence for secondary reworking of the tephra in Formation B is generally poor. The exceptions are the volcaniclastic sediments of member B_7, and the volcaniclastic sediment component of member B_3. The gritstones, sandstones, and pebble conglomerates of member B_7 probably formed as a result of localized secondary reworking of tephra similar to that found in member B_6. Member B_3 represents a short quiescent volcanic period during which a thin sequence of interlayered jasper-magnetite iron formation, cherts, tuffs, and tuffaceous sediments was deposited.

Mafic flows (in members B_1, B_5, and B_6) and two sequences of intermediate feldspar porphyritic flows (members B_2 and B_4) make up the effusive part of Formation B in the South Heninga Lake area. The intermediate feldspar porphyry flows of members B_2 and B_4 are lithologically similar to the crystal tuffs of members A_2 and A_5 suggesting that they may have the same vent source. Archean intermediate feldspar porphyry dykes in the area are also lithologically similar to the intermediate flows of members B_2 and B_4, and may represent part of a feeder dyke system for that vent. The similarity of the mafic flows in Formation B to the essential mafic tephra suggests that possibly the mafic flows in Formation B may have been derived from the vent source to the west indicated in member B_6. The pillowed mafic flow in member B_6 further suggests a subaqueous environment for that flow.

The Archean volcanic rock in the South Heninga Lake area was probably deposited in a subaqueous environment as indicated by pillowed volcanic flows and some evidence of subaqueous reworking of the tephra. The lithological similiarity between many of the members in the two formations and the gradational change in composition throughout the volcanic stratigraphy suggest that, with the possible exception of the three mafic flows in Formation A, all the volcanic rock was derived from the same vent. In addition, evidence from two members (A_4 and B_6) indicates that the vent was south and west of Heninga Lake. The volcanic stratigraphy in the South Heninga Lake area shows two different periods of volcanic activity. Initially, explosive volcanism deposited intermediate and felsic tephra, followed by explosive and effusive volcanism which deposited intermediate to mafic flows and tephra. The South Heninga Lake deposit occurs near the top of the initial sequence of intermediate and felsic tephra.

CHAPTER 4

DISTRIBUTION AND NATURE OF THE SULPHIDE MINERALIZATION OF THE SOUTH HENINGA LAKE DEPOSIT

General Statement

The geology of the sulphide mineralization is based on logs from 22 diamond drillholes drilled in the deposit and on detailed 1:1000 scale surface mapping. For the surface mapping, frost heaved boulders were used where they were judged to reliably represent the bedrock to supplement the low percentage of outcrop around the deposit. An interpreted correlation of the surface geology and the updip projection of the drillholes is shown in Figure 8 (in pocket) at a scale of 1:1000.

The host rocks for the sulphides in the South Heninga Lake deposit are the siliceous ash tuffs, cherts, and lapilli-stones of member A_4. No sulphide mineralization occurs above the contact between members A_4 and A_5. Several east-west trending Kaminak diabase sills and dykes have intruded into the deposit and its host rocks, and apparently have offset the mineralization in some places.

The sulphide mineralization in the South Heninga Lake deposit has been split into three zones: the western zone, the central or Gemex zone, and the eastern zone. Each zone consists of a distinct concordant lens or group of lenses of massive (50 to 70% sulphide minerals) and semi-massive

(30 to 49% sulphide minerals) sulphide mineralization, sometimes with discordant bodies of stringer (5 to 29% sulphide minerals) sulphide mineralization associated with them (Figure 9).

Massive Sulphides

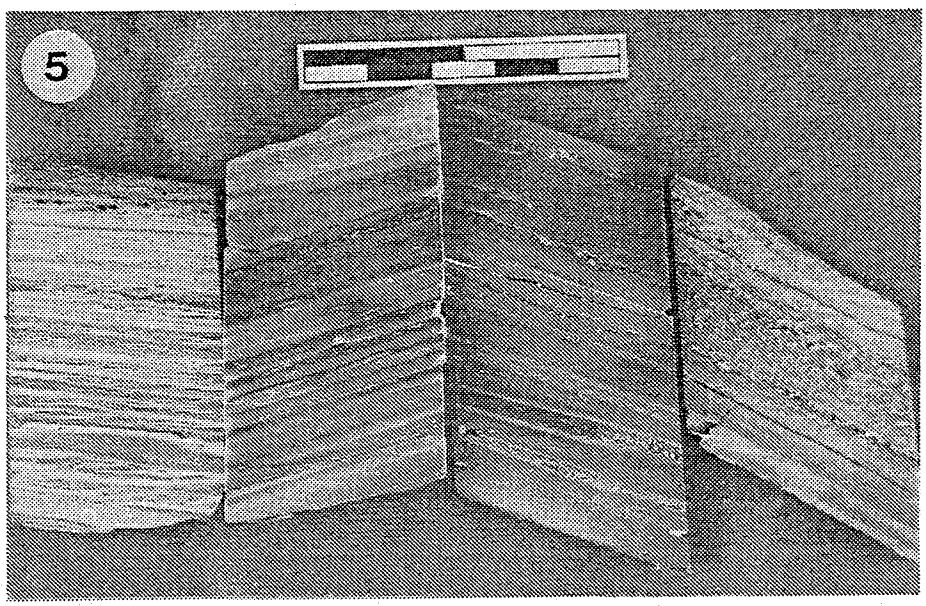
Dimensions and Form

The sulphide lenses of all three zones are concordant with the bedding of the tuffaceous host rocks. The central and the eastern zones are composed of sulphide lenses up to 3 m thick and 90 m long. The western zone largely consists of a single 3 to 4 m thick and 400 m long sulphide lens.

Upper contacts of the sulphide lenses with the ash tuffs and cherts of member A_4 are usually sharp and the lower contacts are usually gradational. However, exceptions to this, that is, gradational upper contacts and sharp lower contacts, do occur locally in the central and eastern zones.

Laterally the sulphide lenses of the central, eastern, and to a lesser extent, western zones thin rapidly and split into multiple, up to 1 m thick concordant beds of massive and semi-massive sulphide mineralization alternating and delicately interlayered with cherts and ash tuffs (Plate 5). These thin beds of sulphide mineralization may extend up to 20 m beyond the end of the main sulphide lens. Thin sulphide beds also occasionally occur interlayered with chert and ash tuff beds between the stacked sulphide lenses of the central zone and the scattered sulphide lenses of the eastern

Plate 5: Delicately layered cherts and cherty ash tuffs with thin beds of pyrite and chalcopyrite. From (left to right) DDH SJ-4-75, 111.08-.12 m; SJ-4-75, 108.28-.33 m; SJ-5-75, 94.51-.64 m; SJ-7-75, 113.10-.14 m.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zone.

Mineralogy and Zoning

The mineralogy of the sulphide lenses of the South Heninga Lake deposit is simple. Pyrite, chalcopyrite, and sphalerite are the major sulphide minerals, and pyrrhotite and galena occur in minor amounts. Tetrahedrite-tennantite was identified in the eastern zone (drillhole SJ-4-75, 97.65-.70 m).

A characteristic mineralogical zoning exists in the sulphide lenses of each zone. In the western zone, there is a structureless core composed primarily of chalcopyrite, pyrite, and some pyrrhotite at the base of the single extensive lens. On top of this massive core, forming the upper part of the lens, is a blanket of layered sphalerite and pyrite, which may contain a small amount of galena.

The sulphide lenses of the central zone often show a similar change from structureless chalcopyrite and pyrite at the base (south) to layered pyrite and sphalerite at the top (north) of each lens. However, some of the lenses may show some variation of this pattern, e.g. a sulphide lens which is composed of layered pyrite and sphalerite between two layers of chalcopyrite and pyrite, or an entire lens composed of chalcopyrite and pyrite with no sphalerite and pyrite.

In the eastern zone, the massive sulphide lenses are composed predominantly of layered sphalerite and pyrite with minor galena and some tetrahedrite, but little chalcopyrite. Assays for the eastern zone show a high silver content (up to 24 oz. Ag/ton compared to a maximum of 7.0 oz. Ag/ton for either the central or western zones).

Primary Textures

Primary sulphide textures, mostly displayed by pyrite, occur in all three zones. Layered (Plate 6) and botryoidal colloform (Plate 7) textures are preserved in the massive and semi-massive sulphide ores of the lenses. Circular pyrite framboids (Plate 8) from 0.1 to 1.0 mm in diameter are preserved in the ash at the edge of the sulphide lenses in the eastern zone.

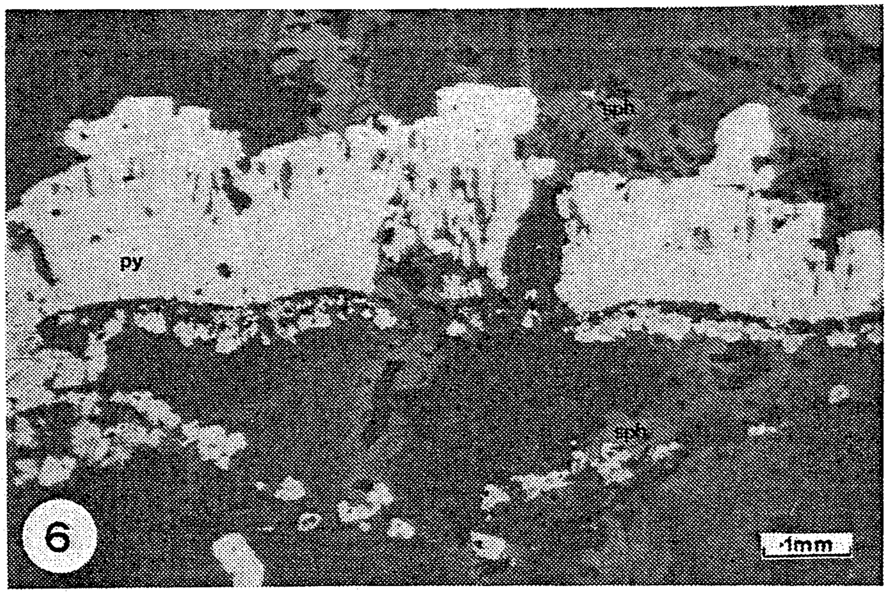
A compositional layering often exists in the massive sulphide lenses of all zones. In the massive, zinc rich portions, a 1 to 2 cm thick layering of pyrite and sphalerite usually occurs. The copper rich sections are usually massive, but a crude layering between the pyrite-chalcopyrite and the pyrrhotite may exist. There is insufficient evidence in the deposit to designate this compositional layering as either primary or secondary. However, similar layering has been interpreted to be a primary feature in other Archean massive sulphide deposits (Sangster and Scott, 1976). This is suggested to be the case in the South Heninga Lake deposit.

Secondary Textures

With the exception of the primary textures described

Plate 6: Layered pyrite in sphalerite. From DDH SJ-2-75, 71.85-.91 m.

Plate 7: Botryoidal colloform pyrite. From DDH SJ-2-75, 70.40-.42 m.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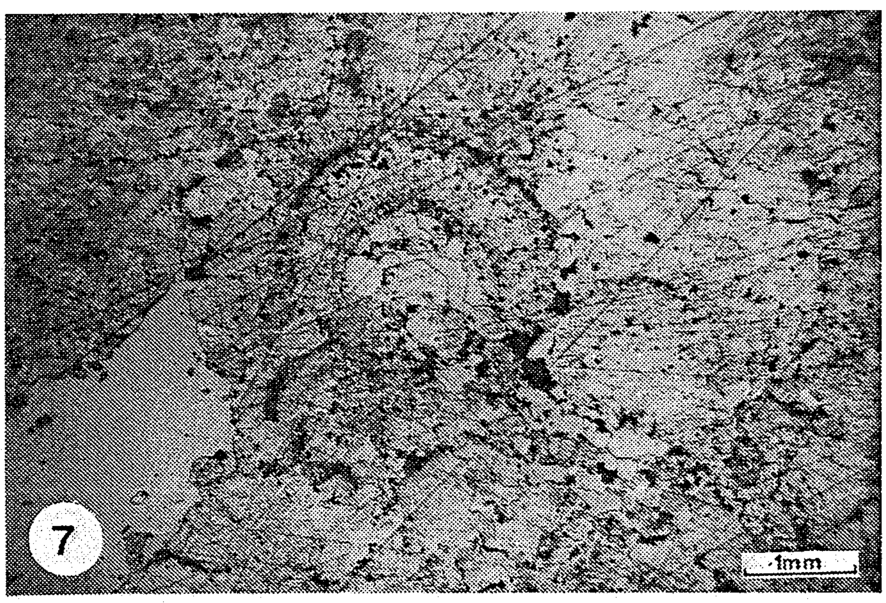
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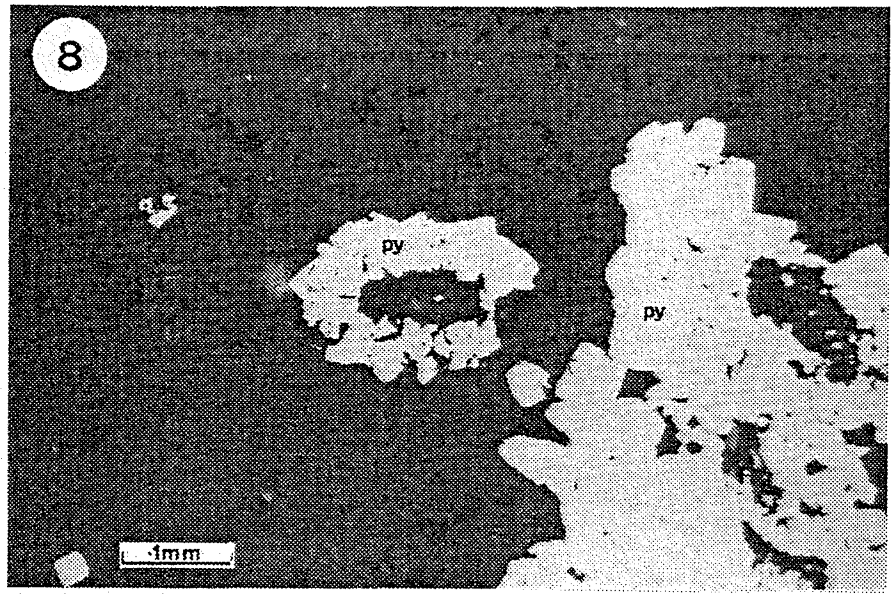
Plate 8: Framboidal pyrite. From DDH SJ-7-75, 113.10-.14 m.

Plate 9: Annealed sphalerite filling fractures in and replacing pyrite. From DDH SJ-4-75, 98.55-.61 m.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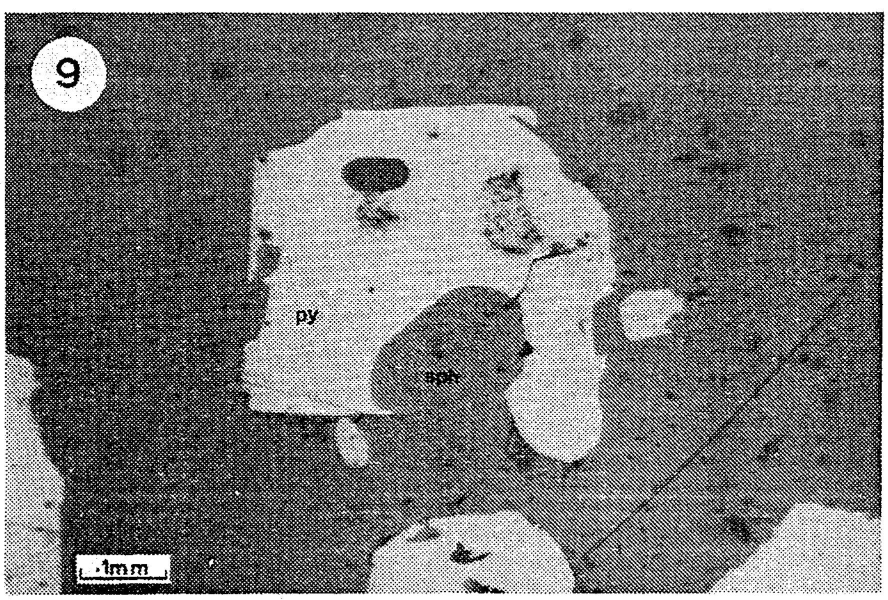
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above, the sulphide minerals have recrystallized forming secondary textures.

Pyrite is ubiquitous throughout the deposit and has usually been recrystallized to euhedral porphyroblasts up to 6 mm in diameter. Some of these have subsequently been milled and fractured by tectonic activity.

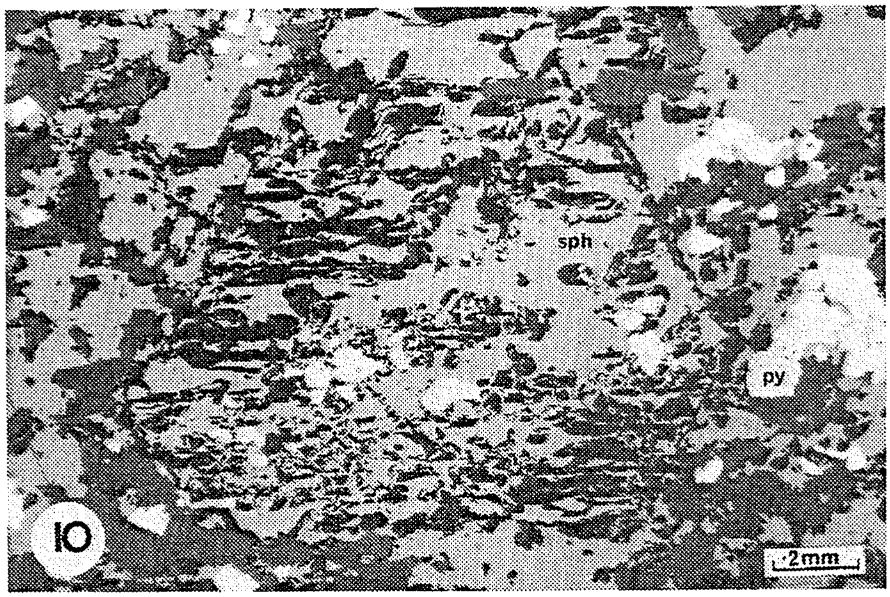
Chalcopyrite is usually found in association with pyrite and pyrrhotite, and to a lesser extent, with sphalerite. The recrystallized chalcopyrite grains are slightly anisotropic, from 0.1 to 0.4 mm in diameter, and are occasionally well twinned. The grains form irregular annealed masses often filling fractures in and replacing pyrite and pyrrhotite.

The concentration of sphalerite varies from that of a major constituent in association with pyrite and galena to a minor constituent with chalcopyrite, pyrite, and pyrrhotite. The sphalerite is coarsely crystalline (1.0 to 2.0 mm in diameter) and well twinned. Where sphalerite is in association with chalcopyrite, it often has chalcopyrite either as inclusions incorporated during crystal growth or as exsolution blebs which are sometimes localized along twin planes in the sphalerite. The sphalerite has flowed into fractures in pyrite, annealed in the fractures, and replaced some of the pyrite (Plate 9). Similarly, it has replaced chalcopyrite, pyrrhotite, and galena. Throughout the deposit, the sphalerite forms occasional hexagonal porphyroblasts up to 4 mm in diameter (Plate 10).

Pyrrhotite occurs in moderate concentrations with the massive pyrite and chalcopyrite, and as accessory partly

Plate 10: Hexagonal porphyroblast of sphalerite with some pyrite. From DDH SJ-2-75, 143.16-.42 m.

Plate 11: Alteration of pyrrhotite to pyrite along fractures. From DDH SJ-2-75, 70.40-.42 m.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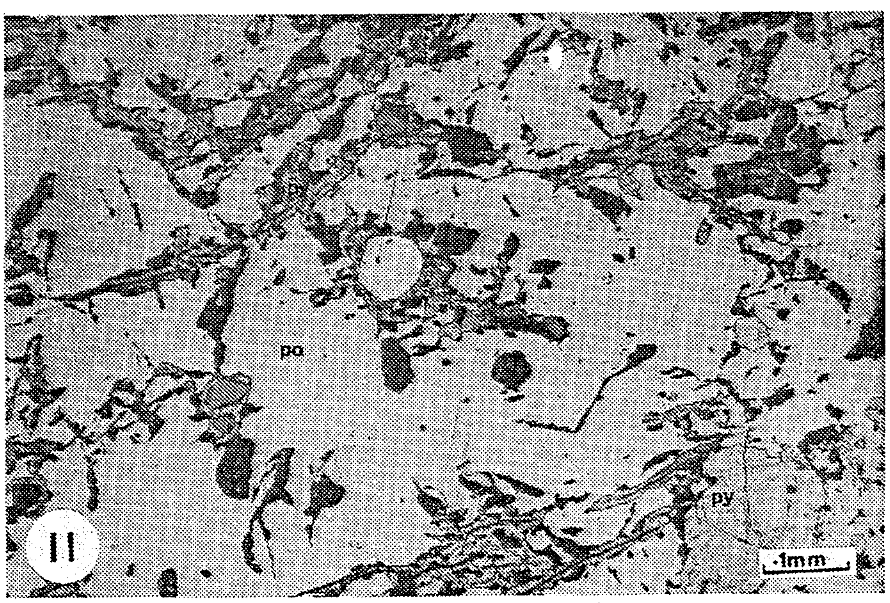
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replaced inclusions with the pyrite and sphalerite. In both cases the pyrrhotite has altered to pyrite along fractures (Plate 11), and occasionally has been partly replaced by chalcopyrite and sphalerite. Grain size is approximately 3 to 4 mm in diameter.

Partly replaced patches of galena sometimes occur with the sphalerite, particularly in the eastern zone. Small irregular masses of tetrahedrite-tenantite were found with the galena in the eastern zone.

Stringer Sulphides

A large body of discordant stringer mineralization extends southward from the base of the massive sulphide lenses in the western zone and a second smaller body of stringer mineralization occurs beneath the massive sulphide lenses in the central zone. The second stringer body is irregular in shape and has been repeatedly offset by the intrusion of Kaminak diabase dykes. Both of these stringer bodies are composed of a stockwork of discordant interconnecting veins of pyrrhotite, pyrite, and chalcopyrite which form 5 to 20% of the rock. Similar to that described above, the pyrrhotite, pyrite, and chalcopyrite in the string have recrystallized; the pyrite to coarse grained subhedral cubes, and the chalopyrite and pyrrhotite to medium grained irregular annealed masses.

Alteration

Immediately above and below the center of the massive sulphide lenses of the central and western zones, approximately where the stringer zones intersect the lenses, the host rocks have been extensively altered to chlorite (Figure 9). This chloritic alteration is closely associated with the massive sulphide lenses.

An extensive halo of rust weathering quartz-sericite-carbonate-pyrite alteration surrounds the chloritic alteration and the deposit. The upper contact of the quartz-sericite-carbonate-pyrite alteration is sharp and approximately corresponds to the contact between members A_4 and A_5. The lower contact, where it can be defined, is irregular, and crosscuts the contact between members A_3 and A_4. Extensive heavy silicification often occurs immediately below and around the chloritic alteration in the central zone, and to a lesser extent, the western zone.

Genesis of the Sulphide Mineralization

The genesis of the sulphide mineralization has been interpreted as syngenetic. The concordant, bedded nature of the massive sulphides in the deposit suggests that they were deposited with the ash tuffs, lapillistones, and cherts of member A_4 at the water-seafloor interface. The central and eastern zones were probably deposited simultaneously along the same stratigraphic level and the westerm zone was deposited slightly later. The stacked nature of the massive sulphide lenses of the central zone and the scattered nature of the lenses of the eastern zone probably resulted from the deposition of volcanic ash and lapilli disrupting or altering the flow of the mineralizing fluids which were depositing the sulphides. The sulphide mineralization of the western zone was deposited under quieter volcanic conditions where there was sufficient time for a single large massive sulphide lens to be deposited. The course of the mineralizing fluids to the site of precipitation is marked by the two discordant stringer sulphide zones which occur beneath the central and western zones. The mineralizing fluids moved up through these zones depositing thin stringers of pyrrhotite, pyrite, and chalcopyrite.

Sangster and Scott (1976) note that the sulphides are ideally precipitated with a distinct mineralogical zonation; massive chalcopyrite-pyrite above the stringer pipe is overlain by layered sphalerite and pyrite, often with some galena. This is in agreement with the mineralogical zonation observed in the massive sulphide lens of the western zone and supports the concept that this lens formed without much disturbance under quiet volcanic conditions. Although the sulphide lenses of the central zone often show a similar mineralogical zonation, the disruption and altering of the flow of the mineralizing fluids by the deposition of volcanic ash and lapilli, produced some abnormal variations of this mineralogical zoning in several of the sulphide lenses.

The sphalerite-pyrite-galena mineral assemblage and the lack of evidence for a stringer zone beneath the eastern sulphide zone indicate that these massive sulphide lenses were deposited away or distal from their source. The similar stratigraphic position of the eastern zone with respect to the central zone suggests that the massive sulphide lenses of the former could have been produced from mineralizing fluids derived from the latter. Mineralizing fluids could have been produced at the central zone, and the chalcopyrite and some pyrite and pyrrhotite could have been precipitated out immediately. Some of the remaining Fe, Zn, Pb, and Ag rich fluids could have flowed away from the central zone through unconsolidated material or along the seafloor to be caught, possibly in small ephemeral basins, at the eastern zone. There the sphalerite, galena, and pyrite could have precipitated out.

The percolation of the mineralizing fluids up through the permeable volcanic ash and lapilli along what is now a zone of stringer mineralization added iron and magnesium to the rocks along that zone and removed silica and calcium (Sangster and Scott, 1976). This alteration is now reflected by an area of intense chloritic alteration where the stringer pipe intersects the massive sulphide lenses of the western and central zones. Chloritic alteration above massive zones suggests that either mineralizing fluids continued after sulphides were buried, or some of the sulphides were precipitated below the sediment-water interface. The silica and calcium derived from the desilicification and decalcification of the stringer zone rock percolated out through the surrounding rock producing what is now seen as an extensive halo of quartz-sericite-carbonate-pyrite alteration which surrounds the deposit and the chloritic alteration. Introduction of the silicia and calcium into the subaqueous environment resulted in the precipitation and deposition of widespread chert nodules and beds, and some thin carbonate beds with the ash and lapilli of member A_4. The start of deposition of the quartz and feldspar crystal tuffs of member A_5 abruptly ended the mineralizing process and produced a sharp upper contact for the quartz-sericite-carbonate-pyrite alteration halo approximately at the member A_4-A_5 contact.

Chapter 5

CONCLUSIONS

1. The geology of the South Heninga Lake area can be subdivided into two formations here informally called Formation A and Formation B. Formation A is the oldest and is composed mostly of intermediate and some felsic tephra. Formation A is overlain by Formation B which is composed of intermediate and mafic tephra and flows. Both formations were deposited under subaqueous conditions.
2. The South Heninga Lake deposit occurs in the upper part of Formation A. Massive sulphide lenses in the deposit are conformable with a sequence of intermediate and felsic ash tuffs and lapillistones.
3. Features of the sulphide mineralization suggest that the deposit is syngenetic with respect to the ash tuffs and lapillistones, and is similar to what many authors call volcanogenic massive sulphide deposits.
4. The deposit is composed of three massive sulphide zones. Two of these occur over unconformable stringer sulphide zones, which are interpreted to be the source conduits for the mineralizing fluids from which precipitated the two proximal sulphide zones. The third zone is interpreted to be distal sulphides precipitated from mineralizing fluids derived from

a source conduit beneath one of the other two proximal zones.

5. Element depletion and enrichment by the mineralizing fluids, followed by later greenschist facies metamorphism, has altered the rocks to chlorite where the stringer zone intersects the two proximal sulphide zones. It has also produced an extensive halo of quartz-sericite-carbonate-pyrite alteration which surrounds the deposit and the chlorite alteration.

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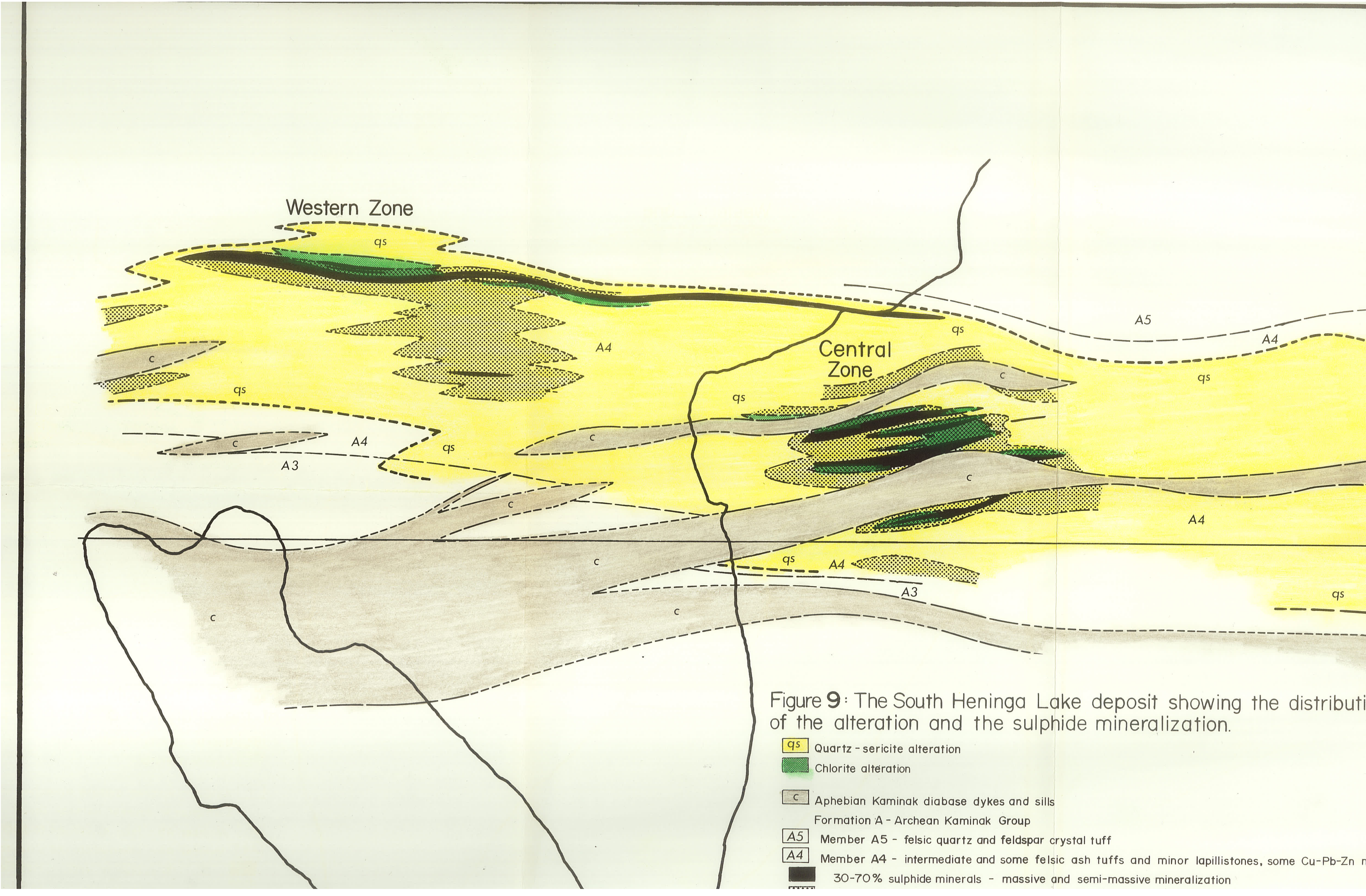
Figure 9: The South Heninga Lake deposit showing the distribution of the alteration and the sulphide mineralization; in The South Heninga Lake Copper-Zinc Deposit, District of Keewatin, N.W.T.; M.Sc. thesis, by Sidney Leggett.



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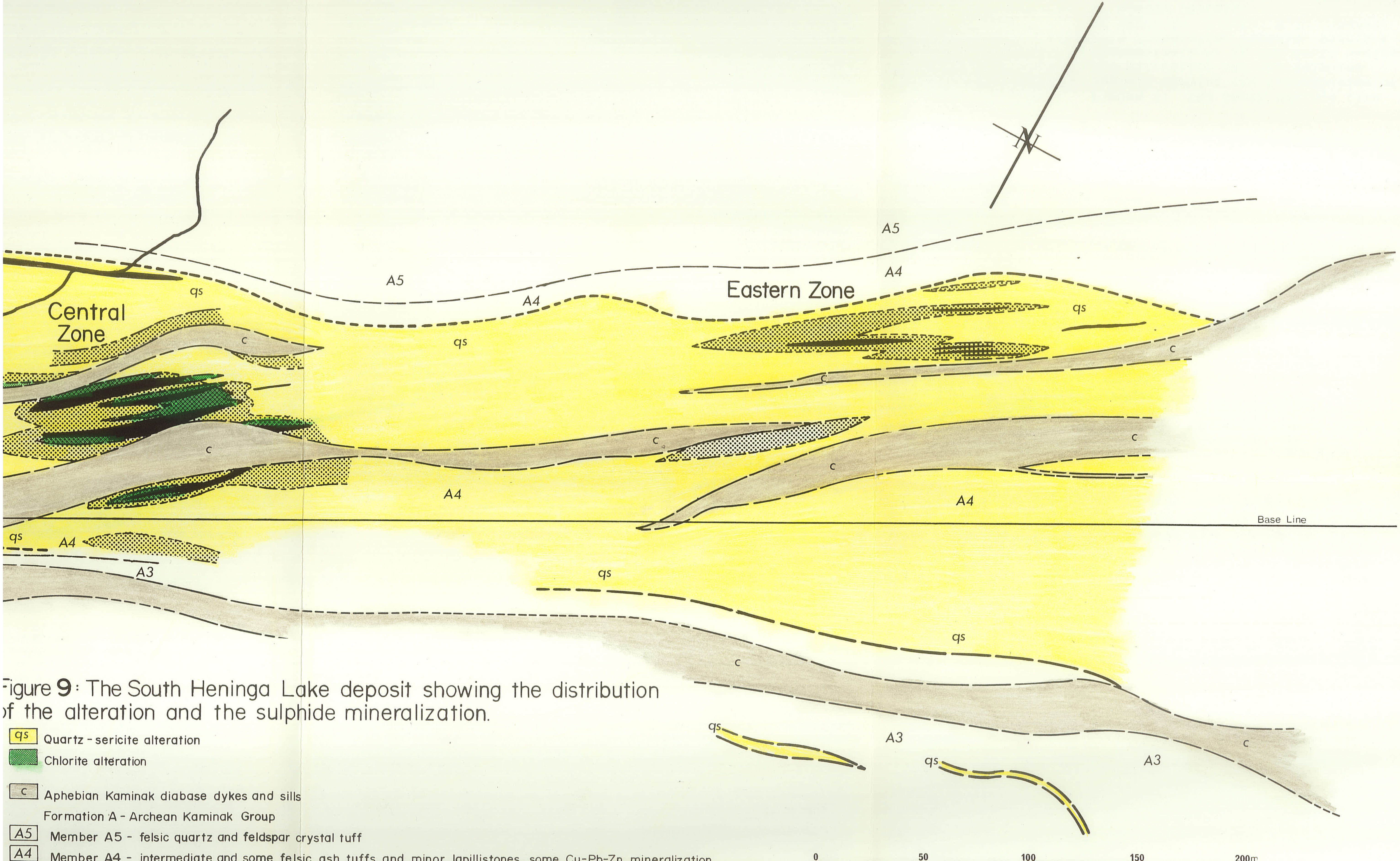


Figure 9: The South Heninga Lake deposit showing the distribution of the alteration and the sulphide mineralization.

qs Quartz - sericite alteration

Chlorite alteration

c Aphebian Kaminak diabase dykes and sills

Formation A - Archean Kaminak Group

A5 Member A5 - felsic quartz and feldspar crystal tuff

A4 Member A4 - intermediate and some felsic ash tuffs and minor lapillistones, some Cu-Pb-Zn mineralization

30-70% sulphide minerals - massive and semi-massive mineralization

5-29% sulphide minerals - stringer mineralization and interbedded sulphide mineralization and ash tuff

Figure 5: Geology of the South Heninga Lake area; *in* The South Heninga Lake Copper-Zinc Deposit, District of Keewatin, N.W.T.; M.Sc. thesis, by Sidney Leggett.

LEGEND

Intrusive Rocks

- d Aphebian or Helikian camptonite lamprophyre stock
- c Aphebian Kaminak diabase sills and dykes
- b Archean granitic intrusives

Archean Kaminak Group

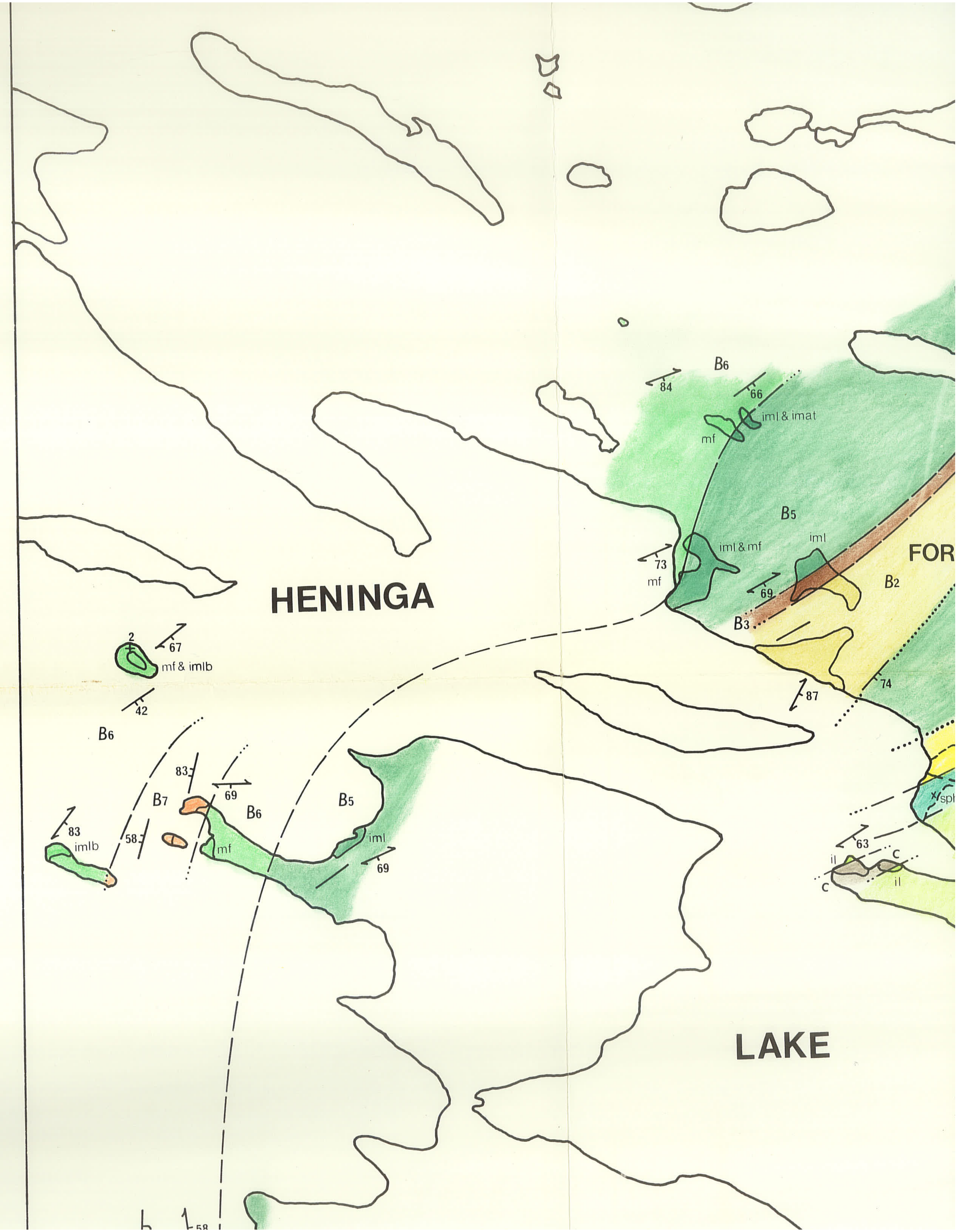
Formation B: Intermediate and mafic lapillistones, breccias, ash tuffs and flows; minor jasper-magnetite iron formation and volcaniclastic sediments

- Member B7 - Volcaniclastic sediments: sandstones, gritstones and conglomerate
- B6 - Intermediate and mafic lapillistones and breccia (imlb), and mafic flows (mf)
- B5 - Intermediate and mafic lapillistones (iml) and ash tuffs (imat), and mafic flows (mf)
- B4 - Intermediate feldspar porphyry flows
- B3 - Interlayered ash tuffs, tuffaceous sediments, cherts and jasper-magnetite iron formation
- B2 - Intermediate feldspar porphyry flows, minor ash tuff
- B1 - Intermediate and mafic lapillistones (iml) and ash tuffs (imat), and mafic flows (mf)

Formation A: Intermediate lapillistones and ash tuffs, felsic quartz and feldspar crystal tuffs, minor mafic flows

- Member A5 - Felsic quartz and feldspar crystal tuff
- A4 - Intermediate and some felsic ash tuffs and minor lapillistone
- A3 - Intermediate lapillistones (il) and ash tuffs (iat), minor mafic flows
- A2 - Felsic quartz and feldspar crystal tuff
- A1 - Intermediate lapillistones (il) and ash tuffs (iat), and mafic flows (mf)

	Area of outcrop
	Area of mapped frost heave
	Geological boundary (defined, approximate, assumed)
60	Bedding, tops known (overturned)
60	Bedding, tops unknown (inclined dip known, inclined dip unknown, dip unknown)
60	Schistosity, foliation (inclined)
	Fault (assumed)
3	Chemical analysis, location
x py,cp,sph	Mineral occurence (pyrite, chalcopyrite, sphalerite)



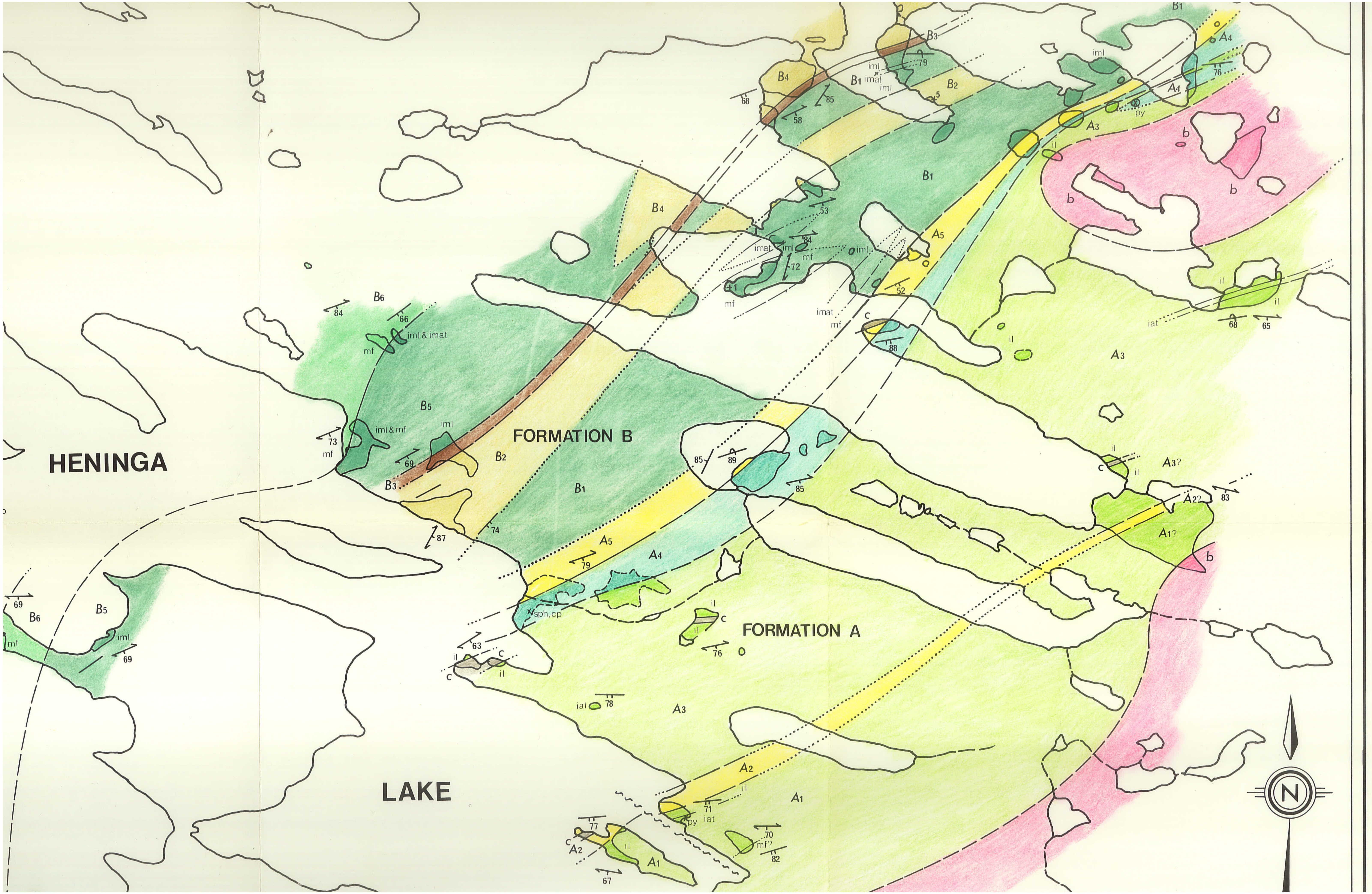

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Figure 6: Detailed geology of the South Heninga Lake area; in The South Heninga Lake Copper-Zinc Deposit, District of Keewatin, N.W.T. M.Sc. thesis, by Sidney Leggett.

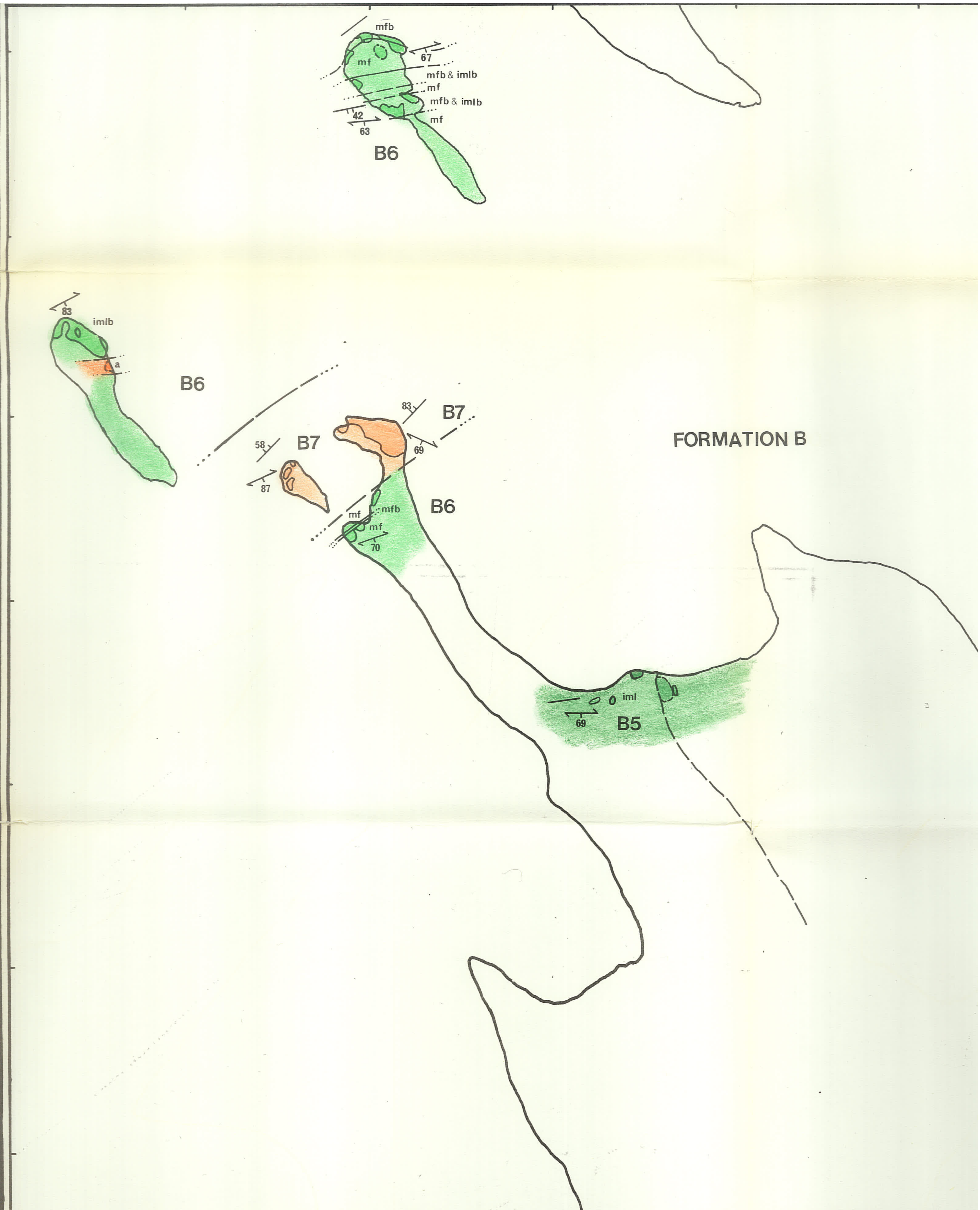


Figure 6: Detailed geology of the South Heninga Lake area.

LEGEND

INTRUSIONS

- c Aphebian Kaminak diabase sills and dykes
- b Archean granitic intrusions
- a Archean intermediate dykes

ARCHEAN KAMINAK GROUP

Formation B: Intermediate and mafic lapillistones, breccia and ash tuffs, mafic flows, minor jasper-magnetite iron formation and volcaniclastic sediments

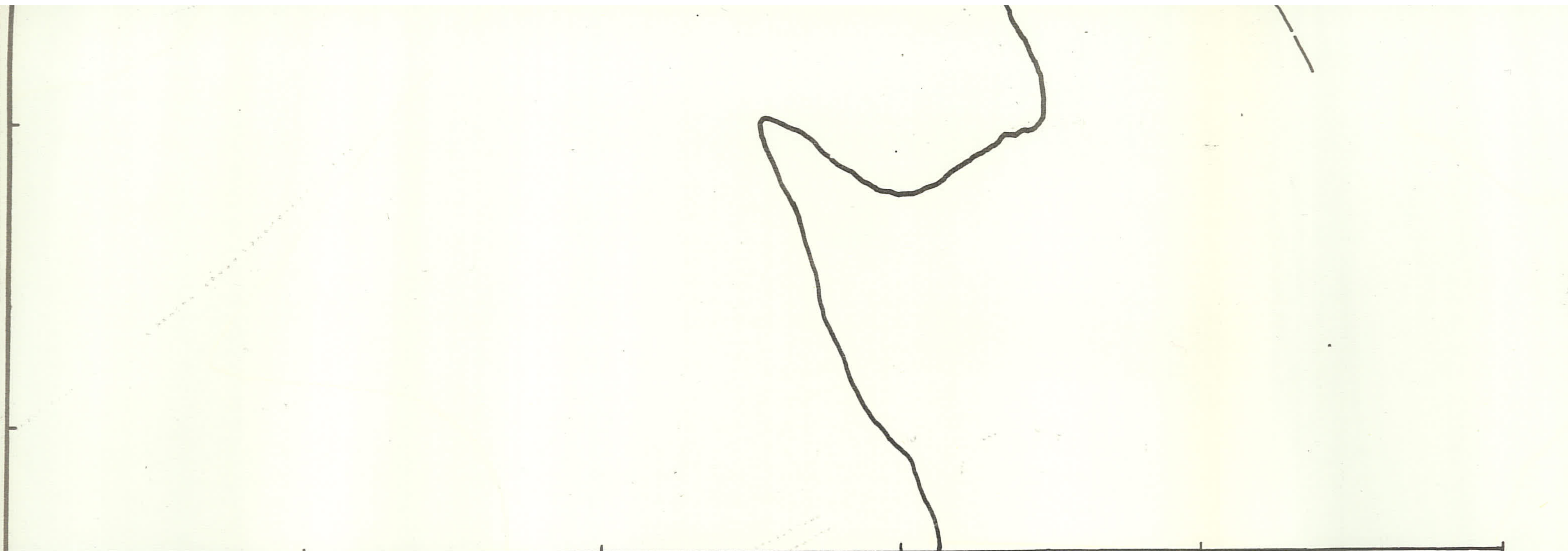


Figure 6: Detailed geology of the South Heninga Lake area.

LEGEND

INTRUSIONS

- c Aphebian Kaminak diabase sills and dykes
- b Archean granitic intrusions
- a Archean intermediate dykes

ARCHEAN KAMINAK GROUP

Formation B: Intermediate and mafic lapillistones, breccia and ash tuffs, mafic flows, minor jasper-magnetite iron formation and volcaniclastic sediments

Member B7 - Volcaniclastic sediments: sandstone, gritstone and conglomerate

B6 - Intermediate and mafic lapillistones and breccia, some mafic flows; imlb, intermediate and mafic lapillistones and breccia; mf, mafic aphyric flows; mpf, mafic pillowed flows; mfb, mafic flow breccia

B5 - Intermediate and mafic lapillistones and ash tuffs, some mafic flows; iml, intermediate and mafic lapillistones; imat, intermediate and mafic ash tuffs; mf, mafic flows

B3 - Interlayered ash tuffs, tuffaceous sediments, cherts and jasper-magnetite iron formation

B2 - Intermediate feldspar porphyry flows and minor ash tuff; ifpf, intermediate feldspar porphyry flows; if, intermediate aphyric flows; ifb, intermediate flow breccia; iat, intermediate ash tuff

B1 - Intermediate and mafic lapillistones and ash tuffs, minor mafic flows

Formation A: Intermediate lapillistones and ash tuffs, felsic quartz and feldspar crystal tuffs, minor mafic flows

Member A5 - Felsic quartz and feldspar crystal tuffs

A4 - Intermediate and some felsic ash tuffs and tuffaceous sediments, may contain some thin beds of lapillistone and minor felsic quartz and feldspar crystal tuffs; fct, felsic quartz and feldspar crystal tuffs; g, gossaniferous weathering ash tuffs and sediments

A3 - Intermediate lapillistone and some ash tuffs, minor mafic flows or intrusions; il, intermediate lapillistones; iat, intermediate ash tuffs; mf, mafic flows or intrusions; g, gossaniferous weathering lapillistones and ash tuffs

A2 - Felsic quartz and feldspar crystal tuffs

A1 - Intermediate lapillistones, ash tuffs and possible mafic flows; il, intermediate lapillistones; iat, intermediate ash tuffs; mf, mafic flows

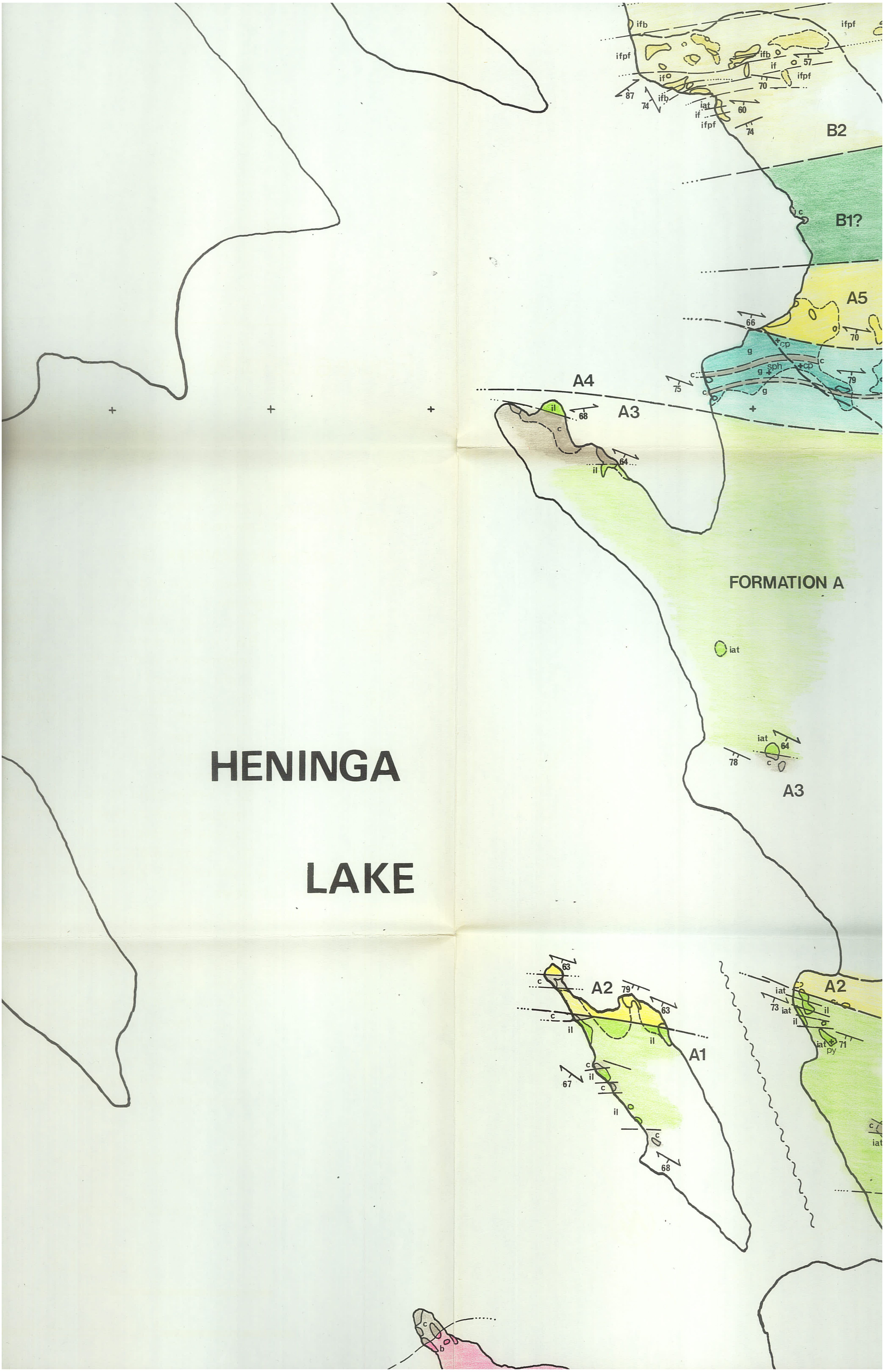
Area of outcrop	Area of mapped frost heave
65 Bedding, tops unknown (dip known, unknown)	65 Bedding, tops known (overturned)
65 Schistosity and foliation	+ Grid, baseline
+py, cp, sph Mineralization (pyrite, chalcopyrite, sphalerite)	Fault (assumed)

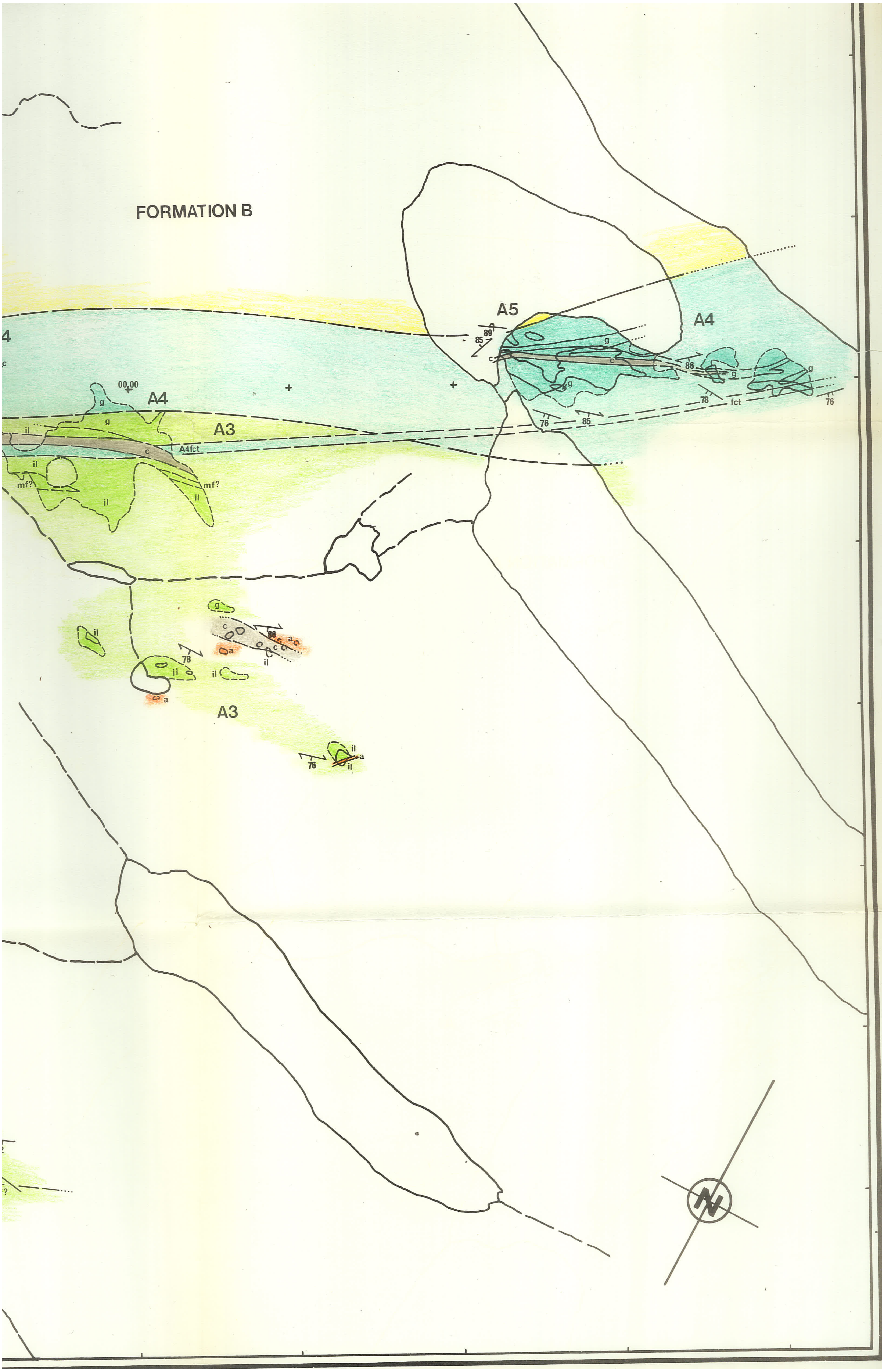
SCALE 1:4800

0 800 1600 2400 ft.

0 200 400 600 800 m


B6
B5
B5
B2
B1?
A4
A3
FORMATION A


HENINGA
LAKE
FORMATION A
A1
A2
A3
A4
A5
B1?
B2
ifb
ifpf
if
iat
il
c
g
sph
cp
py


FORMATION B
A5
A4
A4
A3
A4fct
A3
N

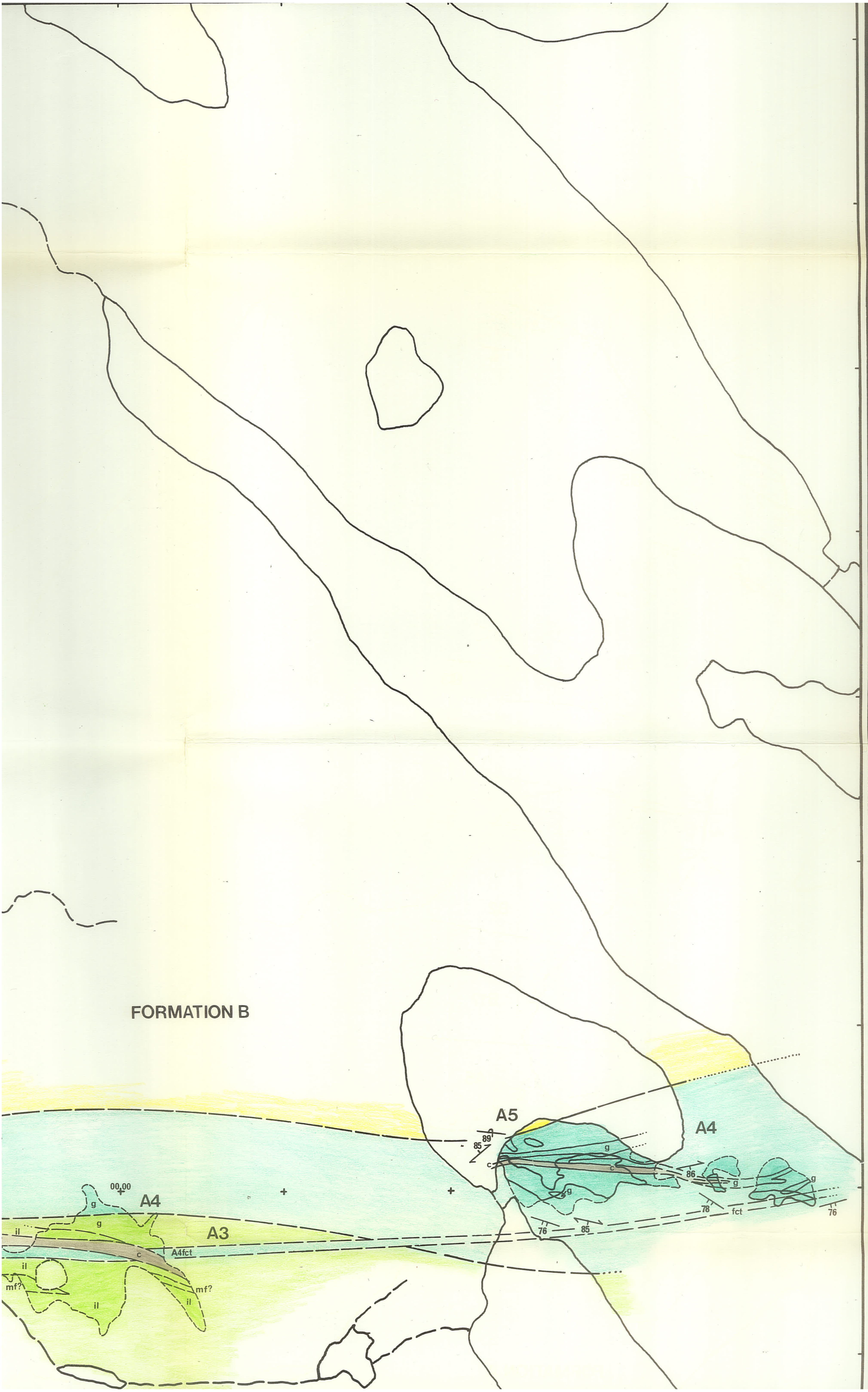
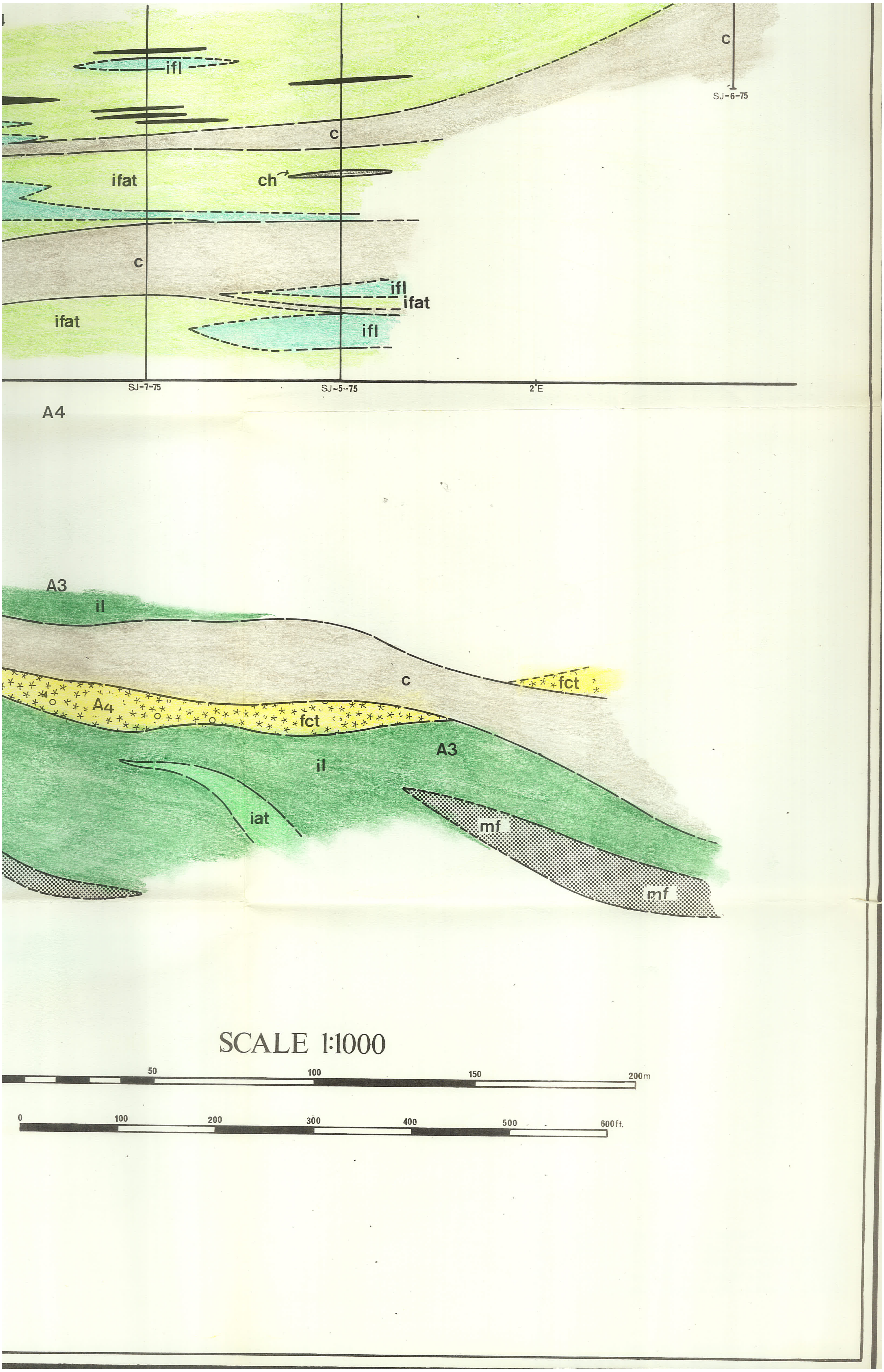
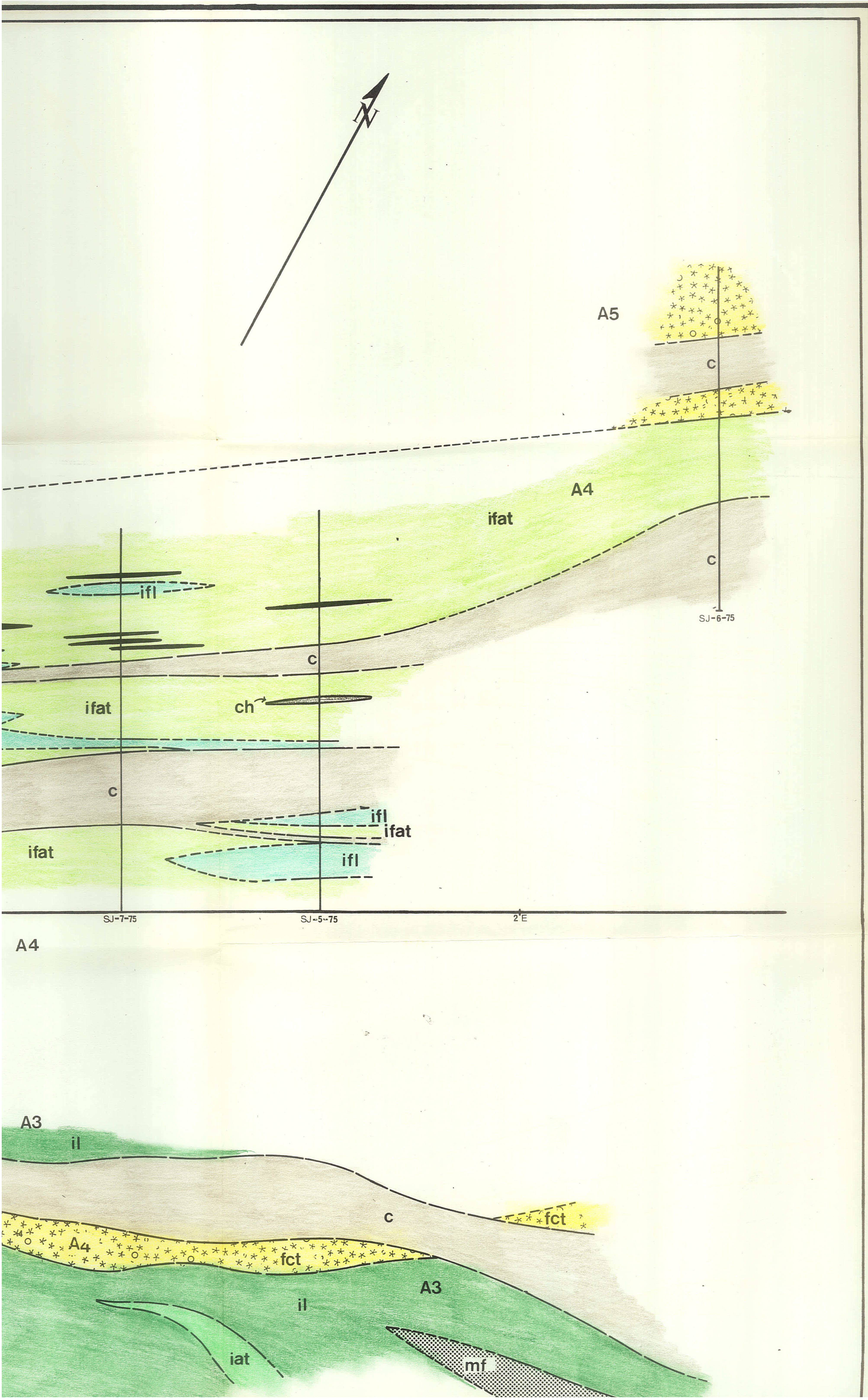
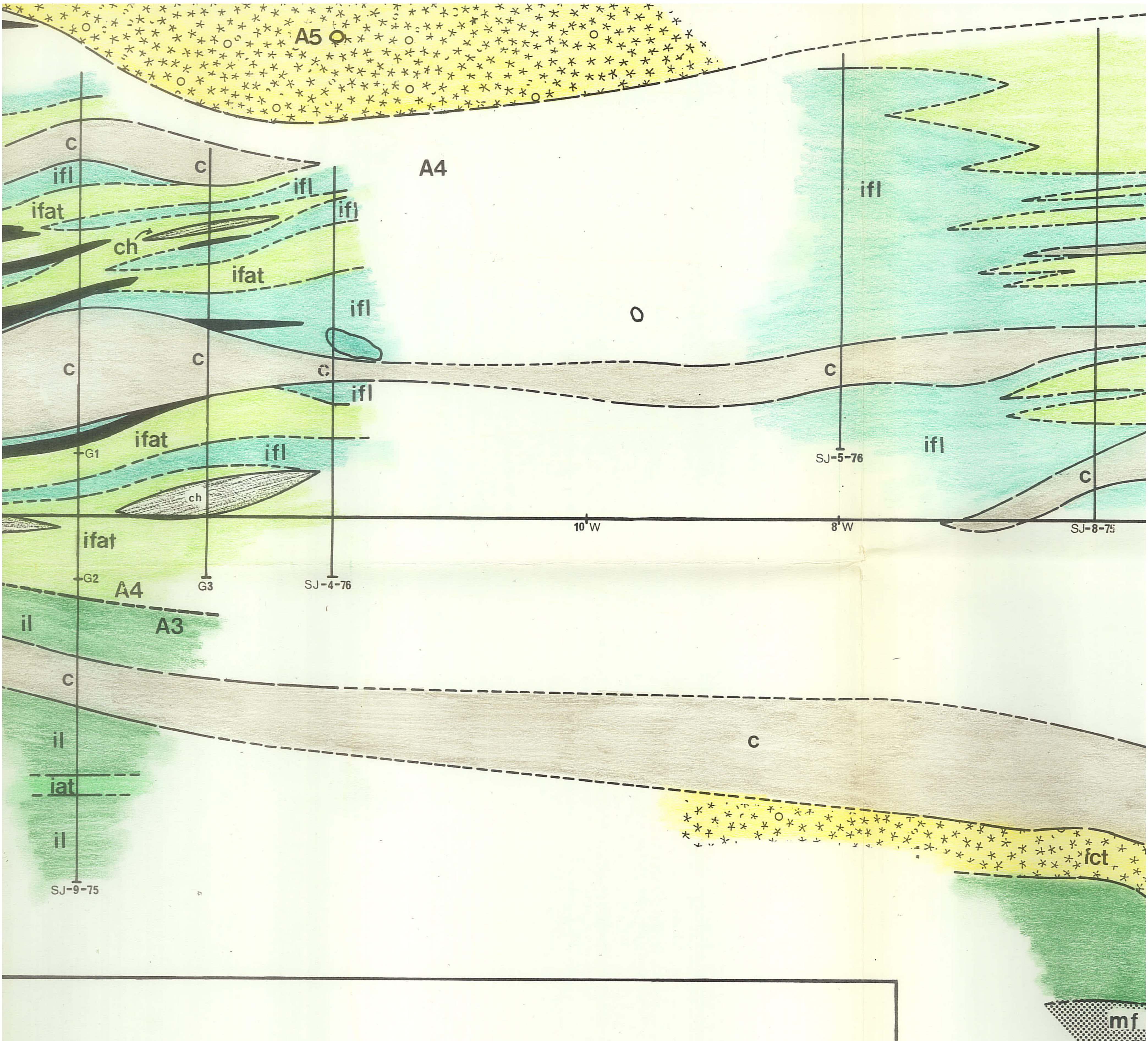

FORMATION B
A5
A4
A4
A3
A4fct
fct

Figure 8: Detailed geology of the South Heninga Lake deposit; <u>in</u> The South Heninga Lake Copper-Zinc Deposit, District of Keewatin, N.W.T. M.Sc. thesis, by Sidney Leggett.


c
SJ-6-75
ifl
c
ifat
ch
c
ifl
ifat
ifat
ifl
SJ-7-75
SJ-5-75
2 E
A4
A3
il
c
fct
A4
fct
A3
il
iat
mf
mf
SCALE 1:1000
50
100
150
200m
0
100
200
300
400
500
600ft.


N
A5
c
A4
ifat
c
SJ-6-75
ifl
c
ifat
ch
c
ifl
ifat
ifat
ifl
SJ-7-75
SJ-5-75
2 E
A4
A3
il
c
fct
A4
fct
A3
il
iat
mf



: Detailed geology of the South Heninga Lake deposit

Aphebian Kaminak diabase dykes and sills

Formation A - Archean Kaminak Group

Member A5 - felsic quartz and feldspar crystal tuffs

Member A4 - intermediate and some felsic ash tuffs, tuffaceous sediments and minor lapillistones, some Cu-Pb-Zn mineralization and cherts

ifat - intermediate and some felsic ash tuffs and tuffaceous sediments, frequently cherty, may contain thin beds and lenses of lapillistone

ifl - intermediate and some felsic lapillistone, may contain thin beds of ash tuff

fct - felsic quartz and feldspar crystal tuff

ch - massive white chert

s - massive and semi-massive sulphide mineralization (greater than 30% sulphide minerals)

Member A3 - intermediate lapillistones and some ash tuffs, minor mafic flows or intrusions

il - intermediate lapillistones, may contain thin beds of intermediate ash

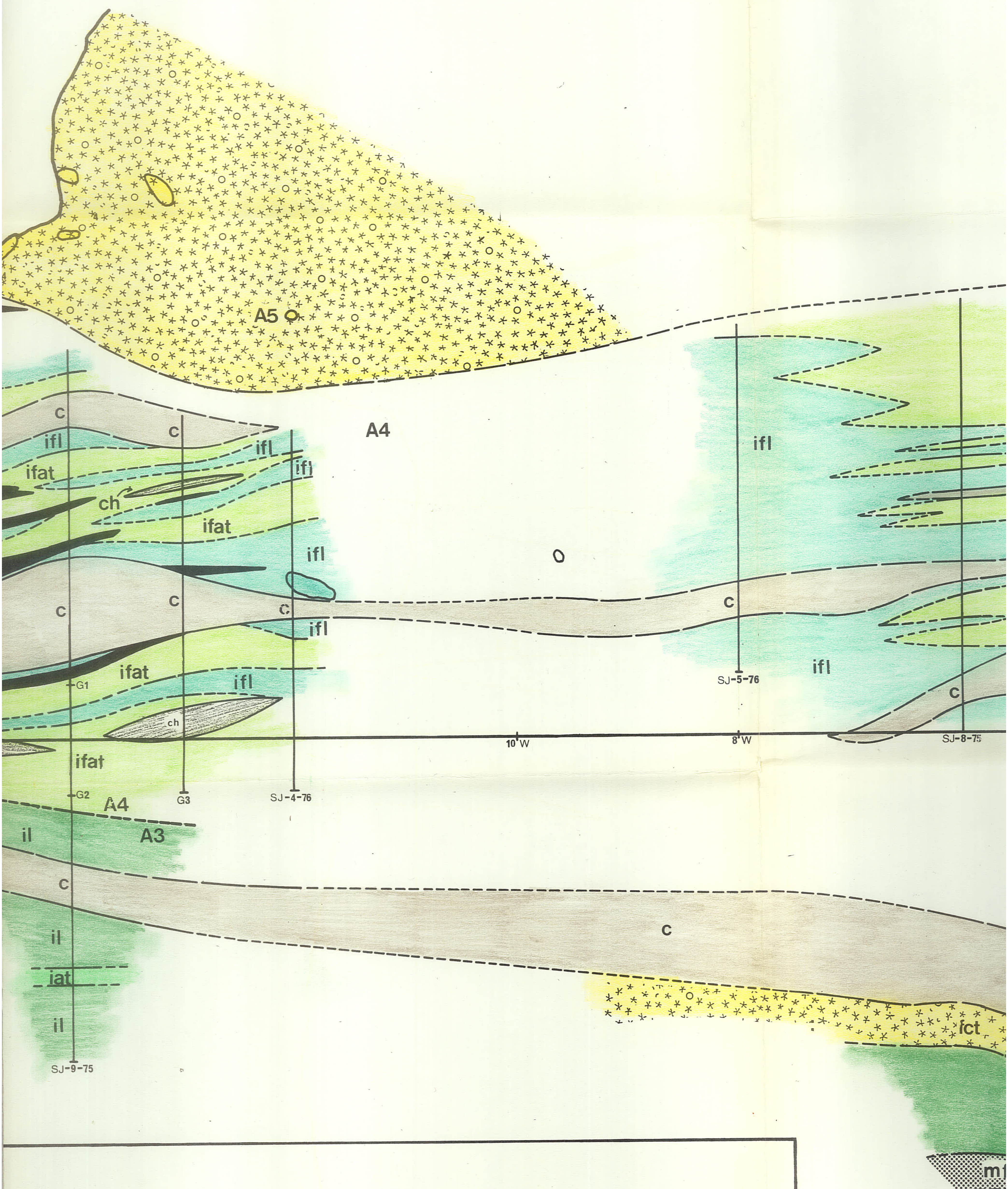
iat - intermediate ash tuff

mf - mafic flows or intrusions

Outcrop

Geological boundary

Grid, in 100s of feet



: Detailed geology of the South Heninga Lake deposit

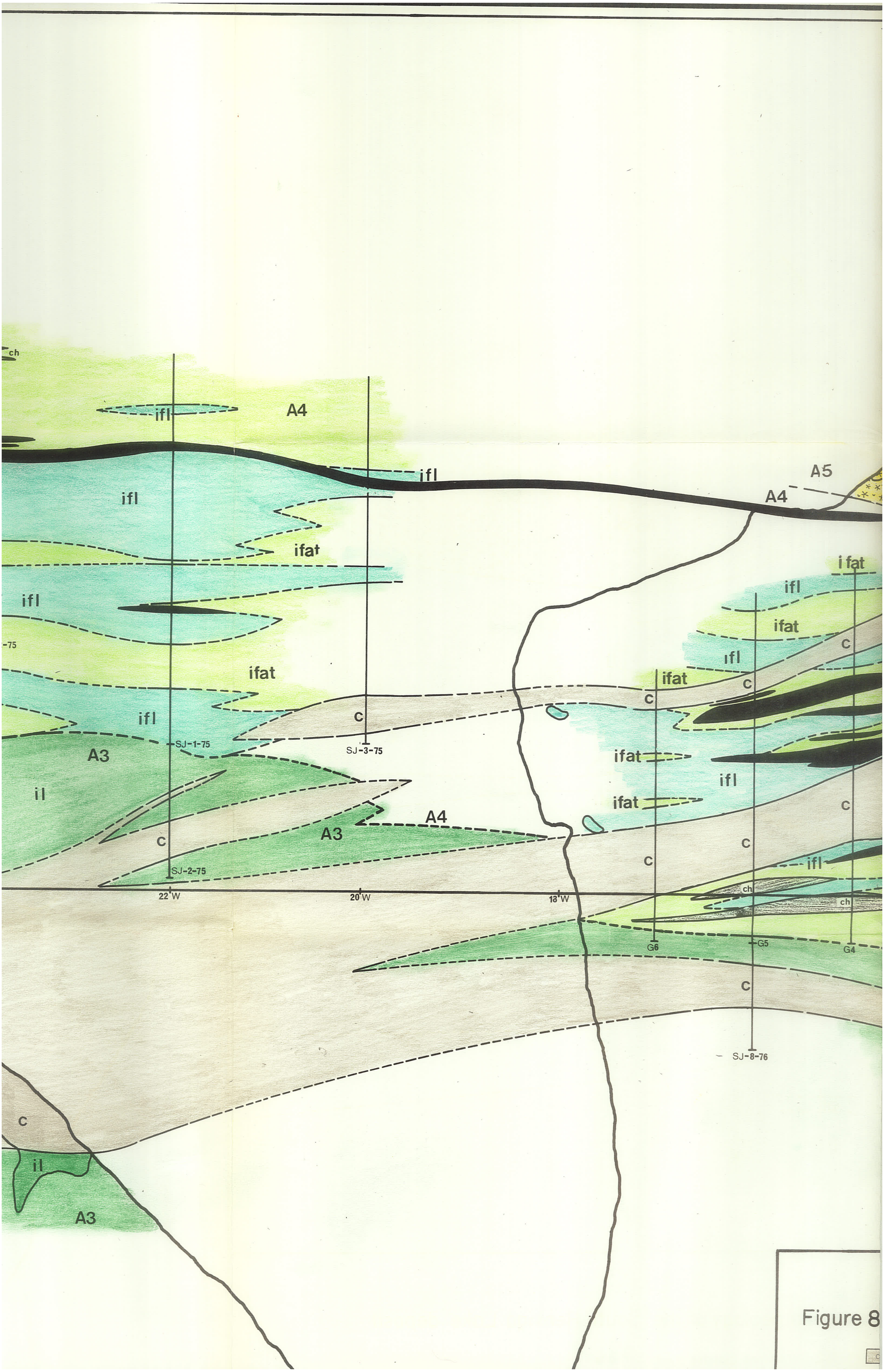
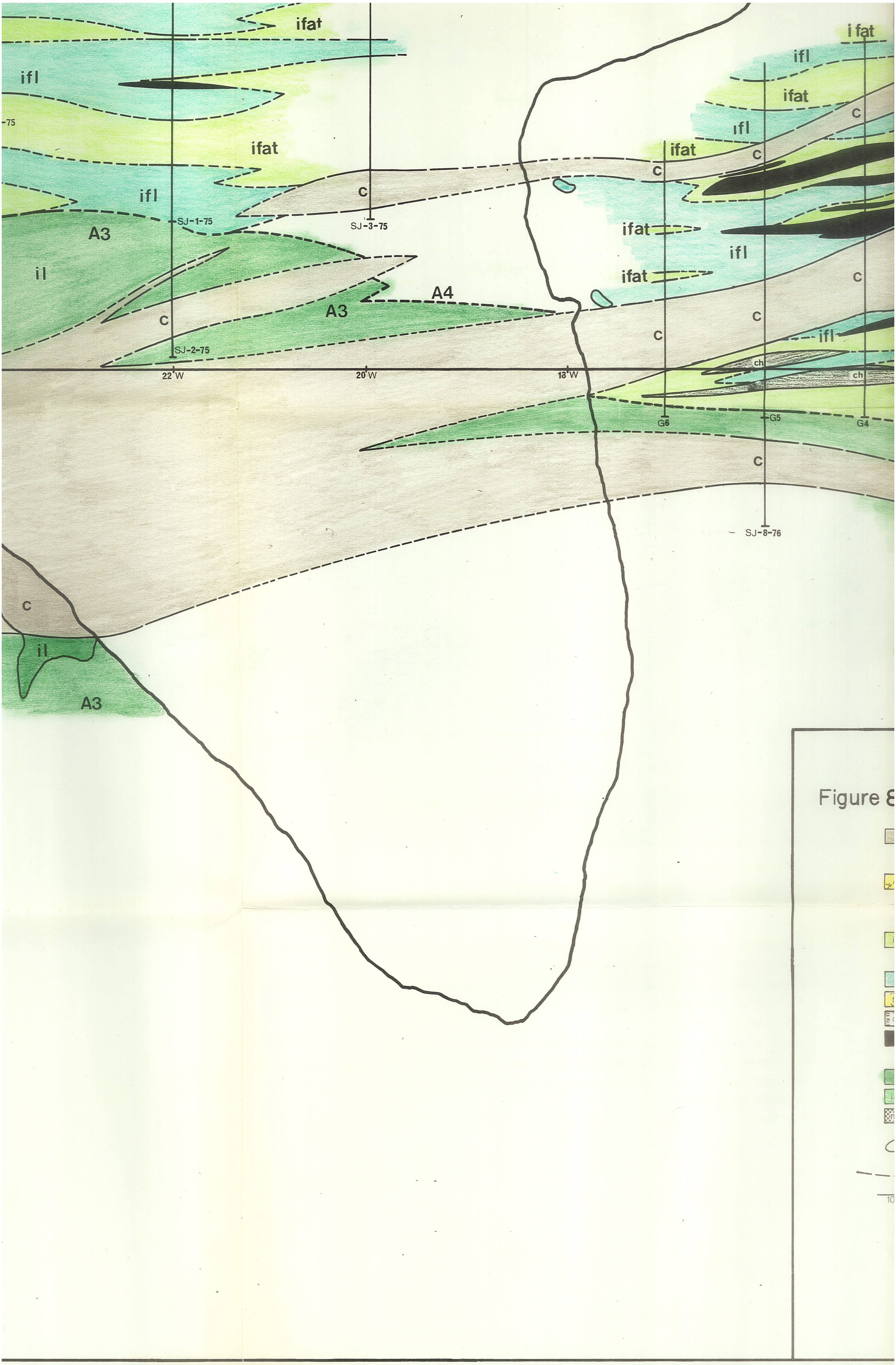
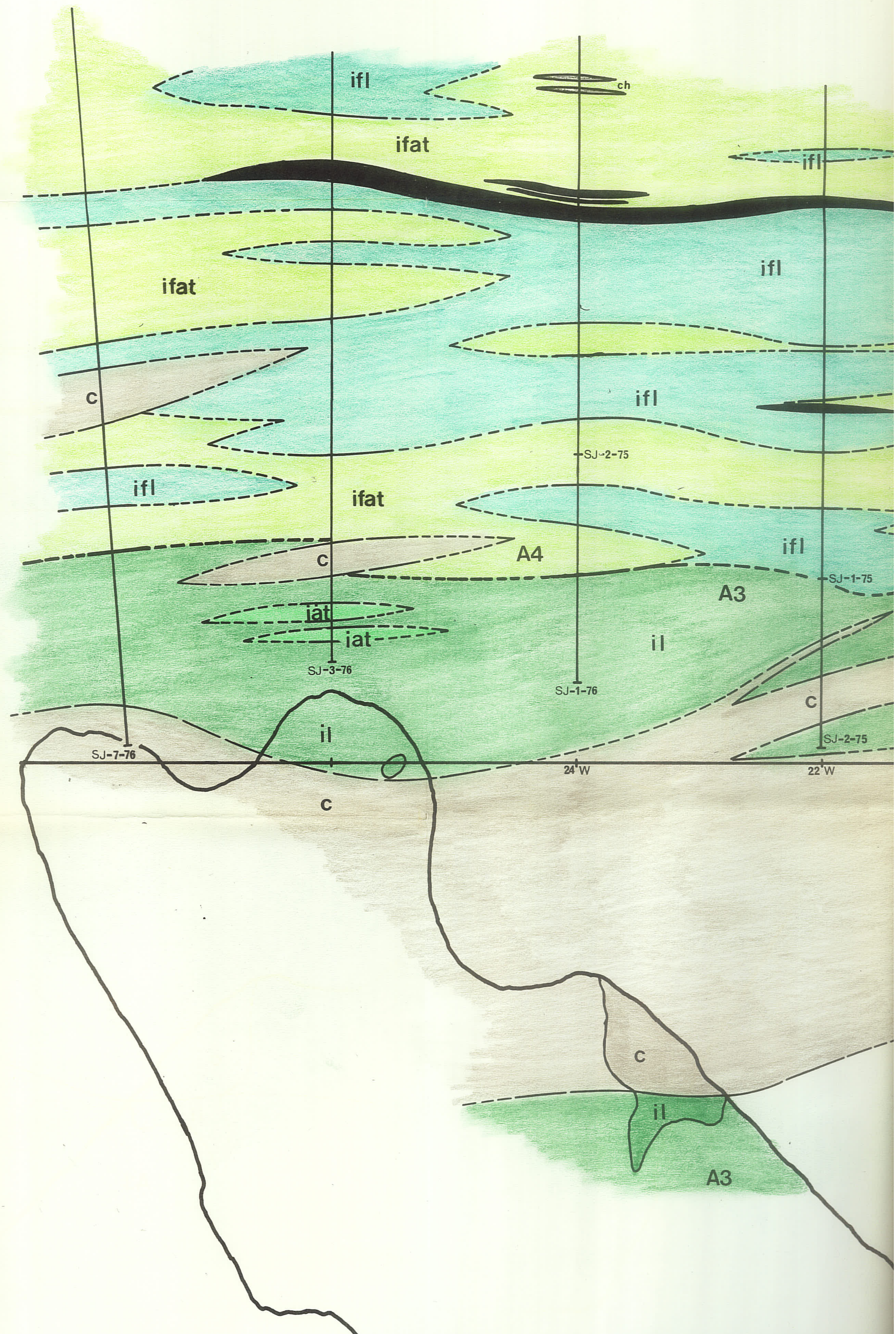

ch
A4
ifl
ifl
A5
A4
ifat
i fat
ifl
ifl
ifat
-75
ifat
ifl
c
ifat
c
c
ifl
c
SJ-1-75
SJ-3-75
A3
ifat
ifl
il
ifat
A4
A3
c
c
c
ifl
SJ-2-75
22 W
20 W
18 W
ch
ch
G6
G5
G4
c
SJ-8-76
c
il
A3

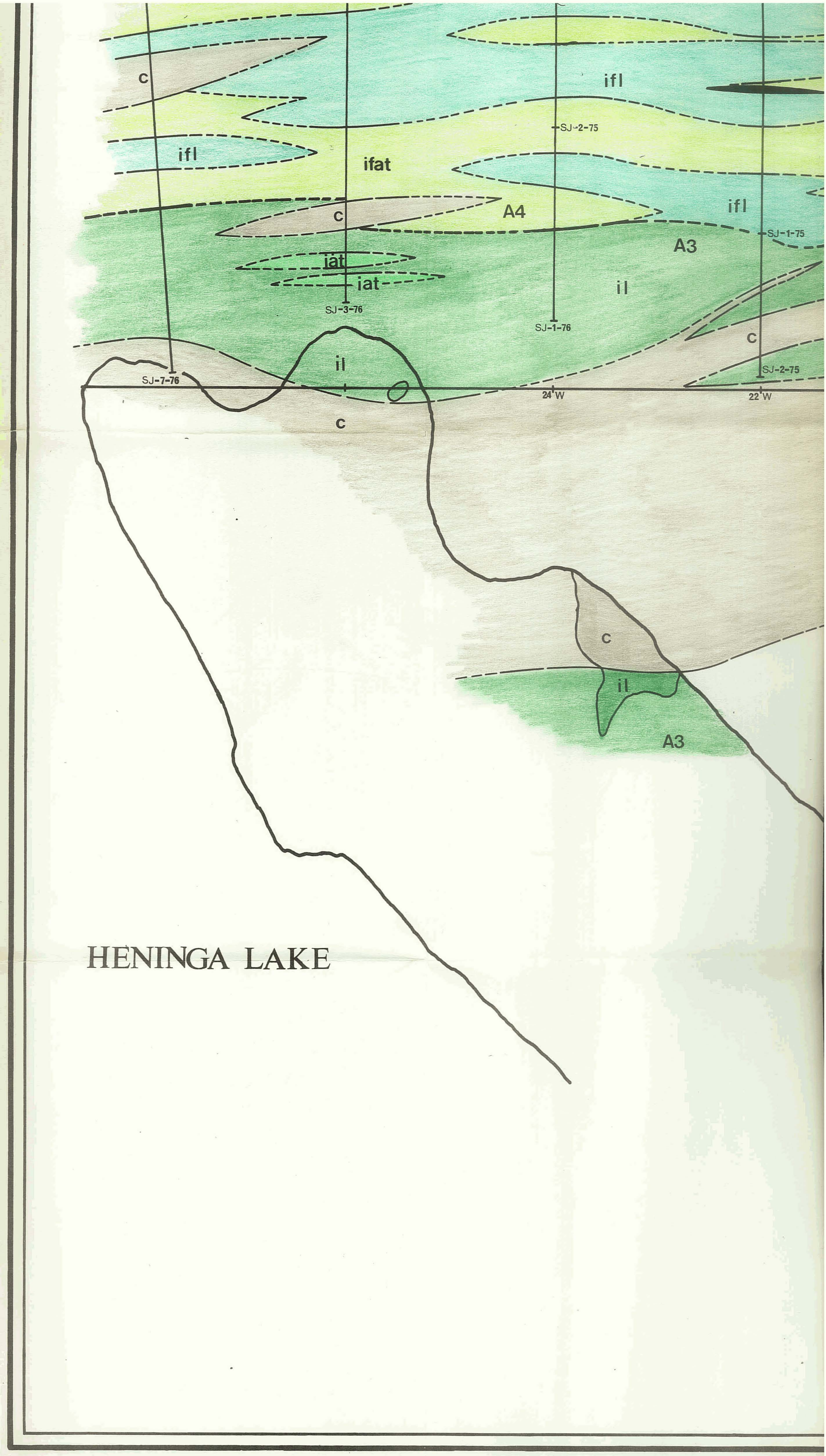
Figure 8



ifat
ifl
-75
ifat
ifl
SJ-1-75
A3
il
c
SJ-2-75
22 W
c
SJ-3-75
20 W
A4
A3
18 W
c
il
A3
i fat
ifl
ifat
c
ifl
c
ifat
c
ifat
ifl
ifat
c
c
c
ifl
ch
ch
G6
G5
G4
c
SJ-8-76
Figure



ifl
ch
ifat
ifl
ifl
ifat
c
ifl
SJ-2-75
ifl
ifat
ifl
A4
c
SJ-1-75
A3
iat
iat
il
SJ-3-76
SJ-1-76
c
il
SJ-7-76
SJ-2-75
24 W
22 W
c
c
il
A3



c
ifl
ifat
ifl
c
A4
ifl
SJ-2-75
SJ-1-75
A3
iat
iat
SJ-3-76
il
SJ-1-76
c
SJ-2-75
SJ-7-76
il
24 W
22 W
c
c
il
A3
HENINGA LAKE