STRATIGRAPHY AND GEOCHEMISTRY OF THE RUSTY LAKE GREENSTONE BELT ADJACENT TO THE RUTTAN MINE, MANITOBA

BY

MICHAEL RALPH JACKSON

Submitted to the University of Manitoba
Faculty of Graduate Studies
in Partial Fulfilment of the Requirements
for the Degree
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ABSTRACT

Greenstone belts in the Churchill Province of northern Manitoba, of probable Aphebian age, are hosts to massive sulphide Zn ± Cu deposits. Towards the southeastern end of the Rusty Lake greenstone belt, 14 miles east of Leaf Rapids, the rocks consist of a metamorphosed sequence of mafic, intermediate, and felsic volcanics and derived volcaniclastic sediments. Mapping was carried out adjacent to the Ruttan Mine for an area of roughly 4 square miles, to outline the volcanic stratigraphy. 123 samples were collected in conjunction with the mapping and chemically analyzed for major elements, Cu, Zn, and S, and were studied in thin section. Mafic flows make up a large portion of volcanic rock types (30% of map area). Felsic volcanics (dacite to rhyolite tuffs, lapilli tuffs, crystal tuffs, agglomerate, and flows) are dominantly fragmental and make up 13% of the area. Intermediate composition volcanics (andesite to dacite tuffs, lapilli tuffs, crystal tuffs, agglomerate, flows) are almost entirely fragmental and make up 7% of the map area. Volcaniclastic sediments (33% of area) are a complexly interstratified sequence of sandstones, siltstones, conglomerates, and debris flow breccias.

The volcanics at Ruttan are geochemically similar

to other PreCambrian volcanic suites. Compared with modern volcanic associations, the Ruttan volcanics most closely resemble the differentiated suites typical of modern island arcs. However, at Ruttan total Fe and MgO are significantly higher, probably as a result of alteration and metasomatism, and Na_2O and K_2O are lower than island arc regimes, probably an effect of PreCambrian alteration. There appears to be a somewhat higher proportion of dacite-rhyolite to andesite than in most Archean volcanic assemblages.

Concentrations of copper, zinc, and sulphur display strong bimodality, indicating background and anomalous populations, the latter representing the overprinting of mineralization. The threshold values for all rock types, above which is the anomalous population, are: Copper - 94 ppm, Zinc - 80 ppm, Sulphur - 700 ppm. Cu, Zn, and S anomalies are not restricted to specific rock types, but are located within well-defined portions of the volcanic pile.

Exploration for massive sulphide deposits should be concentrated within differentiated basaltic to rhyolitic volcanic suites having similar lithological and geochemical characteristics as those at Ruttan.

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CHAPTER I

INTRODUCTION

1. LOCATION

The Ruttan orebody is located towards the southeastern end of the Lynn Lake-Rusty Lake greenstone belt in northern Manitoba, and is 60 miles southeast of Lynn Lake, 135 miles northwest of Thompson, and 14 miles east of Leaf Rapids (Figure 1). The area is accessible by provincial road 391 which interconnects Thompson, Leaf Rapids, and Lynn Lake. An all-weather Sherritt Gordon Mines road connects the Ruttan Mine and adjacent study area with the town of Leaf Rapids.

2. PREVIOUS WORK

The area was included by the Manitoba Mines Branch in regional geological mapping at the scale of 1 inch to 1 mile (1:63,000) by Burwash (1962), Milligan (1964), Pearse (1964), Bristol (1966), and more recently by Steeves and Lamb (1972) at the scale of 1:40,000.

3. PRESENT WORK

Detailed mapping of the property adjoining the Ruttan Mine was carried out at the scale of 1 inch to 200 feet (1:2400) from May 8 to August 31, 1977 by J. Chornoby and

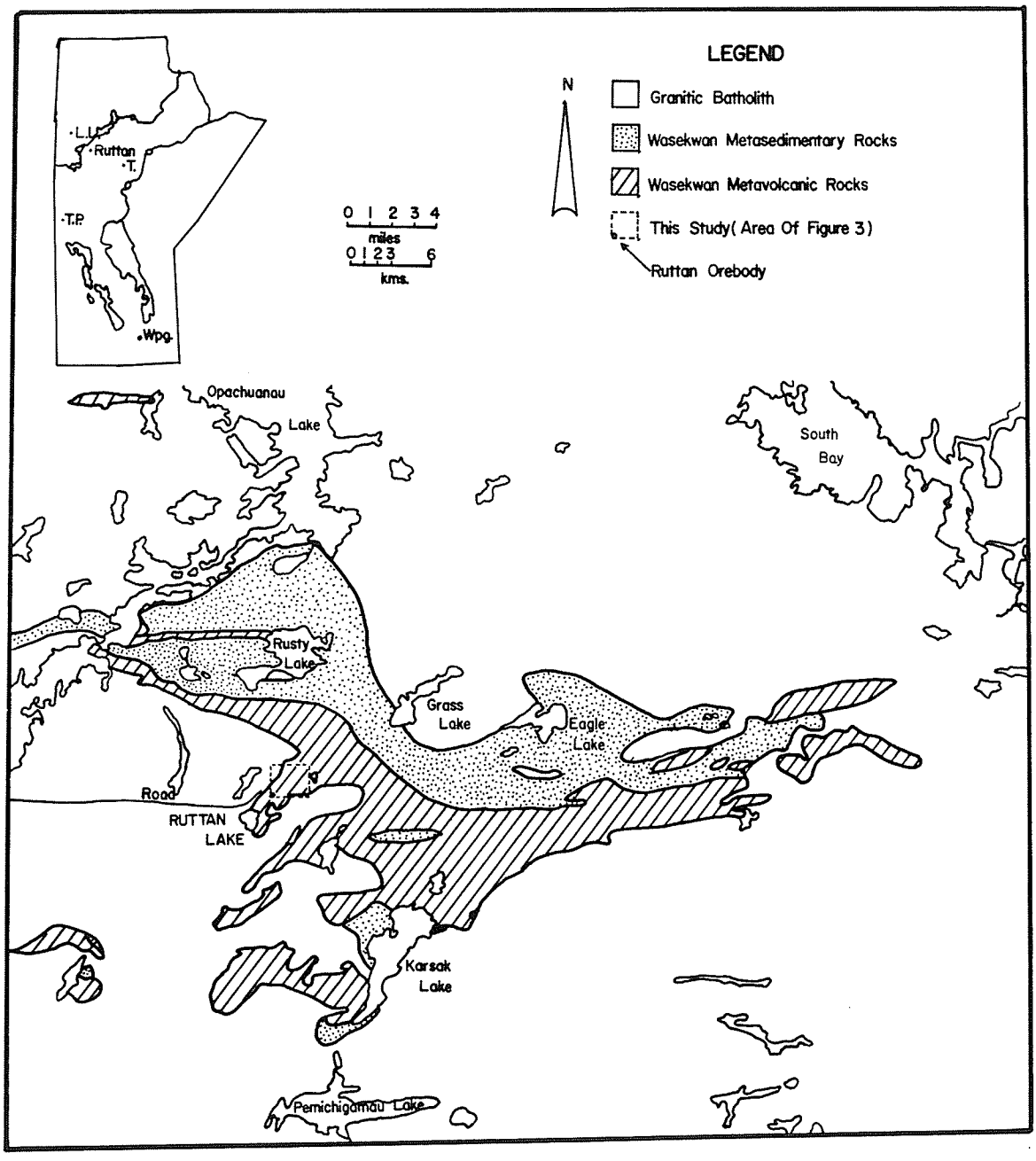

Figure 1. Highly simplified geological map of Rusty Lake Greenstone Belt showing location of Ruttan Map Area.

M. Jackson (Figure 2 - backflap insert).

The purpose was to map out in detail the volcanic stratigraphy from the orebody out into the country rocks, to aid in the study of the geology at Ruttan, with some emphasis on application to exploration.

A metavolcanic-metasedimentary sequence was mapped for a strike length of 12,000 feet (3600 m) northeast from the orebody and for a width of approximately 9,000 feet (2700 m), or 4 square miles. Pace and compass traverses were completed 200 feet (60 m) apart throughout the area. Base maps were prepared at 1 inch to 200 feet (1:2400) and 1 inch to 400 feet (1:4800) scales. Geochemical samples were collected in conjunction with the geological mapping (Figure 3 - backflap).

Accessibility to the mapping area was excellent. An all-weather road from the Ruttan Mine to Southern Indian Lake provided access into the northern and easternmost parts of the area. In addition, there were east-west baselines at 2000 feet (630 m) intervals and north-south grid lines at 200 feet (60 m) intervals throughout the entire mapping area.

Availability of outcrop varied from very good to poor. There was generally very good exposure through much of the mafic volcanics (50-80%), fair exposure in the diverse felsic to intermediate volcanics (20-40%), and quite poor exposure in areas of volcaniclastic sediments (<10%). Considerable muskeg and swamp are located over areas of supposed sediments.

CHAPTER II

GENERAL GEOLOGY

1. INTRODUCTION

The Lynn Lake-Rusty Lake greenstone belt is located in northern Manitoba in the Churchill Province of the PreCambrian Shield. The geology of the Lynn Lake greenstone belt was described by Milligan (1964). It is separated from the Flin Flon-Snow Lake greenstone belt (200 km to the south) by Kisseynew sedimentary gneisses. The regional structures and ages have been reviewed by Sangster (1978). The oldest rocks of the Lynn Lake-Rusty Lake greenstone belt are the Wasekwan Group mafic to felsic volcanics (flows, tuffs, agglomerates), sedimentary rocks (breccias, greywackes, shales), and the mafic to felsic porphyry intrusive equivalents of the extrusive rocks. Overlying the Wasekwan Group conformably and locally unconformably, is the Sickle Group of basal conglomerates (with Wasekwan pebbles) grading up into arkoses, greywacke, and shale.

The portion of the Rusty Lake greenstone belt adjacent and on strike to the Ruttan orebody is a metamorphosed sequence of mafic, intermediate, and felsic volcanics and derived volcaniclastic sediments. The area mapped is made up of, from stratigraphic bottom to top: a 2400 feet (750 m) thick lower Mafic Metavolcanic Formation;

a 2200 feet (660 m) thick middle diverse Intermediate to Felsic Metavolcanic Formation; and a 6000 + feet (1830 + m) thick upper Metasedimentary Formation. The relationship of the metasediments and mafic metavolcanics in the extreme northeast of the map area (see Figure 2) to the rest of the sequence is not known, because there is an unconformable fault contact between those rocks and the lower mafic metavolcanics. Therefore, these rocks are not represented in Figure 2 as a separate formation. Their presence has simply been noted and mapped in relation to the rest of the sequence. The legend in Figure 2 is lithologic rather than stratigraphic because of the uncertainty of structural interpretation and some of the top indicators.

The thickness value for the upper Metasedimentary Formation is a minimum, because it continues on to the south of the area mapped. The thickness value for the lower Mafic Metavolcanic Formation also is a minimum, because it is in unconformable fault contact with the formationally undefined metasediments and mafic metavolcanics, and because it is intruded in the north by a granitic batholith. The thickness value for the middle diverse Intermediate to Felsic Metavolcanic Formation may be the true original thickness.

The dominantly tuffaceous intermediate and felsic metavolcanics are thickest towards the Ruttan orebody to the southwest and thin rapidly towards the east. The mafic metavolcanic flows comprise a thick pile in the

northern part of the map area. The metasediments are volcaniclastic sandstones, siltstones, conglomerates, and debris flow breccias.

LITHOLOGIES

2. MAFIC METAVOLCANICS (Basalt and minor andesite flows; local flow breccia; 30% of map area)

Basaltic flows made up a major part of the volcanic succession, varying from massive to highly schistose. Andesites were distinguished from basalts by a comparatively lighter colour and abundance of plagioclase phenocrysts. The mafic flows overall are black to greenish black to dark grey in colour with a colour index of greater than 50. Primary structures and textures are poorly preserved. Rare amygdaloidal flows contain amygdules filled by quartz and calcite. Flow contacts were rarely observed. Pillowed flows were discernable at a few localities (Figure 4). Commonly, the flows are porphyritic with 20-50% of the rock being comprised of subhedral plagioclase phenocrysts. Uncommonly, the flows contain medium to coarse grained (2-6 mm) hornblende porphyroblasts, which may represent metamorphically recrystallized pseudomorphs after pyroxene, or they may in part be of primary intrusive crystallization origin. A few flows contain magnetite phenocrysts (5-15% of rock) and some are fine grained, equigranular aphanites.

3. INTERMEDIATE METAVOLCANICS (Andesite and dacite tuffs and crystal tuffs; lesser lapilli tuffs and agglomerate; minor flows and pyroclastic breccia; 7% of map area)

Figure 4. Pillow In Basalt Flow with Chill Margin Outlining shape and packing. Top is towards top of photo. Sample Number 18-1. See Figure 3 for location.

Figure 5. Andesite-Dacite Lapilli Tuff. Note angular, unsorted nature of fragments which vary from intermediate to felsic in composition. Matrix is intermediate in composition. Sample Number C-20. See figure 3 for location.





They are medium grey-green in colour with a colour index between 25 and 50, consist of a higher proportion of fragmental material, and are notably lighter in colour than the mafic metavolcanics. They tend to form stratigraphically complex lenses and intercalations with felsic and mafic metavolcanics (see Figure 2). The rocks consist of felsic to intermediate composition tuff, lapilli tuff, and crystal fragments set in an intermediate to mafic matrix (Figure 5). Subordinate flows are fine grained, equigranular, plagioclase phyric rocks. Rare agglomerate occurs locally and discontinuously. Pyroclastic breccia consists of large (20 cm) to small (1-2 mm) felsic and intermediate composition fragments densely packed in an intermediate to mafic matrix. In general, the size of fragments decreases from the southwest to the northeast of the map area, which indicates that their source area is to the southwest (towards the Ruttan Mine).

4. FELSIC METAVOLCANICS (Dacite, rhyodacite, rhyolite tuffs and crystal tuffs; lesser lapilli tuffs, flows, and agglomerate; 13% of map area).

They are dominantly fragmental and readily distinguished from the more mafic metavolcanics by their greyish white to pink colour (especially on weathered outcrops), abundance of biotite and sericitized feldspar, and colour index of less than 25. They vary in structure from massive to highly foliated. Flows, fragment-poor tuffs and volcaniclastic sediments are difficult to dis-

tinguish from each other due to recrystallization, except on weathered outcrops and in places where tuffs are coarser grained and more notably tuffaceous.

The upper felsic volcanic horizon of coarse-grained, quartz-feldspar porphyry appears to be a shallow intrusive which grades laterally along strike into flow breccia-agglomerate and medium to fine grained flow rock (Figure 6). The stratigraphic relationship between the felsic volcanics, and intermediate and mafic volcanics becomes increasingly more complex from the southwest to the northeast (see Figures 2, 3). There are numerous gradational contacts along strike in texture and composition. The individual beds become thinner and shorter with more interfingering and facies changes. Agglomerate is prominent within the thickest, "middle" felsic fragmental unit (see Figure 2) in the most southwesterly exposure (ie. - closest to the Ruttan Mine) of felsic volcanics in the map area (Figure 7). Some of the tuffs are bedded and graded, the gradation to volcaniclastic sediments being indicated in general by a scarcity of lenticular lithic fragments, rounding of fragments and crystals, and better defined sedimentary structures-especially bedding lamination. The tuffs are invariably composed of felsic composition tuff and lapilli tuff fragments in a felsic to intermediate matrix (Figure 8).

Flows have a finer grained matrix in contrast to the tuffs, contain phenocrysts of quartz and feldspar, and are commonly strongly foliated after primary flow structure.

Figure 6. Dacite-Rhyolite Flow Breccia-Agglomerate. Fragments are invariably felsic in a more Intermediate Composition Matrix. Fragments are angular to subrounded and vary in size from 0.5 cms. to 20 cms. Photo taken near sample site 39-3. See Figure 3 for location.

Figure 7. Rhyodacite-Rhyolite Agglomerate. Note large Felsic Fragments stretched in the Plane of Foliation. Sample Number J-3. See Figure 3 for location.

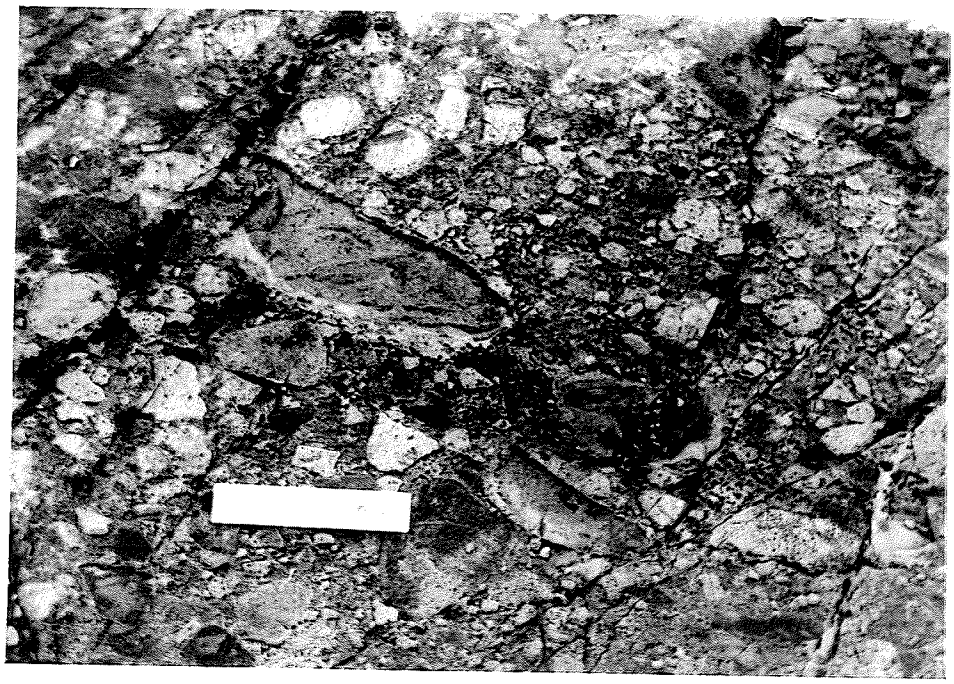



Figure 8. Rhyodacite-Rhyolite Lapilli Tuff. High concentration of Lapilli sized fragments in an Intermediate to Felsic Matrix. Photo taken near Sample Site C-7. See Figure 3 for location.

Figure 9. Graded bedding in Volcaniclastic Sandstone Turbidite. Note coarser grains (white specks) at base of bed near bottom of ruler, and top of bed indicated by parallel laminations near top of photo. Individual bed is about 30 cms. thick. Top is towards top of photo. Photo taken near Sample Site 1-4. See Figure 3 for location.





Also, flows are lacking in pyroclasts.

A very coarse grained fragmental occurs at a few localities (see Figure 2) within the stratigraphically highest felsic unit (see Figure 6). This is thought here to represent a flow breccia-agglomerate from a lateral vent rather than pyroclastic breccia from a main vent.

5. VOLCANICLASTIC METASEDIMENTS (Sandstone and siltstone; debris flow breccias; local conglomerate; 33% of map area).

They are mostly fine to medium grained, granular, and rich in fragments of quartz and feldspar. Primary turbidite sedimentary structures are common, such as: graded bedding, cross bedding, flame structures, and especially bedding laminations (Figure 9). Dark grey, massive, poorly bedded metasediments are difficult to distinguish from felsic and intermediate metavolcanics. Usually these rocks are thinly bedded (beds of 2 to 3 cm thick). Grain size and bedding thickness parameters decrease from the southwest to the northeast of the map area (see Figure 2), indicating that the paleoslope/paleocurrent direction was towards the northeast and the sediment source towards the southwest.

The coarse, clastic metasedimentary beds show numerous features that suggest origin by turbidity flow in a high energy environment (see Figures 9, 10, 11, 12). Volcaniclastic sediments are closely associated with, and therefore directly reworked from the felsic and inter-

Figure 10. Volcaniclastic Debris Flow. Large size and abundance of fragments suggests a Proximal Source. Volcanic Fragments vary from Intermediate to Felsic in Composition. Photo taken near Sample Site C-60. See Figure 3 for location.

Figure 11. Volcaniclastic Debris Flow. Further Reworking of Volcanic Fragments at this locality than in Fig. 10. Photo taken near Sample Site 41-1. See Figure 3 for location.







Figure 12. Volcaniclastic Debris Flow Showing Bedding Lamination and Turbidity Flow Matrix Bending Around Imbricated Volcanic Fragment. Photo taken near Sample Site 1-3. See Figure 3 for location.

mediate pyroclastics. There are gradational changes along strike from well bedded, water lain tuff to massive, poorly sorted and bedded tuff. Compared with sandstones, the siltstones are finer grained, more finely laminated, and commonly garnetiferous. Also, they are more susceptible to tectonic deformation and in places are buckled into tight or open folds.

Conglomerates contain subrounded to well-rounded pebbles, cobbles, and boulders that have undergone tectonic elongation. The fragments range from 2 to 20 cm in diameter, average 2 to 8 cm in diameter, and vary in composition from intermediate to felsic.

Sedimentary breccias are common as beds ranging from 5 cm to 30 m thick, that are laterally continuous for up to 100 m (Figure 11). These may be termed debris flows, mudflow breccias, or laharic breccias. The lensoid units consist of volcanic fragments of all compositions and sizes (1-30 cm) in a fine grained, intermediate matrix. Fragment size decreases progressively in the units from southwest to northeast indicating paleoslope movement was towards the northeast. Imbrication of some fragments also gives a paleocurrent direction to the northeast (Figure 12). These coarse grained deposits are stratigraphically closely associated and interbedded with volcaniclastic sandstones, and were obviously deposited as subaqueous debris flows.

6. INTRUSIVES

DIORITE AND GABBRO (Diorite; subordinate gabbro; 2% of map area)

The rocks are massive and medium to coarse grained with highly irregular, discordant intrusive contacts with the lower mafic volcanics and the upper metasediments. They occur as late plugs and sills intruded into the meta-volcanic-metasedimentary assemblage. Chunks of mafic metavolcanics are incorporated into the intrusive bodies of rock in the northern portion of the map area.

LATE GRANITICS (Granite and granodiorite; 15% of map area)

These rocks outcrop towards the north, west, and south of the map area: they are the edge of a major batholith. They are the youngest rocks in the area since they contain inclusions of metavolcanic and metasedimentary rocks, as well as inclusions of the more mafic intrusive rocks. In appearance they are greyish white to pinkish red and medium to coarse grained. They occur also as numerous cross-cutting dikes, sills, stringers, and veinlets, that display sharp chilled borders against the greenstones that they intrude. All of these granitic phases are probably part of the same post-volcanism and post-sedimentation, regional granitic batholith.

CHAPTER III

STRUCTURAL GEOLOGY

1. INTRODUCTION

The Lynn Lake-Rusty Lake greenstone belt is located in the Churchill Province of the PreCambrian Shield and is approximately 100 km long by 15 to 30 km wide. It is bounded on all sides by granitic intrusions, and is separated from the Flin Flon-Snow Lake greenstone belt by an extensive thickness of supracrustal rocks. The Ruttan portion of this belt is part of a U-shaped, east-west trending greenstone belt, approximately 50 km long by 20 km wide (see Figure 1), which has been disconnected from the Lynn Lake belt by the granitic batholith. The Ruttan study area is a wedge of steeply dipping metavolcanic-metasedimentary rocks that have been isoclinally folded. Structure of this latter area is discussed below.

2. FOLDING

Regional tectonism has produced isoclinal folding trending NNE, according to top determinations (graded beds and shape and packing of pillows). The suggested location of the axis of an overturned anticline is shown in Figure 2. However, top determinations from the pillows are not totally reliable; the axis of the fold may alternatively

pass through the mafic metavolcanic formation, or may be the axis of the "unconformable fault" that is outlined in Figure 18 by high magnetic amplitudes. Top determinations from sedimentary structures are reliable, and indicate that there is an overturning of beds and an anticlinal structure somewhere between the felsic volcanic formation and the formationally undefined metasediments.

3. PRIMARY STRUCTURES

Pillowed mafic volcanic flows were observed in the map area as poorly preserved, tectonically elongated features. Tops (not conclusive) were determined from a few of these. Amygdaloidal mafic volcanic flows were rarely observed, and were too poorly preserved for top determinations. Some of the finer grained, porphyritic felsic volcanics are flow banded, presumed to represent primary flow structure.

Cross bedding, graded bedding, convoluted and parallel laminations (So) in volcaniclastic sediments are very well preserved and give numerous reliable top indicators.

4. SECONDARY STRUCTURES

Foliation: Most of the metavolcanic and metasedimentary rocks have a foliation as defined by the parallel orientation of hornblende, biotite, muscovite, chlorite, and lithic fragments. Schistosity (S_2) is the dominant foliation which is mostly after bedding (So). Schistosity

is also discordant to and distinct from bedding in areas of shearing. Cleavage (S_1), a pseudomorphic structure after bedding, is prominent in fine grained metasediments.

Lineation: is commonly represented by stretching of fragments and by a preferred orientation of hornblende and biotite crystals. Alligned plagioclase phenocrysts may represent primary flow lineation.

Jointing: is prominent throughout the map area. (See Figure 2 for measured parameters).

Shearing: A well defined shear zone sharply transects the regional foliation. It varies from a few mm's to a few metres in width (Figure 13). It may be related to folding or intrusion. The shear is traceable for 200 feet (65m) or so and then continues as a fault through the lower mafic metavolcanics (see Figure 2). Epidote and quartz rich pods and veinlets, mylonitized and sheared rocks are characteristic. This grades into massive unsheared intermediate to felsic metavolcanics to the south.

Faulting: Evidence for faulting occurs in 2 areas. The first is the aforementioned shear zone, where there is slight stratigraphic and structural offsetting, jointing, shearing, and epidote-calcite-quartz-iron wallrock alteration. The shear itself is local but the continuation as a fault, and area of associated alteration is significant (see Figure 2). Displacement along this lineament is only



Figure 13. Shear Zone Showing Highly Deformed Rock and Quartz-Calcite-Epidote-Hematite Alteration. Photo taken near Sample Site 12-11. See Figure 3 For Location.

slight according to the minimal stratigraphic offsetting.

The second major fault is poorly exposed but it is outlined fairly precisely by a strong positive ground magnetic anomaly (ie.-up to 12,000 gammas) and remobilized sulphide and oxide mineralization in drill core (Chornoby, pers. comm.; see Figures 2 and 18 for location of this structure). This structure may represent the major axial trace fault of the overturned anticline, which is indicated by top determinations. Whether or not there is a relation to folding, the structure represents a fault since it unconformably cuts across the trend of Formation boundaries. It is continuous for at least 5 or 10 kms. to the east according to mapping by the author in 1978. It is marked by the same linear, high positive ground magnetic anomalies, and by local areas of extreme shearing, faulting, and scarps. Movement along this structure could be considerable according to a lack of traceability of lithologies across it for at least 5 or 10 km.

CHAPTER IV

STRATIGRAPHY

1. INTRODUCTION

Correlation by stratigraphic columns of the volcanic-sedimentary sequence is shown in Figure 14. The location of these sections is shown by lines in Figure 3, with the top of the section line marked by the appropriate letter (A, B, C, D, E) and the bottom at the northernmost edge of the map area (Figure 3). It is assumed that the pile is continuous and not folded.

2. REGIONAL SETTING

Geological information of the Rusty Lake greenstone belt is limited to reconnaissance type data and mapping (Steeves and Lamb, 1972) at a scale of 1:40,000. As a result, correlation of regional structure and stratigraphy is not known, although similar patterns of mafic-to-felsic cyclic volcanism and sedimentation are indicated.

Felsic volcanics are seen again in exposure 5 to 10 kms. to the southeast of the map area. The main volcanic

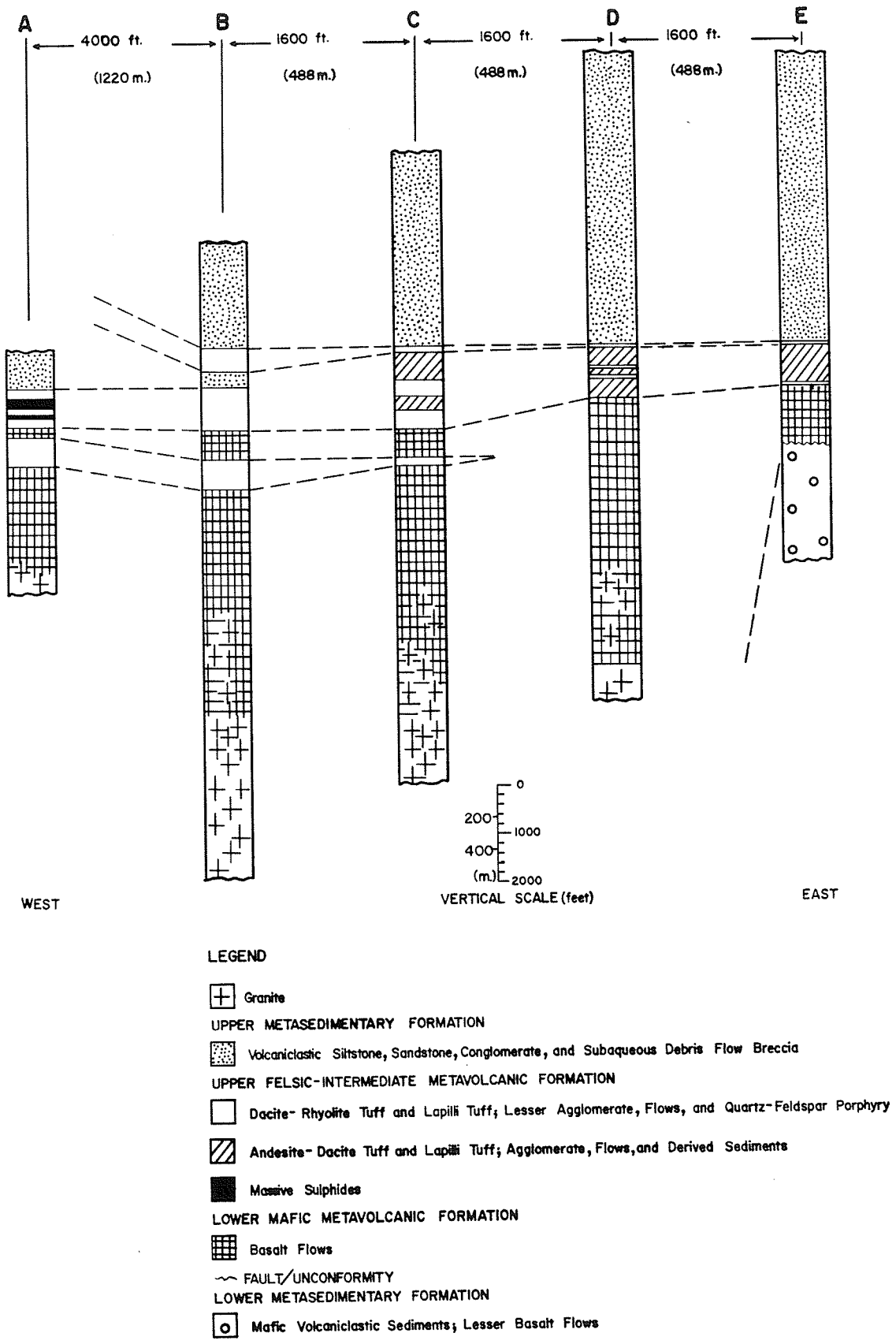

Figure 14. Stratigraphic Columnar Sections in the Rusty Lake Greenstone Belt on Strike with and Including the Ruttan Orebody. Sections Represent Present True Thicknesses.

units of the Ruttan area may be traceable to these volcanics according to mapping by the author in 1978. This accumulation of thick felsic volcanics to the east probably represents a separate felsic volcanic centre (ie. - stratovolcano), which is related to the Ruttan volcanics as having been within the same chain of volcanoes.

The overall regional setting is an east-west trending belt of mafic to felsic volcanic rocks and associated derived sediments (Wasekwan Group; see Figure 1).

There is one centre of felsic volcanism to the west of the Ruttan area (see Figure 16), which is now intruded by granitic rocks, and corresponds with the thickening of the felsic pile from the northeast to the southwest. To the east and southeast of Ruttan, as mentioned above, is a much thicker sequence of volcanics which probably represent another centre of felsic volcanism along the east-west volcanic chain. To the south of the map area are volcaniclastic sediments intruded by the granitic batholith. To the north of the map area the Wasekwan Group volcanics are overlain by a thick sequence of Wasekwan Group sediments.

Further work is currently underway involving regional geological interpretation of stratigraphy and structure in the Rusty Lake greenstone belt by the Manitoba Mines Branch.

3. STRATIGRAPHIC INTERPRETATION

A time-stratigraphic relationship is apparent from

the location of 3 closely associated, partially continuous felsic volcanic horizons in the middle to upper parts of the volcanic pile. These units show a continuity in the map area for 3 to 4 km. Figure 15 shows a reconstructed cross-section of the map area of Figure 3, derived from measuring formation thicknesses from the Ruttan Mine to the edge of the map area in the east.

The middle to upper felsic and intermediate metavolcanics were extruded on top of the basaltic pile. After a period of effusive basaltic volcanism, magmatic differentiation shifted the nature of volcanism to an explosive, felsic type, producing a formation with a total present thickness, in the Ruttan part of the pile, of approximately 2200 feet (660 m). Considerable thickening of the pile towards the central vent to the southwest (within 10 km) would be expected, as envisaged in Figure 16. In this diagrammatic model, the position of the Ruttan orebody and the adjacent volcanic and volcaniclastic sedimentary pile are marked. The area marked by a dashed outline represents the inferred position of the central stratovolcano vent, now intruded and removed by the granitic batholith.

The presence of rock units such as agglomerate, lapilli tuffs, and debris flow breccias, suggests a high energy, high relief, shallow subaqueous environment at the time of deposition. The lower Mafic and upper Felsic Metavolcanic Formations, in the southwestern portion of the volcanic pile shown in Figure 2, or closest to the Ruttan orebody as shown in Figure 15, are defined as belonging

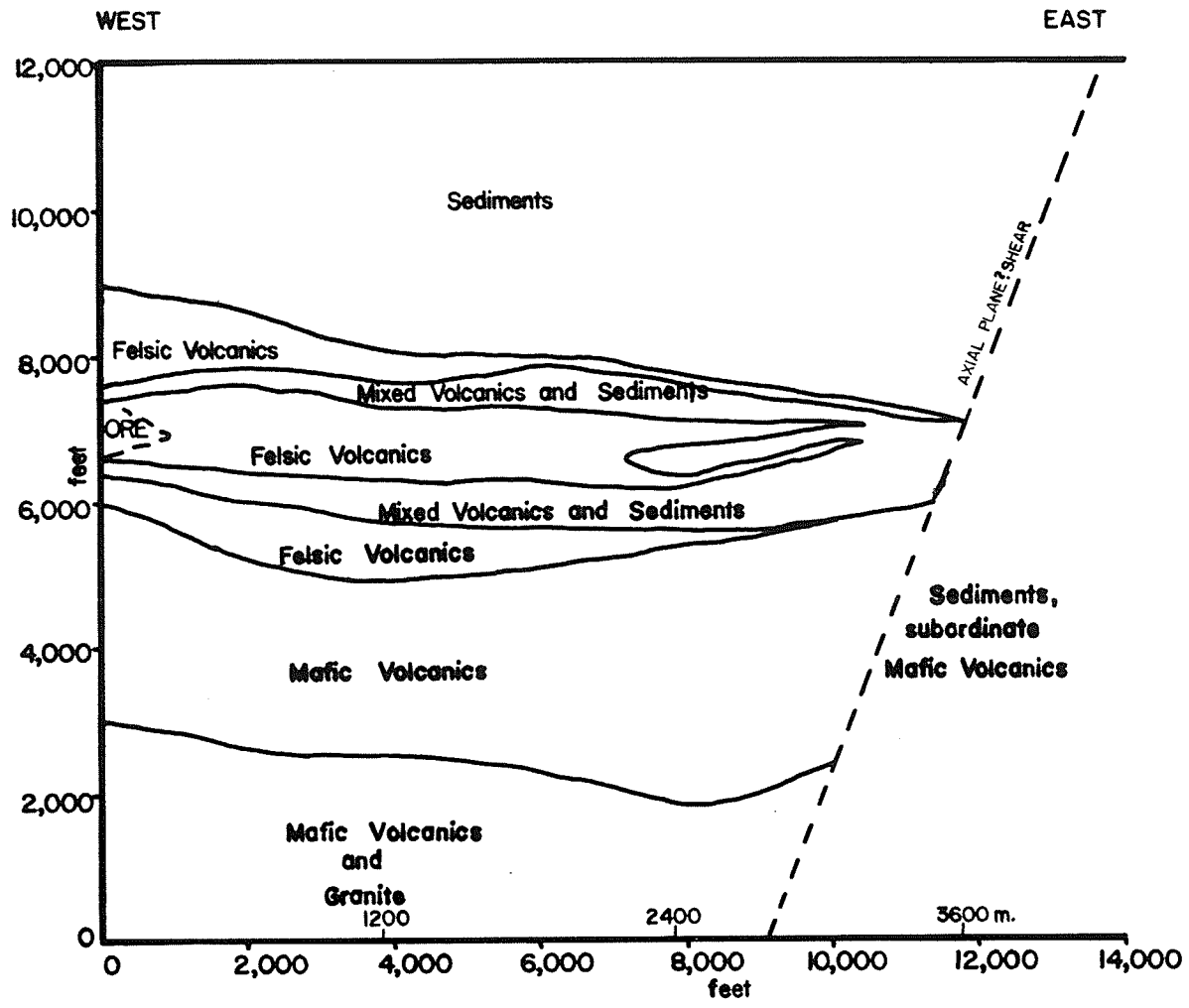

Figure 15. Reconstructed Cross-Section of Mafic to Felsic Cycle of Volcanism and Associated Sedimentation at Ruttan (Represents Area of Figure 3).

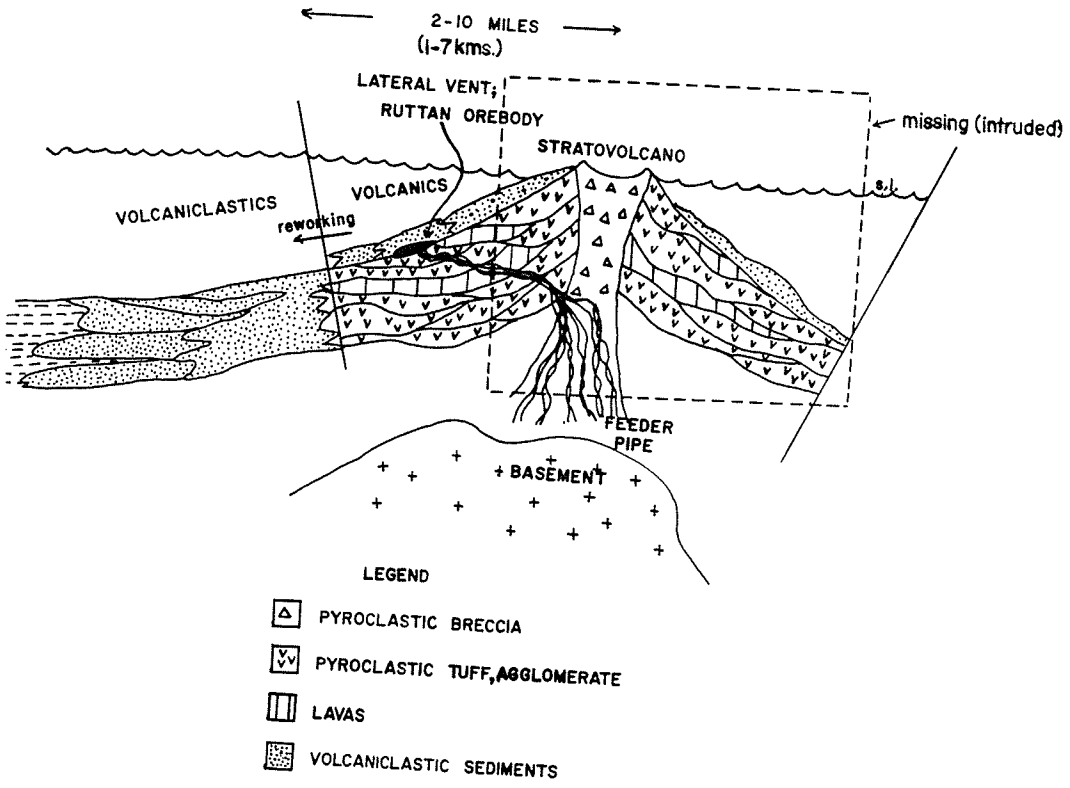

Figure 16. Diagramatic Cross-Section of Volcanic Model, (After Hirokoshi, 1969), Showing Inferred Position of Ruttan Orebody Within Stratovolcano Complex (looking south).

to the proximal facies of the original volcanic centre. Very coarse grained felsic agglomerate occurs in the extreme southwest of the map area in drill core just east of the Ruttan orebody, and in the Ruttan Mine. These are coarser than other agglomerates in the area of Figure 2, and indicate a thinkening progression towards the central vent (Figure 16).

The upper Metasedimentary Formation, a mixed group of volcaniclastics, directly overlies the felsic volcanic sequence. The presence of coarse grained conglomerates and debris flow breccias indicate deposition in an area of high relief in shallow water on the flanks of the volcano. From southwest to northeast, fine grained siltstones and sandstones predominate over coarse grained sandstones, conglomerates, and breccias. This again supports the hypothesis of an eastward progression towards a deeper water, distal facies environment, and conversely, a westward progression towards a high relief, proximal facies environment.

4. CONCLUSIONS

(b) Environment and history of deposition of the Ruttan Volcanic Sequence

The entire mafic-to-felsic volcanic sequence represents a geologically short-lived, single stage evolution from an effusive basaltic shield volcano to an explosive, felsic stratovolcano. A geological history of volcanism at Ruttan can be reconstructed in 3 main phases:

1) Effusive mafic volcanism. Pillows are rarely preserved, but this together with the presence of thin sedimentary intercalations indicate subaqueous emplacement.

2) Gradual magma differentiation and explosive felsic volcanism, rapidly building up a high relief, pyroclastic cone.

3) Quiescence (and sulphide precipitation), subsidence, and erosion of the pile to produce volcaniclastic sandstones, conglomerates, and debris flow breccias.

(b) Orogenic Model of the Rusty Lake Greenstone Belt

The Rusty Lake greenstone belt began it's evolution in Aphebian times (see Age) as an elongated trough or basin adjacent to or between two continental land masses (Figure 17; from Ridler and Goodwin, 1971). Steep geothermal gradients and high rates of volcanism were characteristic of the PreCambrian, probably as a result of high radioactive heating from the earth's core and strong mantle convection (Goodwin, 1977). A chain of volcanoes developed within the basin, which eroded to give large volumes of ash, lava, mudflows and debris flows to the basin, all of which were interlayed with turbidite sediments. The volcanic trough or basin was terminated by folding, faulting, uplift, and erosion.

A brief history of the environment can be stated as follows:

1) Development of an elongated trough or basin alongside a continental land mass, or wedged between two continental

land masses.

2) Sedimentation and subsidence.

3) Volcanism producing large volumes of pyroclastics, lavas, and debris flows mixed with turbidite sediments.

4) Termination of volcanism and sedimentation.

5) Termination of the environment by folding, faulting, uplift.

6) Erosion.

7) Metamorphism and granitization.

8) Erosion.

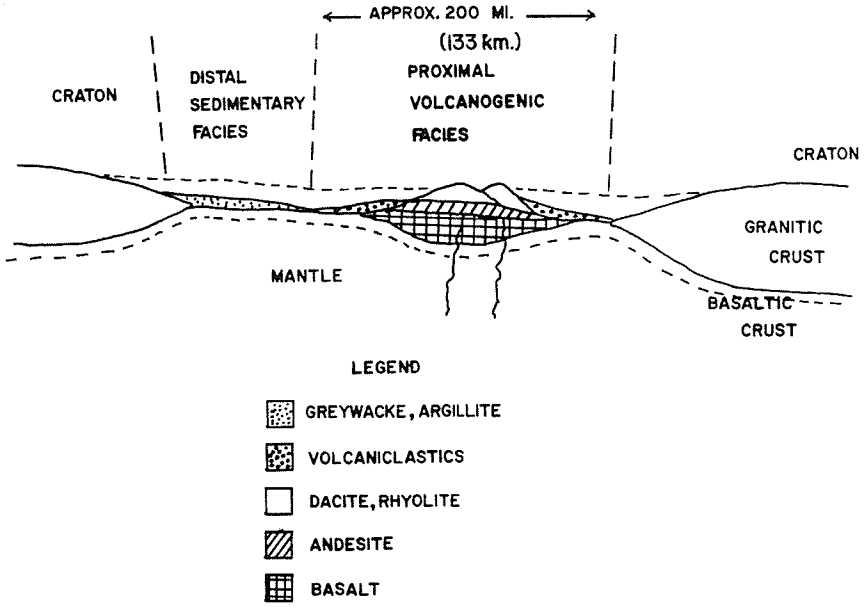

Figure 17. Vertical Cross-Section of Orogenic Model of Rusty Lake Greenstone Belt. (After Goodwin and Ridler, 1971).

CHAPTER V

GEOPHYSICS

An airborne electromagnetic INPUT survey (Man. Mines Br., 1969) reveals 4 individual anomalies in the area of the Ruttan massive Cu-Zn sulphide deposit (from Steeves and Lamb, 1972). Approximately 1 to 3 kms. to the northeast of the Ruttan deposit, and in line with the trend of volcanic stratigraphy, are 5 short electromagnetic trends over areas of overburden and mafic metavolcanics. On surface, these correspond to patches of gossan containing disseminations of pyrite and pyrrhotite.

A ground magnetic survey carried out by Sherritt Gordon Mines Exploration in 1969 is shown in Figure 18 (Backflap). The structually anomalous area in the field thought to represent a fault or axial shear, is identified by a strong positive linear magnetic trend (3,000 to 13,000 gammas; location of magnetic anomaly in Figure 18 represents the northwest-southeast trending fault in Figure 2). The magnetics are useful in outlining precisely the location of this structure since it largely traverses areas of thick overburden. The areas of broad magnetic lows in Figure 18 correspond with areas of sparse outcrop, overburden, and swamp. Strong magnetic anomalies correlate well with the volcanic stratigraphy, possibly representing

conduction by sulphides.

An I.P. survey conducted in 1978 indicates areas of anomalously high chargeability (Atkinson, pers. comm.) which closely parallels the magnetic highs.

CHAPTER VI

AGE

Rb-Sr whole rock, K-Ar, and Pb isotope methods of age dating by Mukherjee (1971), Sangster (1972), and Stauffer (1974) for the Flin Flon-Snow Lake greenstone belt yield ages of 1830 to 1900 m.y. (Aphebian). Sangster (1973, 1978) has reviewed the data on the ages of rocks in the Lynn Lake-Rusty Lake greenstone belt giving ages of between 1700 and 1900 m.y. (Aphebian).

Since the Flin Flon-Snow Lake and Lynn Lake-Rusty Lake greenstone belts are presently taken as being roughly equivalent in development, age, and origin (Moore, 1977; Sangster, 1978), the combined dating results suggest a period of volcanism from 1700 to 1900 m.y. followed by regional metamorphism up to 1950 m.y. for the pair of volcanic arcs. Therefore, the rocks have been subjected to just one major period of orogeny (Hudsonian-ended 1800 m.y.).

CHAPTER VII

METAMORPHISM

The Ruttan area portion of the Rusty Lake greenstone belt has been regionally metamorphosed to the lower to medium grade almandine-amphibolite facies. The rocks throughout the map area are amphibolite schists; no greenschist assemblages were observed in the field or in thin section (hornblende is prominent throughout; chlorite where present is retrograde-see Petrography). This suggests metamorphic temperatures in this part of the belt of 500-700°C and pressures of 7 kbars (Winkler, 1974).

The mafic metavolcanics are made up largely of blue-green, strongly pleochroic hornblende (0.2-6.0 mm) and plagioclase (0.2-2.0 mm). Biotite (0.2-3.0 mm) is prominent in the intermediate to felsic metavolcanics and in the metasediments. Fine grained garnets (0.1-1.0 mm) are common in the metasiltstones. There is a lack of facies indicator minerals other than biotite and garnet, and there are not enough mineralogical variations in this part of the belt to warrant mapping of metamorphic zones. The assemblage of hornblende + plagioclase + biotite + garnet is stable throughout the map area.

Horneblende and biotite occur in subhedral grains (0.2-6.0 mm) that cross-cut primary structures and are clearly metamorphic. On the other hand chlorite, epidote,

and sericite are fine grained (0.01-1.0 mm), and pseudomorph primary structures. These latter minerals may in part be recrystallization products of metamorphism, but are more probably products of alteration processes, as at Mattagami (Roberts and Reardon, 1978), because they are intimately associated with features such as increased sulphides, lower Na/K ratio, and higher Cu, Zn, S concentrations (compare Figure 37 with Figures 33, 34, 35, 36, 38 - backflap). Therefore, mapping of chlorite, epidote, and sericite as zones of alteration may be quite meaningful with regard to locating areas of hydrothermal alteration and mineralization.

CHAPTER VIII

PETROGRAPHY

1. INTRODUCTION

Primary textures have been obscurred by metamorphic recrystallization, but there are pseudomorphs of phenocrysts and relict clastic textures such as crystal fragments and felsic volcanic lithic fragments. It is difficult to distinguish in thin section between tuffs, flows, and volcaniclastic sediments.

Quartz grains commonly occur in elongated grains and in recrystallized polygonized mosaic textures in pyroclastic and clastic sediment thin sections. Hornblende is a dark, pleochroic, bluish-green colour, typically in foliated prismatic form but also as square-shaped pseudomorphs after pyroxene. Garnets occur in siltstones mostly, as equidimensional porphyroblasts. Foliation, flattening, and elongation of hornblende, biotite, white micas, and rock fragments is prominent. Textures are: recrystallized, porphyroblastic, foliated.

Retrograde reactions are the breakdown of plagioclase to sericite + saussurite + clays, especially in the fragmental rocks. Leaching of alkalis is shown by the growth of chlorite; introduction of K is represented by an abundance

of sericite.

2. MAFIC FLOWS

They are largely recrystallized to blue-green hornblende and are typically composed of 50-70% hornblende, 20-30% plagioclase, 2-5% Fe-Tioxides, 2-5% quartz (Table 1). Hornblende occurs in a variety of forms from coarse grained matted aggregates, to medium grained, subhedral metacrysts, to fine grained blady aggregates. Plagioclase commonly occurs in subhedral, tabular phenocrysts-sometimes mimicking an original doleritic texture. Magnetite is present as fine grained disseminations throughout the groundmass. The mafics frequently contain oriented, Fe-rich, microshears of hematite, biotite, suphides, and veinlets or patches of quartz and epidote alteration.

Assemblage: Hornblende + Plagioclase $\pm$ Biotite $\pm$ Fe-Ti oxides $\pm$ Epidote $\pm$ Quartz
- minor sericite, carbonate, sulphides, hematite, chlorite, apatite, zircon, sphene.

3. INTERMEDIATE AND FELSIC TUFFS

A pyroclastic origin is commonly indicated for these rocks in outcrop, but it is not nearly so detectable in thin section. They vary from fine grained, massive, and featureless, to coarse grained and highly fragmental. They are altered tuffs, lapilli tuffs, and agglomerates with abundant felsic crystals and altered rock fragments. Mineralogical

TABLE I. MODAL ANALYSES*

MAFIC METAVOLCANICS

Sample No.	12-1	12-2	12-9	12-14	13-1	13-2	13-4	14-2	14-3	15-1	15-2	15-3	15-4	16-1
PLAG.	19	15	15	14	10	32	24	19	10	17	27	27	31	32
QTZ.	3	3	...	...	...	...	...	...	...	8	...	...	...	...
Q-Fg.m.	...	...	...	...	...	...	...	...	...	...	...	...	...	...
HBLD.	71	51	78	83	70	63	59	68	70	62	68	65	63	63
BIOT.	...	...	...	...	...	...	...	...	...	...	...	...	...	...
R. FR.	...	...	...	...	...	...	...	...	...	...	...	...	...	...
CHLO.	...	...	...	...	1	...	...	...	1	...	...	...	...	...
MUSC.	...	...	...	...	...	...	...	...	...	...	...	...	...	...
SER.	...	...	3	...	6	...	...	...	6	...	1	1	2	...
EPID.	1	28	...	...	5	...	...	...	13	2	...	1	...	...
CARB.	...	...	...	...	...	...	...	...	...	...	...	...	...	...
GARN.	...	...	...	...	...	...	...	...	...	...	...	...	...	...
MGT.	...	...	...	3	...	4	...	13	...	...	...	8	4	4
HEM.	...	...	...	...	...	...	...	...	...	3	...	...	...	...
RUT.	5	2	4	...	8	1	...	...	...	8	4	1	...	1
PYR. (+cpy+pyh)	1	1	...	...	...	...	17	...	...	...	1	...	...	...
AP+ZIR+SPH	...	...	...	...	...	...	...	...	...	...	...	...	...	...

*values in percent

TABLE I - continued

MAFIC METAVOLCANICS

SAMPLE NO.	16-5	16-6	17-1	17-2	17-3	18-1	18-2	19-4	20-1	21-4	22-1	28-1	29-1	30-1
PLAG.	27	13	23	12	19	24	26	33	23	23	28	31	34	33
QTZ.	3	3	2	...	...	3	...	...	...	8	2	...	...	...
Q-Fg.m.	...	...	...	...	...	...	...	...	...	...	...	...	...	...
HBLD.	65	78	66	71	68	67	62	53	72	57	61	62	60	60
BIOT.	...	...	...	14	...	...	...	4	...	...	...	...	...	...
R.FR.	...	...	...	...	...	...	...	...	...	...	...	...	...	...
CHL.	...	...	...	...	...	...	...	...	...	...	...	...	...	...
MUSC.	...	...	...	...	...	...	...	...	...	...	...	...	...	...
SER.	...	...	2	...	...	...	...	...	...	...	...	...	1	1
EPID.	...	6	1	...	...	...	...	...	...	...	...	1	1	1
CARB.	...	...	...	...	...	...	...	...	...	7	...	...	...	...
GARN.	...	...	...	...	...	...	...	...	...	...	...	...	...	...
MGT.	...	...	...	3	13	6	12	8	5	2	9	...	3	...
HEM.	1	...	...	...	...	...	...	2	...	1	...	...	2	...
RUT.	2	...	6	...	...	...	...	...	...	2	...	2	...	2
PYR. (+cp+pyh)	2	...	...	...	...	...	...	...	...	1	...	4	...	3
AP+ZIR+SPH.	...	...	...	...	...	...	...	...	...	...	...	...	...	...

TABLE I - continued

MAFIC METAVOLCANICS

SAMPLE NO.	31-3	39-3	40-1	C-8	C-10	C-14	C-15	C-23	C-32	C-33	C-34	C-36	C-37	C-38
PLAG.	36	31	28	27	29	25	22	23	36	22	32	26	14	20
QTZ.	...	...	2	1	...	...	...	1	...	4	...	...	7	...
Q-Fg.m.	...	...	7	...	...	...	...	...	...	...	...	...	...	...
HBLD.	57	62	59	53	62	72	71	73	58	68	46	67	74	76
BIOT.	...	...	...	3	...	...	1	1	...	...	13	...	...	...
R.FR.	...	...	...	...	1	...	...	...	...	...	...	...	...	...
CHL.	...	...	...	...	...	...	1	...	...	...	...	...	...	...
MUSC.	...	...	...	...	...	...	...	...	...	...	...	...	...	...
SER.	1	2	2	...	...	...	...	1	...	1	...	...	...	...
EPID.	2	...	...	8	...	1	...	1	...	...	...	...	...	...
CARB.	...	...	...	...	...	...	...	...	...	...	3	...	...	...
GARN.	...	...	...	...	...	...	...	...	...	...	...	...	...	...
MGT.	...	4	2	5	...	2	5	2	6	5	...	1	...	...
HEM.	1	...	...	...	...	...	...	...	...	...	3	...	...	...
RUT.	4	...	...	3	...	1	...	...	...	...	1	6	5	2
PYR. (cp+pyh)	...	...	...	...	8	...	...	...	...	...	2	...	...	2
AP+ZIR+SPH.	...	...	...	...	...	...	...	...	...	...	...	...	...	...

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TABLE I - continued

	MAFIC METAVOLCANICS					INTERMEDIATE METAVOLCANICS							
SAMPLE NO.	C-39	C-42	C-44	C-45	C-49	12-18	16-3	16-4	18-4	19-1	19-2	19-3	21-1
PLAG.	26	23	21	6	12	16	...	54	15	33	21	18	22
QTZ.	...	...	2	...	2	6	...	...	1	...	2	3	...
Q-Fg.m.	...	...	...	...	...	31	41	...	...	...	...	...	28
HBLD.	63	51	70	53	80	44	56	36	55	47	54	55	38
BIOT.	2	20	...	...	...	...	...	7	...	...	17	...	9
R.FR.	9	...	...	(37) (epid.)	...	...	...	...	(26) (epid.)	(5) (epid.)	...	(2) (epid.)	...
CHL.	1	...	...	...	...	...	...	...	...	...	...	...	...
MUSC.	...	...	...	...	...	...	...	...	...	...	...	...	...
SER.	2	...	...	1	...	...	...	1	...	1	...	...	...
EPID.	1	...	...	37	...	...	...	1	26	15	3	21	...
CARB.	...	...	...	...	...	...	...	...	...	1	...	...	...
GARN.	...	...	...	...	...	...	...	...	...	...	...	...	...
MGT.	...	6	7	...	6	3	3	...	...	...	...	...	3
HEM.	1	...	...	...	...	...	...	...	...	...	...	...	...
RUT.	...	...	...	2	...	...	...	2	3	3	3	3	...
PYR. (cp+pyh)	4	...	...	1	...	...	...	...	...	...	...	...	...
AP+ZIR+SPH	...	...	...	1	...	...	...	...	...	...	...	...	...

TABLE I - continued

INTERMEDIATE METAVOLCANICS

SAMPLE NO.	21-2	22-2	22-3	23-1	23-2	23-3	37-4	38-1	39-5	C-20	C-40	C-48	C-51	C-69	C-73
PLAG.	25	1	...	...	8	...	14	13	32	20	46	36	...	40	12
QTZ.	4	3	...	9	6	...	19	25	8	2	3	19	...	4	...
Q-Fg.m.	...	58	29	57	36	41	...	...	...	22	...	...	65	...	40
HBLD.	39	26	23	31	35	35	62	67	37	52	48	30	22	37	11
BIOT.	...	9	13	1	10	24	...	...	19	...	...	1	9	16	22
R.FR.	(5) (ep+carb)	...	(10) (epid)	...	...	...	...	...	...	...	1	...	1	...	(3) (carb)
CHL.	...	...	...	...	...	...	...	...	...	1	1	4	...	...	1
MUSC.	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
SER.	...	1	1	1	1	...	...	...	1	1	1	...	...	...	1
EPID.	20	1	32	...	2	...	...	...	...	1	1	5	...	...	10
CARB.	7	...	...	...	...	...	...	...	...	...	...	2	...	...	3
GARN.	...	...	...	...	...	...	1	2	...	...	...	...	...	...	...
MGT.	2	1	1	1	...	...	4	3	3	...	...	...	...	3	...
HEM.	...	...	...	...	...	...	...	...	...	...	...	...	2	...	...
RUT.	3	1	1	...	...	...	...	...	...	...	1	2	...	...	...
PYR. (cp+pyh)	...	...	...	...	2	1	...	...	...	2	2	1	...	...	...
AP+ZIR+SPH	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...

TABLE I - continued

	FELSIC METAVOLCANICS														
SAMPLE NO.	12-19	20-2	21-3	37-3	38-2	39-4	39-6	40-2	43-2	C-17	C-22	C-46	C-72	C-75	J-3
PLAG.	...	24	30	...	13	20	...	11	2	...	...	...	6	...	7
QTZ.	...	20	7	3	17	3	...	...	...	...	...	...	...	...	...
Q-Fg.m.	81	35	...	83	39	40	60	59	63	56	73	80	55	58	62
HBLD.	...	...	31	1	9	...	5	11	19	...	...	...	33	17	...
BIOT.	8	9	8	10	17	32	28	15	11	11	23	15	...	16	27
R.FR.	4	...	(3)	...	...	...	...	...	...	...	...	...	1	...	...
CHL.	3	...	(ep) ...	...	...	...	...	...	...	4	...	1	4	...	...
MUSC.	...	9	...	...	...	...	...	...	...	3	...	...	...	...	...
SER.	3	...	1	...	2	1	...	1	...	2	...	2	...	1	...
EPID.	...	2	20	3	2	4	7	4	5	22	4	2	1	8	1
CARB.	...	...	...	...	1	...	...	...	...	...	...	...	...	...	...
GARN.	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
MGT.	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
HEM.	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
RUT.	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
PYR. (cp+pyh)	1	1	...	...	...	...	...	...	...	2	...	1	1	1	2
AP+ZIR+SPH.	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

TABLE I - continued

ALTERED METAVOLCANICS

SAMPLE NO.	12-12	18-3	20-3	25-1	31-1	C-7	C-12	C-13	C-50	C-55	C-74
PLAG.	...	13	...	...	16	23	...	...	...	22	21
QTZ.	...	...	...	...	1	9	...	...	...	2	6
Q-Fg.m.	...	...	35	33	...	40	...	...	31	...	...
HBLD.	5	83	18	45	53	8	32	...	...	69	48
BIOT.	14	...	...	...	3	17	14	...	...	...	...
R.FR.	(26) (ep)	...	...	...	...	...	...	...	7	...	3
CHL.	9	...	...	...	...	...	26	47	...	...	1
MUSC.	...	...	...	...	...	...	...	...	26	...	...
SER.	39	...	...	...	...	1	...	...	...	...	...
EPID.	26	...	42	...	23	3	23	...	7	...	11
CARB.	...	...	...	...	...	...	1	42	...	...	...
GARN.	...	...	...	...	...	...	...	...	...	...	...
MGT.	...	3	...	...	...	...	...	...	...	...	...
HEM.	...	...	_1	...	...	...	1	...	...	...	1
RUT.	6	1	3	8	2	...	...	...	...	3	3
PYR. (cp+pyh)	1	...	2	14	3	...	...	11	29	4	6
AP+ZIR+SPH.	...	...	...	...	...	1	1	...	...	...	...

TABLE I - continued

METASEDIMENTS

SAMPLE NO.	16-2	23-4	25-5	26-1	26-2	27-2	C-25	C-27	C-28	C-41	C-47	C-52	C-56	C-61	C-67
PLAG.	...	...	...	14	...	12	34	21	1	18	...	3	7	46	35
QTZ.	...	...	50	6	...	4	17	11	1	...	34	4	...	6	34
Q-Fg.m.	63	41	...	38	38	48	...	10	47	59	41	47	34	...	...
HBLD.	9	18	45	34	45	2	31	35	5	...	...	42	43	29	6
BIOT.	22	22	...	...	13	33	17	4	34	11	8	2	11	16	...
R.FR.	2	...	...	6	...	...	...	(17) (hbld)	8	(3) (ep)	1	...	...	...	...
CHL.	...	...	...	...	...	...	...	...	...	3	...	...	...	1	22
MUSC.	...	...	...	...	...	...	...	...	...	...	9	...	...	...	...
SER.	2	1	...	...	1	...	1	...	...	1	...	...	...	...	2
EPID.	1	...	...	...	1	...	1	...	3	3	4	...	...	...	...
CARB.	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
GARN.	1	10	...	5	...	...	...	...	...	...	...	...	...	...	...
MGT.	...	8	5	3	...	1	...	2	1	2	...	2	4	2	...
HEM.	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
RUT.	...	...	...	...	3	1	...	...	...	...	...	...	...	...	...
PYR.	...	...	...	...	...	...	...	...	...	...	3	...	...	...	...
(cp+pyh)															
AP+ZIR+SPH.	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

composition is highly variable. They are composed of 10-50% feldspar (dominantly plagioclase, minor k-spar), 10-60% recrystallized quartzofeldspathic groundmass, 0-50% hornblende, o-20% biotite, 0-20% lithic fragments, and variable amounts of alteration products (Table I).

No primary vitric clasts or textures (ie. shards, perlitic cracks, spherulites) or welded fragments are preserved. However, these rocks may have originally been vitroclastic in part. Sand-sized quartz grains generally make up less than 15% of the sections; they are much more abundant in the metasedimentary thin sections.

Angular feldspar and subordinate quartz clasts are set in a fine grained, recrystallized, quartzofeldspathic groundmass which is rich in sericitic and epidotic alteration. Plagioclase crystal fragments and felsic rock fragments are preferentially replaced by epidote, sericite, and chlorite. In comparison, the clastic sediments contain much more abundant clasts, especially quartz, and display more granular, interlocking texture-which occasionally shows microscopic grain size grading. Lithic fragments are rare in finer grained tuffs (obscurred by alteration perhaps) but are seen to make up to 20% of the coarser pyroclastics. Most of the rock fragments are strongly or totally replaced by epidote, sericite, carbonate, and chlorite. This is an important feature with regard to alteration related to mineralization. A few of the samples are rich in disseminations, veinlets, and patchworks of sulphides (dominantly pyrite; subordinate pyrrhotite,

chalcopyrite, and sphalerite ie. sample no.'s C-13, C-15, 25-1; Table I).

Textural variation between fine grained massive tuffs, coarse grained pyroclastics, volcaniclastic sediments, and felsic flows are best observed on weathered outcrops rather than in thin section, due to the intense recrystallization.

Assemblage: Plagioclase + Quartz + Hornblende + Biotite ± Fe - Ti oxides ± Sericite ± Epidote ± Lithic Fragments.

- minor chlorite, sulphides, carbonate, garnet, apatite, zircon, sphene.

4. FELSIC FLOWS

They consist of 10-20% subhedral, medium grained, strongly altered plagioclase phenocrysts, and 0-10% quartz phenocrysts. Feldspar phenocrysts commonly occur as glomeroporphritic clusters. No crystal or lithic fragments are observed. The quartzofeldspathic groundmass probably represents original fine grained devitrified glass, but is now totally recrystallized and partially replaced by sericite and epidote.

Assemblage: Plagioclase + Quartz + Biotite + Hornblende ± Sericite ± Epidote ± Fe- Ti oxides.

- minor chlorite, carbonate, sulphides, garnet, apatite, zircon, sphere.

5. VOLCANICLASTIC SEDIMENTS

In comparison with pyroclastic rocks, they contain significantly more clasts (especially quartz), and have a

granular interlocking texture with variable grain size (Table I). Plagioclase grains are common but greatly subordinate to quartz. In comparison with mafic volcanics, mafic volcaniclastic sediments contain abundant biotite, common garnets, more quartz, and granular-interlocking texture.

Assemblage: Quartz + Plagioclase + Biotite ± Hornblende ± White Micas ± Garnet ± Epidote.

- minor chlorite, carbonate, Fe-Tioxides, sulphides, apatite, zircon, sphene.

6. MASSIVE SULPHIDE MINERALIZATION

The massive mineralization from the Ruttan orebody contains 60-90% sulphides. Pyrite, pyrrhotite, sphalerite and subordinate amounts of chalcopyrite are the ore minerals.

The massive sulphide layers are distinctly richer in either pyrite or pyrrhotite, and sphalerite is closely associated with pyrite. Some parts of the massive sulphide layers contain thin discontinuous silicate lenses which are alligned parallel to the foliation of enclosing wallrock. The sulphide ore commonly shows minor banding of pyrite and sphalerite, and to a lesser extent pyrrhotite. Banding is also present as monominerallic pyrite layers according to variation in grain size and texture.

Prominent features of the massive mineralization include a streaky layering of pyrrhotite parallel to foliation in the wallrock and gneissic textured banding. Granoblastic texture is characterized by mosaic development of equigranular

pyrite crystals. Poikiloblasts and porphyroblasts of pyrite are often embedded in poikiloblastic spalerite matrix. Brecciation of the more competent pyritic layers and plastic flowage of chalcopyrite and pyrrhotite around silicate fragments into pressure shadows is common.

CHAPTER IX

GEOCHEMISTRY

1. PROBLEM OF PRECAMBRIAN ALTERATION EFFECTS

Major element analyses of metavolcanic rocks in the Ruttan area may not represent primary composition due to the metasomatic introduction of calcite, quartz, and epidote (represented chemically by high H_2O, CO_2, CaO). Therefore, considerable care was taken both in the field and in the laboratory in preparing homogeneous, representative samples for whole rock analysis. Major and minor element geochemistry is listed in Table II and Norm Calculations are given in Table III.

In the field, the most homogeneous and texturally representative rock was sampled. Visible secondary quartz and calcite were removed. A cut-off point of 3.8% H_2O + CO_2 was used for identifying secondary alteration (after Wilson et. al., 1965). It turns out that careful sampling avoided this problem because none of the analyses in this study contain more than 3.8% total volatiles.

2. DEFINITION OF "ALTERED" VOLCANIC ROCKS

No method of igneous classification of the rocks by chemical composition is completely satisfactory because

TABLE II MAJOR OXIDE AND TRACE ELEMENT VARIATION*

	BASALTS													
SAMPLE NO.	12-1	12-2	12-3	12-9	12-11	12-13	13-1	13-2	13-3	13-4	14-2	14-3	15-1	15-2
SiO_2	45.41	47.14	47.70	47.19	48.87	48.99	48.05	46.20	45.46	45.35	47.20	47.75	49.00	49.40
TiO_2	0.24	1.43	0.88	1.03	1.33	1.05	1.84	0.97	1.64	0.85	1.05	0.93	1.33	0.79
Al_2O_3	15.13	14.89	14.28	13.06	16.20	17.86	12.44	17.81	13.62	18.44	13.78	13.82	14.18	15.20
Fe_2O_3	3.91	4.90	3.14	2.76	4.04	2.03	5.50	4.68	5.33	6.29	2.74	2.63	3.86	2.00
FeO	11.52	8.37	8.84	10.07	8.48	11.19	9.48	8.44	13.72	7.50	8.40	8.88	9.24	8.00
MnO	0.29	0.23	0.22	0.26	0.28	0.16	0.34	0.26	0.29	0.22	0.20	0.22	0.24	0.18
MgO	8.61	5.84	8.25	11.26	7.35	8.00	5.60	5.30	7.41	4.50	6.75	9.35	6.26	7.60
CaO	12.49	14.27	11.55	12.62	10.09	8.82	11.80	11.85	10.10	12.40	13.08	13.70	11.10	12.70
Na_2O	1.92	2.59	1.93	1.03	3.11	1.64	1.68	1.67	2.20	1.88	2.30	0.98	2.20	1.78
K_2O	0.39	0.33	0.40	0.71	0.24	0.26	0.34	0.74	0.24	0.62	0.37	0.34	0.43	0.21
P_2O_5	0.13	0.11	0.07	0.12	0.14	0.19	0.12	0.23	0.16	0.09	0.06	0.05	0.12	0.05
H_2O			1.69				2.10	1.68		1.65	1.62	2.02	1.64	1.60
CO_2			0.37				0.36	0.31		0.29	2.02	0.32	0.40	0.36
TOTAL	100.13	100.10	99.33	100.11	100.13	100.19	99.83	100.26	100.17	100.10	99.98	101.03	100.01	99.89
Cuppm	95	150	75	60	70	65	79	48	60	156	172	113	57	121
Znppm	170	160	76	190	180	180	142	89	200	93	99	72	102	67
S ppm	650	2100	140	440	500	75	1820	1200	950	1040	3100	440	170	190

*Values in weight percent.

TABLE II - continued

BASALTS

SAMPLE NO.	15-3	15-4	16-1	16-5	16-6	17-1	17-2	17-3	18-1	19-4	29-1	30-1	31-3	C-8
SiO_2	47.65	49.10	50.70	49.05	50.60	49.65	47.40	50.30	48.05	48.50	50.05	47.65	48.35	49.97
TiO_2	1.80	0.88	1.17	0.88	1.60	0.91	0.83	1.77	1.62	1.51	1.32	1.33	1.11	0.37
Al_2O_3	13.64	15.64	13.88	15.26	13.78	17.81	13.54	13.36	13.80	13.82	13.74	14.70	13.27	17.69
Fe_2O_3	7.35	3.28	2.92	2.88	3.87	3.16	3.38	2.87	2.93	3.44	3.55	3.25	5.10	4.65
FeO	10.32	8.00	9.60	9.19	9.02	8.08	9.84	12.70	12.68	11.44	10.55	9.50	7.16	8.44
MnO	0.23	0.21	0.21	0.22	0.24	0.25	0.24	0.24	0.32	0.24	0.20	0.18	0.22	0.24
MgO	4.80	7.05	6.45	5.85	5.45	4.05	9.44	5.45	5.95	6.35	6.25	6.05	6.70	4.01
CaO	9.50	9.60	9.35	11.18	10.90	12.70	10.26	9.35	10.20	8.64	10.00	12.10	13.06	12.54
Na_2O	2.97	2.93	3.55	2.80	1.73	0.85	1.70	1.63	2.00	2.82	1.75	1.62	1.57	1.59
K_2O	0.19	0.65	0.24	0.29	0.31	0.48	0.37	0.29	0.29	0.29	0.20	0.22	0.22	0.49
P_2O_5	0.10	0.08	0.09	0.09	0.13	0.18	0.08	0.14	0.11	0.11	0.13	0.12	0.09	0.17
H_2O	1.72	1.64	1.44	1.60	1.79	1.49	2.09	1.55	1.08	1.82	1.63	1.46	2.09	
CO_2	0.36	0.18	0.36	0.38	0.31	0.31	0.41	0.22	0.47	0.47	0.25	0.29	0.58	
TOTAL	100.66	99.24	99.97	99.67	99.81	99.92	99.58	100.06	99.54	99.50	99.66	98.83	99.65	100.16
Cuppm	68	70	69	65	103	43	33	107	40	38	50	81	81	320
Znppm	77	109	76	130	102	110	105	115	135	124	91	82	110	120
S ppm	210	10	90	60	600	20	40	1920	370	480	380	3500	1300	600

TABLE II - continued

	BASALTS													
SAMPLE NO.	C-14	C-15	C-23	C-32	C-33	C-34	C-36	C-37	C-38	C-39	C-42	C-44	C-45	C-49
SiO_2	50.82	48.89	45.77	47.85	46.95	46.72	45.30	48.67	45.78	48.18	46.65	48.42	44.95	48.74
TiO_2	0.86	1.17	0.68	1.43	1.03	1.19	1.15	1.18	1.04	1.02	1.06	1.66	1.02	1.47
Al_2O_3	16.27	19.00	18.55	13.81	13.17	14.98	14.38	14.91	13.29	16.38	19.48	13.97	16.20	14.18
Fe_2O_3	2.13	1.98	2.21	3.89	1.70	2.37	1.55	1.45	1.48	1.89	1.55	2.33	3.59	0.89
FeO	8.24	10.36	12.14	11.08	11.63	11.08	11.50	10.37	12.75	10.73	11.07	13.70	10.51	12.74
MnO	0.20	0.17	0.31	0.21	0.25	0.25	0.24	0.21	0.23	0.22	0.23	0.24	0.26	0.26
MgO	7.81	6.54	5.52	7.77	10.90	9.09	9.56	8.10	10.31	8.36	6.00	6.87	7.74	7.41
CaO	10.91	9.58	11.05	10.73	12.25	10.89	14.44	12.95	13.41	10.62	10.43	10.04	13.52	12.57
Na_2O	2.51	1.92	3.13	3.00	1.89	2.52	1.60	1.66	1.43	2.35	3.24	2.57	1.66	1.49
K_2O	0.24	0.40	0.63	0.22	0.23	0.92	0.28	0.51	0.28	0.24	0.30	0.19	0.56	0.24
P_2O_5	0.16	0.16	0.08	0.10	0.08	0.09	0.09	0.09	0.08	0.10	0.17	0.12	0.11	0.12
H_2O														
CO_2														
TOTAL	100.15	100.17	100.07	100.09	100.08	100.10	100.09	100.10	100.08	99.99	100.18	100.11	100.12	100.11
Cuppm	35	35	46	37	210	210	83	77	33	83	25	80	100	79
Znppm	160	160	180	93	120	130	110	160	200	160	130	190	200	180
S ppm	27	57	100	220	170	2770	300	990	370	3240	38	140	150	1940

TABLE II - continued

ANDESITES										
SAMPLE NO.	10-3	11-1	12-17	12-21	16-3	23-2	37-4	C-20	C-40	C-69
SiO_2	52.55	57.10	52.21	55.60	54.15	55.55	54.70	54.60	53.50	55.66
TiO_2	0.61	0.66	0.62	0.66	1.02	0.68	0.42	0.67	0.53	1.37
Al_2O_3	14.18	16.40	17.34	19.28	14.86	16.46	17.07	17.22	17.94	15.68
Fe_2O_3	2.24	3.18	2.05	2.83	2.48	3.03	2.83	1.23	0.64	1.50
FeO	7.18	7.20	10.45	4.52	9.62	7.66	9.20	8.60	7.27	9.38
MnO	0.24	0.21	0.23	0.15	0.25	0.17	0.22	0.20	0.15	0.21
MgO	7.20	2.45	4.66	2.20	5.40	2.50	2.05	4.55	4.66	2.06
CaO	9.14	8.35	10.36	9.00	6.75	6.97	7.78	9.78	10.95	9.46
Na_2O	2.15	2.52	1.94	3.42	3.23	2.55	3.03	2.83	2.96	2.09
K_2O	0.76	0.54	0.14	0.66	0.14	1.13	0.68	0.33	0.40	2.59
P_2O_5	0.16	0.11	0.11	0.12	0.11	0.12	0.20	0.12	0.13	0.44
H_2O	2.29	1.08		1.07	1.36	2.45	1.18			
CO_2	0.87	0.19		0.30	0.52	0.33	0.22			
TOTAL	99.58	100.07	100.11	99.83	99.90	99.76	99.60	100.13	99.13	100.44
Cuppm	26	152	140	88	40	117	22	170	25	55
Znppm	97	74	140	67	120	106	143	120	83	170
S ppm	130	840	200	200	20	1490	80	120	94	260

TABLE II - continued

	DACITES							RHYODACITES					
SAMPLE NO.	5-1	12-18	23-1	C-48	C-51	C-53	C-73	2-1	40-2	43-1	C-72	C-75	J-3
SiO_2	63.95	58.07	61.90	59.69	61.51	63.86	61.42	62.25	65.50	68.00	66.08	64.47	67.77
TiO_2	0.42	0.85	0.51	0.67	0.57	0.51	0.49	0.40	0.59	0.36	0.40	0.49	0.52
Al_2O_3	14.72	15.52	16.26	16.53	16.42	16.62	16.48	14.96	13.56	13.60	13.91	15.96	14.75
Fe_2O_3	1.67	1.94	1.98	1.53	1.23	0.39	1.15	2.07	1.41	1.88	0.61	1.23	0.66
FeO	4.92	10.59	4.38	5.95	6.24	4.68	6.33	4.88	6.70	4.44	5.59	6.09	5.95
MnO	0.19	0.22	0.15	0.19	0.11	0.11	0.15	0.16	0.20	0.13	0.14	0.15	0.11
MgO	1.50	2.61	2.85	3.81	3.56	3.24	4.41	1.95	2.45	1.35	1.32	1.59	1.65
CaO	7.05	5.75	6.96	8.11	6.20	5.37	5.05	4.65	4.30	4.80	7.58	5.25	2.53
Na_2O	1.92	4.11	3.92	2.91	2.91	2.79	3.40	2.22	2.08	1.68	2.79	2.56	3.97
K_2O	1.46	0.33	0.56	0.61	1.31	2.42	1.12	1.69	0.82	2.49	1.57	2.21	2.08
P_2O_5	0.14	0.14	0.11	0.13	0.10	0.11	0.12	0.15	0.27	0.09	0.11	0.14	0.10
H_2O	1.02		1.02					1.04	1.49	0.93			
CO_2	0.37		0.14					0.30	0.41	0.27			
TOTAL	99.33	100.13	100.74	100.13	100.10	100.10	100.12	99.75	99.78	100.02	100.10	100.14	100.09
Cu ppm	36	120	8	55	17	31	65	37	13	32	54	46	60
Zn ppm	89	180	56	130	83	63	150	101	83	90	97	110	140
S ppm	10	15	60	210	110	660	190	240	...	30	150	97	180

TABLE II - continued

	RHYOLITES										
SAMPLE NO.	1-6	3-1	8-1	10-2	12-14	12-19	20-2	37-3	C-17	C-22	C-46
SiO_2	73.50	72.10	74.55	81.10	72.10	73.22	74.10	76.00	74.27	72.93	76.08
TiO_2	0.22	0.38	0.22	0.20	0.26	0.15	0.15	0.23	0.27	0.28	0.22
Al_2O_3	13.66	12.96	12.70	8.51	14.62	13.26	13.36	11.02	12.83	12.69	12.17
Fe_2O_3	0.79	1.81	0.93	0.88	0.88	1.05	0.98	1.16	1.13	0.36	...
FeO	2.12	3.68	2.10	2.62	2.04	3.83	2.20	3.42	3.40	4.83	3.10
MnO	0.11	0.10	0.05	0.06	0.07	0.08	0.04	0.08	0.12	0.10	0.04
MgO	0.55	1.30	0.65	0.96	0.65	1.01	0.44	0.80	0.76	1.05	0.42
CaO	2.05	2.50	2.35	1.28	2.70	3.55	2.32	3.45	4.03	4.57	2.01
Na_2O	2.65	3.48	2.73	1.90	3.08	2.64	0.51	1.48	2.08	0.95	1.66
K_2O	2.92	1.48	2.32	1.44	2.35	1.19	4.39	0.97	1.09	2.28	4.30
P_2O_5	0.02	0.10	0.02	0.03	0.03	0.03	0.01	0.06	0.06	0.07	0.03
H_2O	0.89	0.83	0.79	0.72	0.77		1.23	0.72			
CO_2	0.38	0.25	0.48	0.26	0.51		0.57	0.52			
TOTAL	99.86	100.97	99.90	99.97	100.06	100.01	100.30	99.91	100.04	100.08	100.03
Cuppm	15	16	21	14	25	81	20	34	120	70	38
Znppm	59	69	44	46	51	86	54	60	170	99	75
S ppm	40	10	50	70	90	3050	90	50	4600	140	170

TABLE II - continued

ALTERED VOLCANICS											
SAMPLE NO.	12-12	18-3	20-3	21-3	25-1	C-7	C-12	C-13	C-50	C-55	C-74
SiO_2	32.01	43.35	50.75	44.85	48.90	54.12	44.25	25.75	51.52	47.27	44.53
TiO_2	1.42	0.81	0.74	0.76	1.50	0.71	0.55	0.84	0.86	1.30	0.43
Al_2O_3	25.52	15.96	17.27	18.03	14.64	21.13	13.79	16.57	19.95	17.99	18.70
Fe_2O_3	1.65	3.71	4.73	5.92	1.52	1.17	4.25	5.24	0.81	2.55	3.69
FeO	8.21	11.12	8.70	7.16	10.84	7.13	6.52	9.94	6.67	11.84	10.09
MnO	0.21	0.30	0.23	0.25	0.21	0.16	0.33	0.38	0.12	0.26	0.25
MgO	7.45	7.65	2.40	5.35	5.65	2.73	9.45	16.01	7.95	5.13	7.12
CaO	18.44	11.98	10.90	10.36	11.95	7.76	20.13	20.13	9.16	10.22	13.71
Na_2O	0.10	1.43	1.78	2.02	1.37	2.10	0.35	0.05	1.20	2.61	1.26
K_2O	4.99	0.36	0.60	2.08	0.18	2.99	0.36	5.08	1.76	0.84	0.43
P_2O_5	0.12	0.06	0.14	0.12	0.17	0.17	0.21	0.22	0.18	0.18	0.13
H_2O		1.92	1.62	1.79	1.16						
CO_2		0.17	0.28	0.40	0.70						
TOTAL	100.12	98.84	100.17	99.70	100.91	100.17	100.19	100.21	100.18	100.19	100.14
Cuppm	40	107	81	147	191	50	30	20	85	70	150
Znppm	120	154	130	149	92	150	170	210	57	160	130
S ppm	430	150	310	6100	21100	35	400	250	31900	640	6700

TABLE II - continued

SEDIMENTS

SAMPLE NO.	6-1	10-1	12-22	12-24	16-2	23-4	25-5	26-1	26-2	27-2	C-25	C-27	C-28	C-41
SiO_2	73.40	51.75	54.10	57.20	65.05	45.34	59.75	62.85	48.15	65.05	51.45	55.54	59.41	68.72
TiO_2	0.19	0.86	0.70	0.56	0.44	0.98	0.91	0.65	0.72	0.60	0.59	0.52	0.70	0.26
Al_2O_3	13.94	17.96	19.42	16.95	14.37	23.91	15.40	13.90	19.11	15.22	20.92	17.11	17.96	16.27
Fe_2O_3	0.78	2.79	2.64	3.93	2.78	2.00	2.45	2.06	3.17	1.93	2.22	1.30	1.33	0.51
FeO	2.44	7.28	6.78	5.34	5.84	10.24	6.32	7.20	8.12	3.68	8.58	9.23	7.41	2.89
MnO	0.07	0.17	0.19	0.22	0.11	0.24	0.21	0.22	0.19	0.13	0.16	0.20	0.15	0.05
MgO	0.70	5.10	2.30	1.90	1.00	3.65	2.45	1.85	4.25	1.00	3.11	4.69	2.73	1.00
CaO	2.75	6.00	8.90	11.25	4.55	5.85	5.65	7.20	11.70	2.65	8.34	8.78	5.66	2.35
Na_2O	3.00	3.30	2.67	0.75	2.87	3.48	4.77	2.38	2.00	5.35	3.08	2.20	2.96	3.72
K_2O	2.08	2.80	0.54	0.43	1.19	2.40	0.29	0.40	0.74	1.41	1.55	0.40	1.68	4.23
P_2O_5	0.01	0.22	0.10	0.10	0.13	0.20	0.23	0.16	0.12	0.12	0.08	0.10	0.14	0.10
H_2O	0.95	1.56	1.16	1.21	1.05	1.62	0.91	1.00	1.31	0.82				
CO_2	0.50	0.14	0.38	0.32	0.45	0.23	0.33	0.16	0.06	0.83				
TOTAL	100.81	99.94	99.89	100.16	99.84	100.16	99.68	95.04	99.67	98.80	100.08	100.07	100.13	100.10
Cuppm	17	157	30	54	14	25	47	21	79	36	120	130	30	70
Znppm	39	89	132	77	84	120	112	116	79	70	110	150	180	92
S ppm	60	10	80	20	130	20	130	50	320	110	200	600	65	2460

TABLE II - continued

	SEDIMENTS											
SAMPLE NO.	C-47	C-52	C-56	C-57	C-60	C-61	C-64	C-65	C-67	C-68	C-70	C-71
SiO_2	72.44	60.33	52.17	67.17	53.03	59.65	59.77	65.39	63.48	75.98	50.69	58.49
TiO_2	0.27	0.60	1.46	0.36	0.68	1.00	0.85	0.53	0.53	0.20	0.82	0.76
Al_2O_3	12.69	16.98	15.71	15.85	20.54	15.47	16.47	18.38	15.82	12.23	19.82	17.67
Fe_2O_3	1.71	1.46	1.91	0.60	1.37	1.54	0.95	...	4.84	0.14	2.25	0.62
FeO	4.98	7.36	13.94	4.95	7.53	8.00	8.27	3.48	3.09	2.93	7.59	7.96
MnO	0.10	0.17	0.24	0.08	0.16	0.17	0.17	0.10	0.15	0.08	0.19	0.12
MgO	0.58	2.64	3.38	4.87	4.33	1.07	3.01	0.76	2.46	1.17	4.08	3.62
CaO	3.43	5.79	7.09	2.59	8.06	7.52	5.55	7.84	3.47	2.43	10.28	6.14
Na_2O	0.59	3.69	2.58	2.64	3.74	2.61	4.11	2.52	2.99	2.46	2.80	2.80
K_2O	3.21	0.96	1.51	0.88	0.55	2.98	0.84	0.99	3.18	2.39	1.49	1.84
P_2O_5	0.05	0.13	0.28	0.09	0.13	0.26	0.16	0.14	0.13	0.03	0.23	0.22
H_2O												
CO_2												
TOTAL	100.05	100.11	100.27	100.08	100.12	100.27	100.15	100.13	100.14	100.04	100.24	100.21
Cuppm	110	12	95	100	33	75	80	25	130	13	130	12
Znppm	310	140	180	120	100	130	140	45	99	46	110	110
S ppm	11200	36	21	1430	10	75	550	160	150	17	96	20

TABLE III BARTH-NIGGLI NORMS*

BASALTS

SAMPLE NO.	12-1	12-2	12-3	12-9	12-11	12-13	13-1	13-2	13-3	13-4	14-2	14-3	15-1	15-2
QTZ	...	...	...	...	...	0.24	5.82	0.18	8.15	...	...	...	1.87	0.60
COR	...	...	...	...	...	...	...	...	...	...	...	...	...	...
OR	2.35	2.00	2.45	4.25	1.45	1.55	2.15	4.55	4.30	1.45	2.35	2.10	2.65	1.30
AB	14.50	19.65	17.95	9.30	28.10	14.90	16.10	15.60	22.60	20.35	21.65	9.00	20.65	16.50
AN	31.80	28.35	30.20	29.05	29.60	41.08	26.95	40.43	28.35	27.28	27.38	33.08	28.63	33.75
NE	1.77	2.40	...	...	...	...	...	...	...	...	...	...	...	...
LC	...	...	...	...	...	...	...	...	...	...	...	...	...	...
WO	12.36	17.42	11.54	13.62	8.32	1.30	13.82	7.68	8.00	9.72	16.12	14.52	5.59	12.34
DI — EN	7.56	11.88	7.62	9.70	5.80	0.78	8.86	4.82	5.74	5.52	10.70	10.22	7.06	8.32
FS	4.80	5.54	3.56	3.92	2.52	0.52	4.96	2.86	2.26	4.20	5.42	4.30	4.12	4.02
HY — EN	...	...	11.40	8.30	6.28	21.60	7.60	10.40	9.86	5.98	2.40	14.20	10.94	13.30
FS	...	...	5.32	3.36	2.72	14.38	4.12	6.16	3.88	4.56	1.22	5.98	6.42	6.42
FO	12.36	3.38	3.48	9.99	6.26	...	...	...	...	7.16	4.83	1.56	...	...
OL — FA	7.79	1.58	1.62	4.05	2.72	...	...	...	...	5.45	2.45	0.66	...	...
AC	...	...	...	...	...	...	...	...	...	...	...	...	...	...
MGT	4.14	5.21	3.41	2.91	4.25	2.15	6.12	5.10	4.70	5.73	3.02	2.84	4.22	2.15
HEM	...	...	...	...	...	...	...	...	...	...	...	...	...	...
ILM	0.34	2.02	1.26	1.44	1.86	1.48	2.72	1.40	1.00	1.34	1.54	1.32	1.94	1.14
PYR	0.24	0.56	0.03	0.11	0.14	0.03	0.51	0.32	0.03	0.27	0.84	0.11	0.06	0.06
AP	...	...	0.16	...	...	...	0.27	0.51	1.12	...	0.13	0.11	0.27	0.11
TOTAL	100.01	99.90	100.00	100.00	100.02	100.01	100.00	100.01	107.99	99.01	100.05	100.00	100.01	100.01
PLAG.COMP. (AN)	69	59	63	76	51	73	63	72	56	57	56	79	58	67

Values in Percent; Calcite-Free

TABLE III - continued

BASALTS

SAMPLE NO.		15-3	15-4	16-1	16-5	16-6	17-1	17-2	17-3	18-1	19-4	29-1	30-1	31-3	C-8
	QTZ	2.55	...	1.31	...	8.11	8.63	...	7.06	4.01	...	6.16	2.82	4.78	5.30
	COR	...	...	...	...	...	...	...	...	...	...	...	...	...	...
	OR	1.15	4.00	1.55	1.80	1.95	3.00	2.25	1.85	1.48	1.80	1.20	1.40	1.40	3.00
	AB	28.00	27.15	33.65	26.10	16.40	8.05	15.90	15.45	15.12	26.55	16.55	15.35	14.90	14.70
	AN	24.48	28.33	22.28	24.15	30.45	45.55	29.33	29.75	29.15	25.35	30.53	33.80	30.00	40.73
	NE	...	...	...	...	...	...	...	...	...	...	...	...	...	...
	LC	...	...	...	...	...	...	...	...	...	...	...	...	...	...
DI	WO	9.76	8.10	10.40	11.10	10.32	7.82	9.28	7.32	9.34	7.58	8.54	11.46	15.14	9.32
DI	EN	5.90	5.50	5.48	6.54	6.38	4.24	6.34	3.64	4.48	4.28	5.06	7.08	11.38	5.00
DI	FS	3.86	2.60	4.92	4.56	3.94	3.58	2.94	3.68	4.86	3.30	3.48	4.38	3.76	4.32
HY	EN	8.04	8.82	8.02	7.28	9.50	7.54	16.52	12.26	12.80	13.62	13.12	10.52	8.16	6.40
HY	FS	5.26	4.18	7.24	5.10	5.88	6.38	7.68	12.44	13.90	10.48	9.10	6.46	2.68	5.52
OL	FO	...	4.32	...	2.24	...	...	3.21	...	...	0.39	...	...	...	...
OL	FA	...	2.04	...	1.56	...	...	1.50	...	...	0.30	...	...	...	...
	AC	...	...	...	...	...	...	...	...	...	...	...	...	...	...
	MGT	8.09	3.54	3.21	3.12	4.28	3.48	3.68	3.16	3.23	3.78	3.92	3.59	5.63	5.01
	HEM	...	...	...	...	...	...	...	...	...	...	...	...	...	...
	ILM	2.64	1.26	1.72	1.26	2.34	1.34	1.20	2.60	2.36	2.20	1.96	1.94	1.64	0.54
	PYR	0.06	...	0.03	0.03	0.17	...	...	0.51	0.11	0.14	0.11	0.96	0.35	0.17
	AP	0.21	0.16	0.19	0.19	0.27	0.40	0.16	0.29	0.24	0.24	0.13	0.27	0.19	...
TOTAL		100.30	100.00	100.00	100.03	99.99	100.01	99.99	100.01	101.08	100.01	99.86	100.03	100.01	100.01
PLAG.COMP. (AN)		47	51	40	53	65	85	65	66	66	49	65	69	67	74

TABLE III - continued

		BASALTS												
SAMPLE NO.		C-14	C-15	C-23	C-32	C-33	C-34	C-36	C-37	C-38	C-39	C-42	C-44	C-45	C-49
	QTZ	...	...	...	...	...	...	...	...	...	...	...	...	...	...
	COR	...	...	...	...	...	...	...	...	...	...	...	...	...	...
	OR	1.45	2.40	3.75	1.30	1.35	5.45	1.65	3.05	1.65	1.45	1.80	1.15	3.35	1.45
	AB	22.60	17.50	16.40	27.30	17.00	22.55	7.30	15.05	10.95	21.10	22.60	23.60	11.10	13.65
	AN	32.43	42.50	34.93	23.83	26.80	26.73	31.40	31.95	29.25	33.35	37.73	26.53	35.55	31.80
	NE	...	...	7.17	...	...	...	4.32	...	1.20	...	3.96	...	2.43	...
	LC	...	...	...	...	...	...	...	...	...	...	...	...	...	...
DI	WO	8.74	2.28	8.16	12.04	13.68	10.88	16.32	13.20	15.18	7.76	5.68	9.76	13.04	12.70
DI	EN	5.90	1.30	3.88	7.54	8.98	7.04	10.30	8.22	9.38	4.88	3.00	5.06	8.18	6.90
DI	FS	2.84	0.98	4.28	4.50	4.70	3.84	6.02	4.98	5.80	2.88	2.68	4.70	4.86	5.80
HY	EN	13.78	16.48	...	0.88	...	0.16	...	6.90	...	6.56	...	7.38	...	10.74
HY	FS	6.62	12.08	...	0.54	...	0.10	...	4.20	...	3.88	...	6.86	...	9.02
OL	FO	1.47	0.39	8.63	9.99	15.92	13.38	12.23	5.60	14.52	8.73	10.22	5.22	10.14	2.42
OL	FA	0.72	0.33	9.50	5.91	8.33	7.34	7.16	3.41	8.94	5.19	9.24	4.86	6.06	2.00
	AC	...	...	...	...	...	...	...	...	...	...	...	...	...	...
	MGT	2.25	2.10	2.38	4.13	1.79	2.48	1.64	1.53	1.56	1.98	1.64	2.49	3.81	0.95
	HEM	...	...	...	...	...	...	...	...	...	...	...	...	...	...
	ILM	1.20	1.64	0.96	2.02	1.44	1.66	1.62	1.66	1.46	1.42	1.48	2.36	1.44	2.08
	PYR	...	0.03	0.03	0.06	0.06	0.74	0.08	0.27	0.11	0.84	...	0.03	0.06	0.51
	AP	...	...	...	...	...	...	...	...	...	...	...	...	...	...
TOTAL		100.02	100.01	100.07	100.04	100.05	102.35	100.04	100.02	100.00	100.02	100.03	100.00	100.02	100.02
PLAG. COMP. (AN)		59	71	66	47	61	54	81	68	73	61	63	53	76	70

TABLE III - continued

	ANDESITES									
SAMPLE NO.	10-3	11-1	12-17	12-21	16-3	23-2	37-4	C-20	C-40	C-69
QTZ	5.78	15.86	5.82	9.32	7.11	13.65	9.59	5.99	2.15	7.87
COR	...	...	...	...	...	...	...	...	...	...
OR	4.70	3.35	0.85	4.00	0.85	7.10	4.20	1.00	2.40	15.80
AB	20.20	23.55	17.85	31.50	30.10	24.20	28.50	25.80	26.65	19.35
AN	27.95	33.05	39.55	36.18	26.48	31.78	32.28	34.18	37.23	26.48
NE	...	...	...	...	...	...	...	...	...	...
LC	...	...	...	...	...	...	...	...	...	...
DI WO	7.36	3.74	5.26	4.58	3.00	1.58	2.68	6.02	6.90	8.76
DI EN	5.06	1.68	2.50	2.68	1.66	0.70	0.84	3.10	3.84	2.84
DI FS	2.30	2.06	2.76	1.90	1.34	0.88	1.84	1.92	3.06	5.92
HY EN	15.74	5.36	10.68	3.54	13.80	6.60	5.08	9.64	9.06	3.02
HY FS	7.20	6.48	11.86	2.54	11.28	8.46	10.94	9.08	7.26	6.30
OL FO	...	...	...	...	...	...	...	...	...	...
OL FA	...	...	...	...	...	...	...	...	...	...
AC	...	...	...	...	...	...	...	...	...	...
MGT	2.45	3.47	2.21	3.03	2.69	3.36	3.09	1.31	0.69	1.62
HEM	...	...	...	...	...	...	...	...	...	...
ILM	0.88	0.96	0.88	0.94	1.46	1.00	0.62	0.94	0.74	1.96
PYR	0.03	0.21	...	0.06	...	0.41	...	0.03	0.03	0.08
AP	0.35	0.24	...	0.27	0.24	0.27	0.43	...	...	...
TOTAL	100.00	100.01	100.22	100.54	100.01	99.99	100.09	99.01	100.01	100.00
PLAG. COMP. (AN)	58	58	69	53	47	57	53	57	58	58

TABLE III - continued

	DACITES							RHYODACITES					
SAMPLE NO.	5-1	12-18	23-1	C-48	C-51	C-53	C-73	2-1	40-2	43-1	C-72	C-75	J-3
QTZ	27.80	9.49	16.06	14.35	15.93	17.38	14.14	29.12	31.89	32.84	23.56	21.99	22.77
COR	...	...	...	...	...	...	0.52	1.51	1.81	...	...	...	1.48
OR	9.05	2.00	3.35	3.65	7.85	14.45	6.65	10.45	5.15	15.45	9.50	13.40	12.45
AB	18.10	37.70	35.70	26.50	26.50	26.26	30.70	20.90	19.80	15.80	25.70	23.55	36.15
AN	28.58	23.33	25.33	30.58	28.13	25.78	25.20	23.15	22.05	23.23	21.25	26.08	12.75
NE	...	...	...	...	...	...	...	...	...	...	...	...	...
LC	...	...	...	...	...	...	...	...	...	...	...	...	...
WO	2.92	2.32	3.56	4.08	1.22	0.44	...	...	...	...	...	...	...
)I EN	1.26	0.78	2.18	2.38	0.66	0.26	...	...	...	0.46	6.92	0.24	...
FS	1.66	1.54	1.38	1.70	0.56	0.18	...	...	...	0.20	2.20	0.08	...
IY EN	3.08	6.58	5.78	8.28	9.30	8.76	12.26	...	...	0.26	4.72	0.16	...
FS	4.16	13.00	3.62	5.88	7.72	6.20	8.58	5.62	7.14	3.72	1.54	4.42	4.62
)L FO	...	...	...	...	...	...	...	6.00	9.40	5.28	3.32	8.16	8.28
FA	...	...	...	...	...	...	...	...	...	...	...	...	...
AC	...	...	...	...	...	...	...	...	...	...	...	...	...
MGT	1.85	2.07	2.10	1.62	1.31	0.41	1.22	...	...	...	...	...	...
HEM	...	...	...	...	...	...	...	2.27	1.56	2.06	0.66	1.32	0.71
ILM	1.24	1.20	0.72	0.94	0.80	0.72	0.68	...	...	...	...	...	...
PYR	...	...	...	0.06	0.03	0.18	0.06	0.58	0.86	0.52	0.58	0.70	0.74
AP	0.29	...	0.24	...	...	...	...	0.08	...	...	0.06	0.03	0.06
								0.32	0.16	0.19	...	...	...
OTAL	99.99	100.01	100.02	100.02	100.01	011.01	100.01	100.00	99.82	100.01	100.01	100.13	100.01
PLAG. COMP. (AN)	61	33	42	54	52	51	45	53	53	60	45	53	26

TABLE III - continued

	SAMPLE NO.	1-6	3-1	8-1	10-2	12-14	12-19	20-2	37-3	C-17	C-22	C-46
		RHYOLITES										
	QTZ	38.54	34.72	40.77	57.11	35.41	35.30	52.70	41.90	43.95	41.87	42.57
	COR	2.70	3.75	1.65	1.77	2.41	1.30	4.11	1.23	0.98	0.38	1.25
	OR	17.95	8.95	14.25	9.00	14.35	7.00	22.00	13.54	6.65	14.05	26.25
	AB	24.75	32.00	25.55	18.00	28.55	23.60	3.68	22.76	19.20	8.90	15.40
	AN	10.60	10.16	12.00	6.55	13.65	17.40	12.20	12.44	20.60	23.65	10.30
	NE	...	...	...	...	...	...	...	...	...	...	...
	LC	...	...	...	...	...	...	...	...	...	...	...
DI	WO	...	...	...	...	...	...	...	...	...	...	...
DI	EN	...	...	...	...	...	...	...	...	...	...	...
DI	FS	...	...	...	...	...	...	...	...	...	...	...
HY	EN	1.58	3.68	1.88	2.80	1.86	2.78	1.30	3.36	2.18	3.02	1.20
HY	FS	2.70	4.16	2.48	3.42	2.40	10.48	2.68	4.48	3.60	7.30	4.62
OL	FO	...	...	...	...	...	...	...	...	...	...	...
OL	FA	...	...	...	...	...	...	...	...	...	...	...
	AC	...	...	...	...	...	...	...	...	...	...	...
	MGT	0.86	1.94	1.01	0.98	0.95	1.10	1.10	0.15	1.23	0.39	...
	HEM	...	...	...	...	...	...	...	...	...	...	...
	ILM	0.32	0.54	0.32	0.30	0.36	0.20	0.22	...	0.38	0.40	0.32
	PYR	...	...	0.03	0.03	...	0.78	0.03	0.24	1.25	0.03	0.08
	AP	0.05	0.21	0.05	0.05	0.05	0.05	...	...	...	...	...
	TOTAL	100.05	100.11	99.99	100.01	99.99	99.99	100.02	100.10	100.02	99.99	101.99
PLAG. COMP. (AN)		30	24	32	27	32	42	77	40	52	73	40

TABLE III - continued

	SEDIMENTS													
SAMPLE NO.	6-1	10-1	12-22	12-24	16-2	23-4	25-5	26-1	26-2	27-2	C-25	C-27	C-28	C-41
QTZ	37.43	...	21.07	24.07	35.24	...	12.52	25.67	0.79	18.31	...	9.43	13.62	20.75
COR	2.00	...	...	...	0.43	5.99	...	...	...	0.04	...	...	1.05	1.40
OR	12.65	16.90	5.30	2.70	5.92	14.45	1.80	2.50	4.50	8.60	9.25	2.40	10.10	25.05
AB	27.65	30.20	19.80	7.10	21.68	25.80	44.00	22.45	18.65	49.70	27.90	20.10	27.00	33.45
AN	13.95	26.33	29.63	44.00	22.80	28.20	20.13	27.23	42.35	13.60	39.00	36.20	28.55	11.65
NE	...	...	...	...	...	3.63	...	...	...	...	...	...	...	...
LC	...	...	...	...	...	...	...	...	...	...	...	...	...	...
WO	...	1.18	2.20	5.80	...	...	2.86	3.64	6.78	...	1.12	3.28	...	...
EN	...	0.64	0.80	2.94	...	...	1.40	1.30	3.72	...	0.48	1.64	...	...
FS	...	0.40	1.40	2.86	...	...	1.46	2.34	3.06	...	0.64	1.64	...	...
EN	1.98	8.38	5.38	2.60	2.92	...	5.54	4.06	8.44	2.86	7.44	11.56	7.66	2.78
FS	3.20	5.12	9.70	2.54	7.00	...	5.86	7.24	6.88	3.82	9.62	11.46	9.96	3.32
FO	...	3.86	...	...	...	7.70	...	...	...	...	0.57	...	...	...
FA	...	2.30	...	...	...	10.29	...	...	...	...	0.75	...	...	...
AC	...	...	...	...	...	...	...	...	...	...	...	...	...	...
MGT	0.84	2.97	3.32	4.35	3.06	2.13	2.63	2.25	3.44	2.09	2.34	1.38	1.41	0.54
HEM	...	...	...	...	...	...	...	...	...	...	...	...	...	...
ILM	0.26	1.22	1.22	0.82	0.64	1.40	1.30	0.96	1.04	0.86	0.84	0.74	1.00	0.36
PYR	...	0.03	0.20	...	0.03	...	0.03	0.03	0.08	0.03	0.06	0.17	0.03	0.66
AP	0.03	0.45	...	0.21	0.30	0.43	0.48	0.35	0.27	0.27	...	...	...	...
TOTAL	99.99	100.16	100.02	99.99	100.02	100.02	100.01	100.02	100.00	100.18	100.01	100.00	100.02	99.96
LAG. COMP. AN)	34	47	60	86	52	52	31	55	69	22	58	64	51	26

TABLE III - continued

	SEDIMENTS											
SAMPLE NO.	C-47	C-52	C-56	C-57	C-60	C-61	C-64	C-65	C-67	C-68	C-70	C-71
QTZ	43.88	12.92	2.64	29.70	0.38	12.44	10.15	25.41	20.88	40.94	...	9.92
COR	2.21	...	...	6.37	...	...	...	...	1.24	1.29	...	...
OR	19.55	5.75	9.25	5.25	3.25	18.15	5.00	5.95	19.15	14.50	8.90	11.00
AB	5.45	33.60	23.95	23.95	33.55	24.10	37.25	23.05	27.40	22.70	25.35	25.45
AN	17.55	27.23	27.63	13.00	37.50	22.23	24.15	36.53	17.55	12.40	37.30	30.43
NE	...	...	...	...	...	...	...	...	...	...	...	...
LC	...	...	...	...	...	...	...	...	...	...	...	...
DI WO	...	0.76	3.48	...	0.98	6.46	1.46	1.24	...	...	5.66	0.16
DI EN	...	0.32	1.16	...	0.54	1.46	0.62	0.38	...	...	3.10	0.08
DI FS	...	0.44	2.32	...	0.44	5.00	0.84	0.86	...	...	2.56	0.08
HY EN	1.64	7.08	8.48	13.56	11.40	1.58	7.78	1.76	6.92	3.32	4.96	10.04
HY FS	4.44	9.52	16.92	6.66	9.58	5.46	10.38	4.00	0.88	4.42	4.10	11.10
OL FO	...	...	...	...	...	...	...	...	...	...	2.48	...
OL FA	...	...	...	...	...	...	...	...	...	...	2.06	...
AC	...	...	...	...	...	...	...	...	...	...	...	...
MGT	1.85	1.55	2.07	0.63	1.44	1.65	1.01	...	5.16	0.15	2.37	0.66
HEM	...	...	...	...	...	...	...	...	...	...	...	...
ILM	0.40	0.84	2.10	0.50	0.94	1.44	1.20	0.76	0.76	0.28	1.16	1.08
PYR	3.05	...	...	0.38	...	0.03	0.17	0.06	0.06	...	0.03	...
AP	...	...	...	...	...	...	...	...	...	...	...	...
TOTAL	100.02	100.01	100.00	100.00	100.00	100.00	100.01	100.00	100.00	100.00	100.03	100.00
PLAG. COMP. (AN)	53	45	54	35	53	48	39	61	39	35	60	55

the rocks have been affected by hydrothermal alteration and mineralization. This alteration has affected some rocks to the point where they cannot be classified, even by using SiO_2 content. For examples: felsic volcanics with abnormally high sulphides (sample no. C-50), leached SiO_2 in felsic volcanics (sample no. C-7), sheared mafic volcanics enriched in FeO + MgO +Ca) and depleted in alkalis (sample no.'s C-12, C-13, 12-12). Therefore "altered" volcanic rocks must be identified and removed from the "unaltered" volcanics before classification of primary volcanics can be done.

The diagram shown in Figure 19 may indicate metasomatically altered igneous rocks for those samples with alkali parameters that plot outside of the "igneous spectrum" (Hughes, 1972). However, many PreCambrian volcanics plot outside of this field that are probably not metasomatically altered. For example, some tholeiitic basalts and andesites and most felsic volcanics from the Flin Flon area plot outside the igneous spectrum, as shown by Stauffer (1975). The Ruttan volcanics also overlap the igneous spectrum (Figure 19). In fact, some of all rock types, and 36 of 76 points, plot outside of the igneous spectrum. Therefore, it is concluded that interpretation of Figure 19 is uncertain and not a useful guide to distinguishing unaltered from metasomatically altered volcanic rocks.

Since no variation diagram can clearly divide altered from unaltered specimens, the choice was made arbitrarily using mean chemical compositions and field mapping evidence.

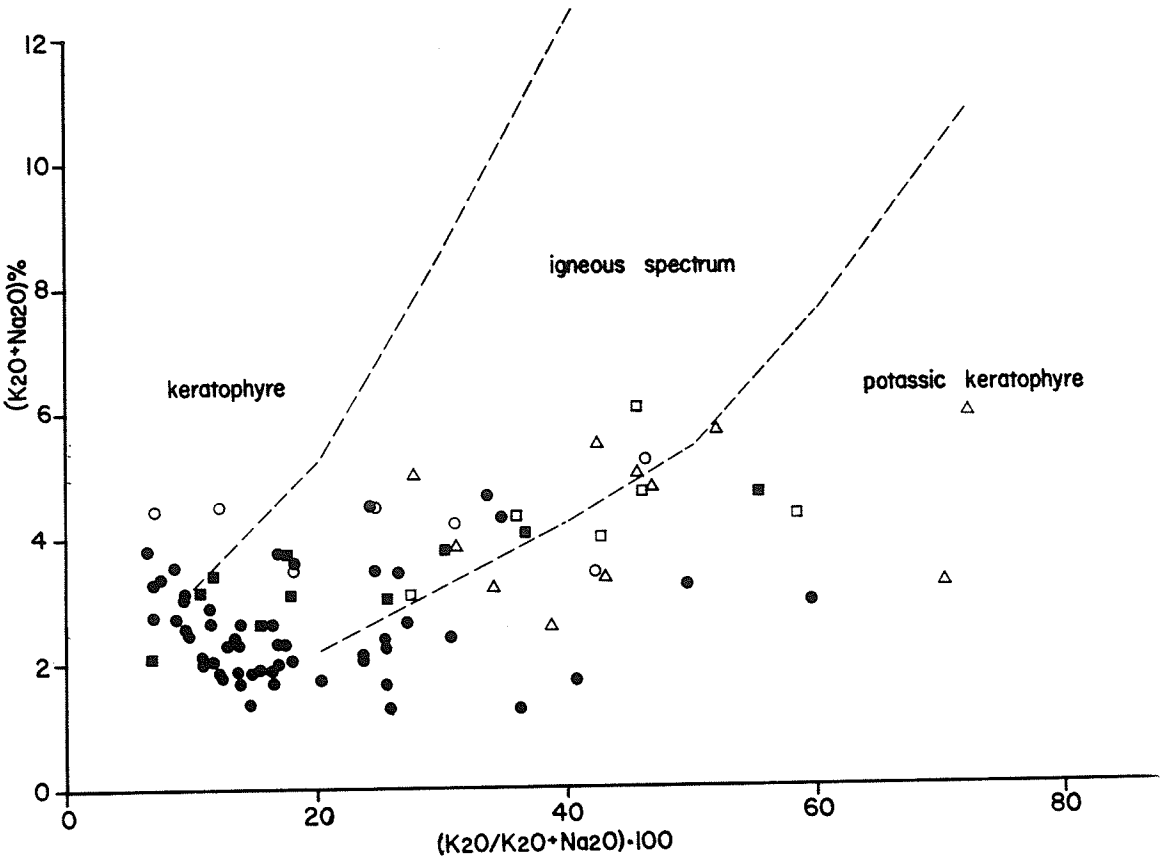

Figure 19. Alkali Igneous Spectrum Diagram (Hughes, 1972) For Volcanics at Ruttan. Legend Same as in Figure 25. Concentration of Oxides in Weight Percent.

Rocks that are abnormally low in SiO_2 and Na_2O, and high in Al_2O_3, FeO, MgO, CaO, and S--in comparison with the bulk of the analyses--have been termed "altered", and not used further in chemical variation diagrams. (See Table II for altered compositions and Table IV for mean chemical compositions of Ruttan volcanics). The threshold values of each major oxide, above which are the altered values, are:

1. $SiO_2 < 58\%$ for felsic volcanics
2. $SiO_2 < 45\%$ for mafic volcanics
3. $Al_2O_3 > 19\%$
4. $MgO > 12\%$
5. $CaO > 14\%$
6. $Na_2O < 0.5\%$
7. $S > 5000$ ppm.

3. IGNEOUS CLASSIFICATION

Four methods of classification of the unaltered volcanic rocks are considered:

1. Streckeisen's Mineralogical Classification (1967) is not useful because it relies on the relative abundance of quartz, plagioclase, and alkali-feldspar in the modal analyses. Extensive metamorphic recrystallization of hornblende and biotite, and intense alteration of plagioclase to sericite, saussurite, and carbonate, has rendered the modal analyses unreliable for representing compositions of the original volcanic rocks. Therefore, igneous classification is based on chemical rather than modal analyses.

2. Normative An-Ab-Or is dependent on feldspar compositions that are in turn dependent on alkali concentrations; the latter are thought to be lower than the original concentrations (see section on comparison with other volcanic rocks). Low Na_2O causes the formation of feldspars that are too calcic (ie. - too basic), and as a result there is a displacement of the Ruttan volcanics towards more mafic rock types than is realistic. (Figure 20; compare rock types shown here classified by SiO_2 content with Irvine and Baragar's An-Ab-Or classification of volcanic rocks). By this method, the Ruttan volcanics with SiO_2 contents of between 60 and 70% have normative An compositions typical of basalts and andesites.

3. Irvine and Baragar's (1971) method of classifying volcanic rocks is based on colour index v.s. normative feldspar composition. As mentioned above, low alkalis (especially low Na), results in Ca/Na ratios-and therefore An compositions-that are higher than would be expected for relatively fresh volcanic rocks. Again, there is a displacement of samples with SiO_2 contents between 60 and 70% towards mafic rock types.

4. SiO_2 content is the best method of classifying the Ruttan volcanics because SiO_2 is relatively stable, except for samples in areas affected by the shear zone and by localized alteration. (These were defined as "altered" and removed from classification). SiO_2 classification is as

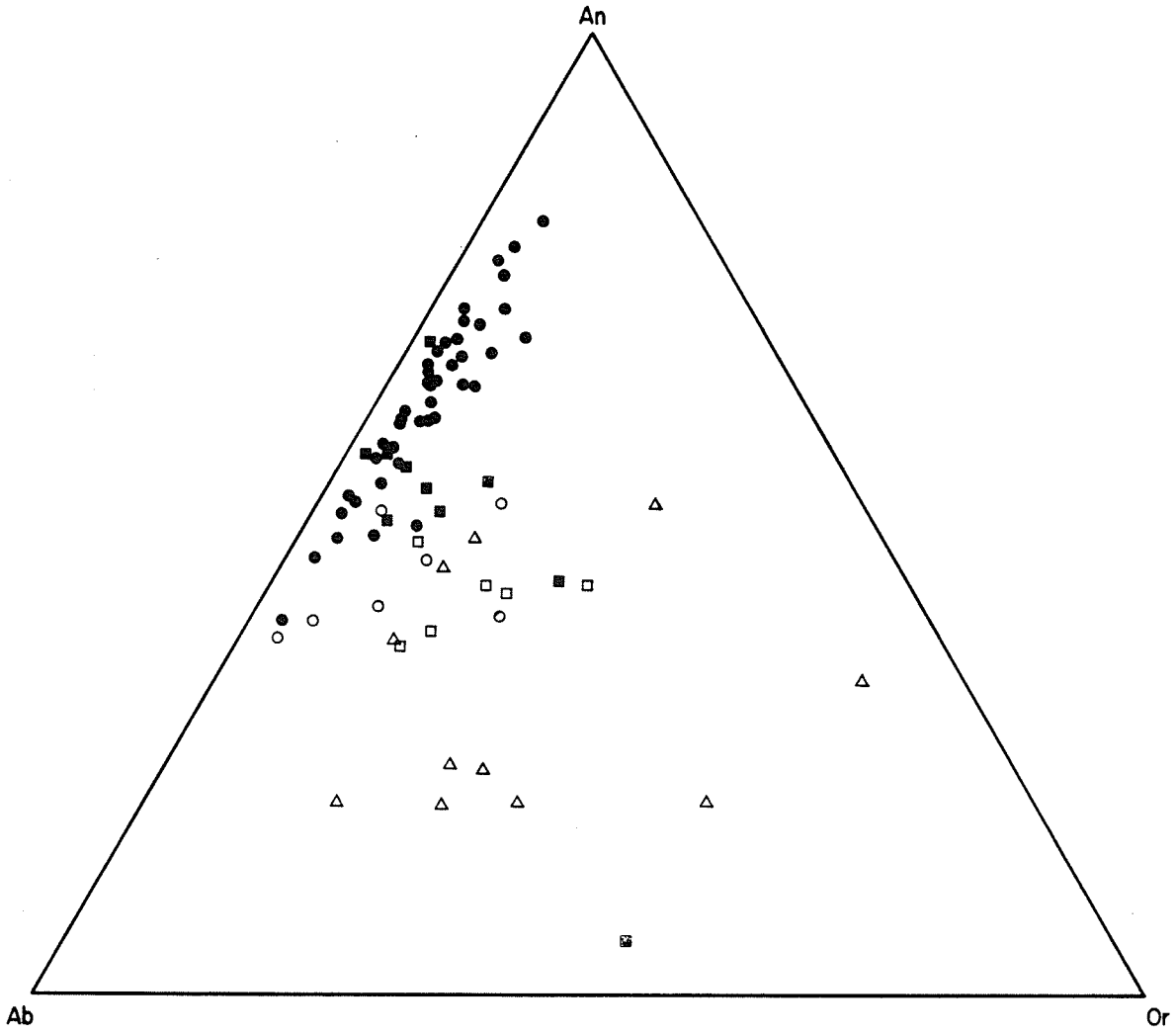

Figure 20. Normative An-Ab-Or Diagram of Volcanic Rocks at Ruttan. AN = Anorthite, AB = Albite, OR = Orthoclase. Legend Same as in Figure 25. Data from Table III.

follows: basalt 45-52%, andesite 52-58%, dacite 58-64%, rhyodacite 64-71%, rhyolite>71% (after Goodwin, 1968).

In conclusion, classification is based on chemical rather than modal analyses because metamorphism and alteration of feldspar has rendered the mineralogical compositions unreliable as being representative of the original rocks. Alkali concentrations are lower than would be expected for relatively fresh volcanic rocks and therefore, classification based on normative feldspar composition is unreliable. Instead, the redistribution of alkalis, and plots such as An-Ab-Or (Figure 20), are used to study alteration patterns of geochemistry. SiO_2 content appears to be the method least affected by alteration and metamorphism, and is used for classifying the Ruttan volcanic rocks.

4. COMPARISON WITH OTHER VOLCANIC ROCKS

A comparison is made between the Ruttan volcanic sequence and the following volcanic associations:

1. Island Arcs
2. Alkaline Volcanic Regimes
3. Intracratonic Extensional Spreading Systems
4. Oceanic Spreading Systems
5. Oceanic Basins

A comparison is also made between the Ruttan volcanic sequence and volcanic rocks of Proterozoic and Archean age (Figures 21, 22, 23; Table IV).

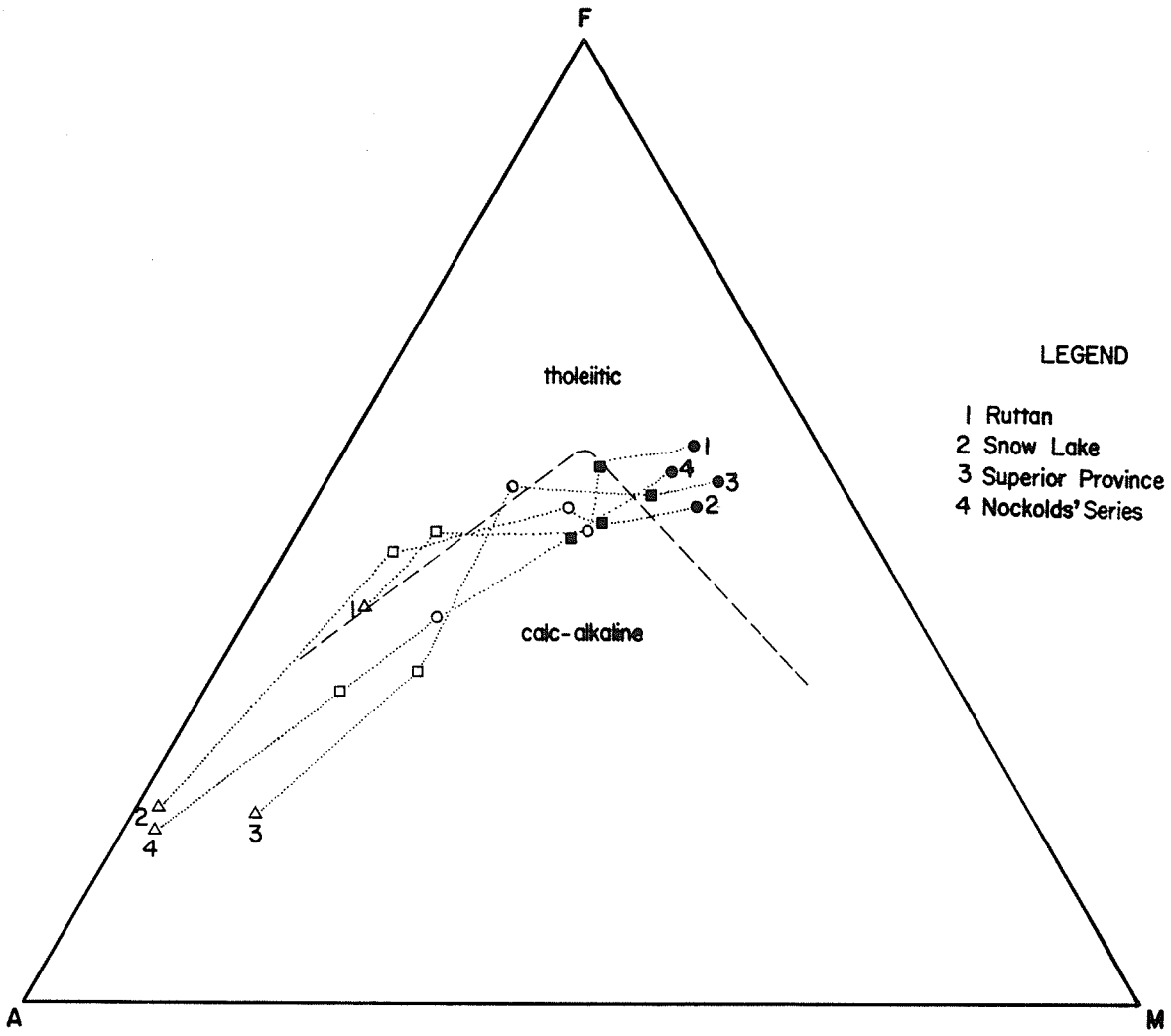

Figure 21. AFM Fractionation Trends For Various Volcanic Suites-Compared with Ruttan. Dashed Line = Calc-Alkaline-Tholeiitic Dividing Line (after Irvine and Baragar, 1971). Legend Same As In Figure 25. 1 - This Study. 2 - Moore, 1977. 3 - Goodwin, 1977. 4 - Nockolds, 1954.

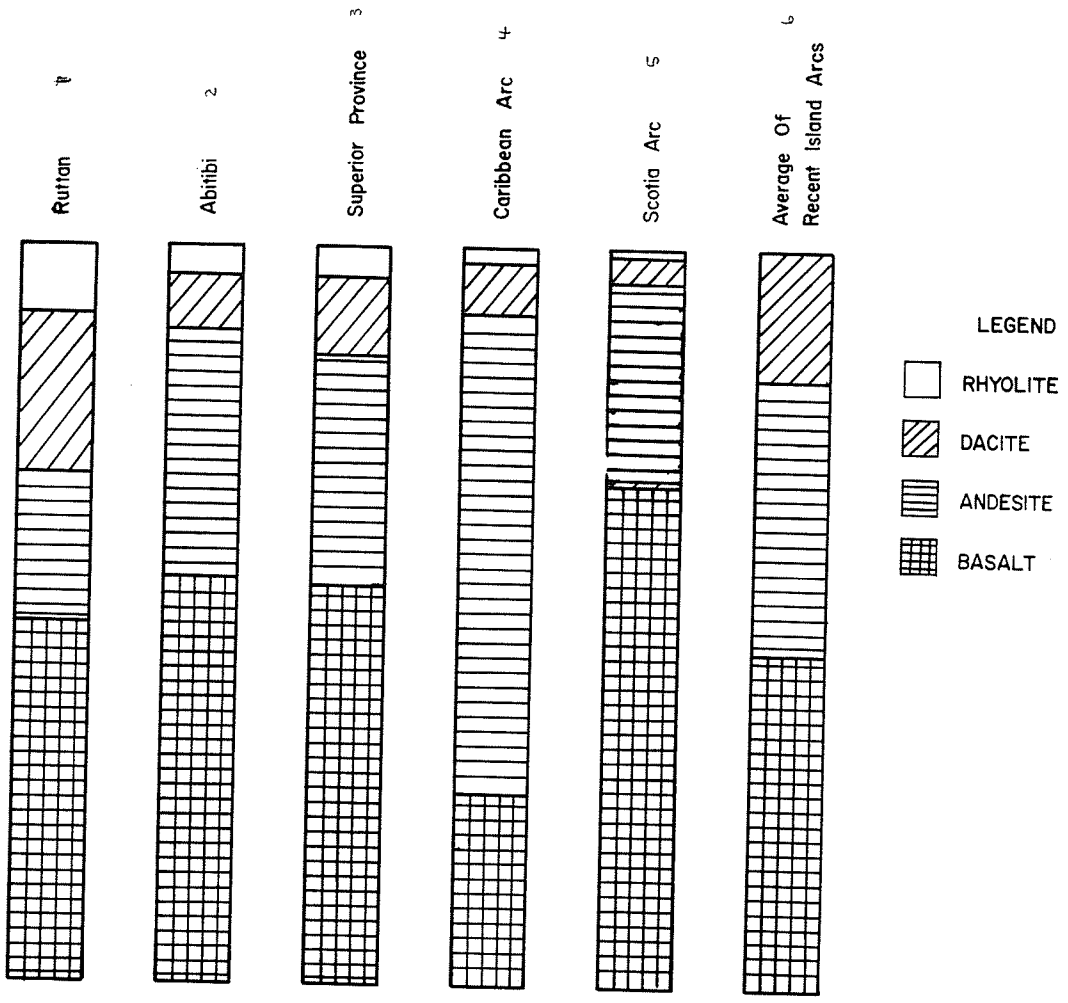

Figure 22. Mean Abundances of Volcanic Classes for Pre-Cambrian to Recent Volcanic Rocks. 1 - This Study. 2, 3 - Goodwin, 1977. 4, 5 - Baker, 1968a. 6 - Jakes and White, 1971.

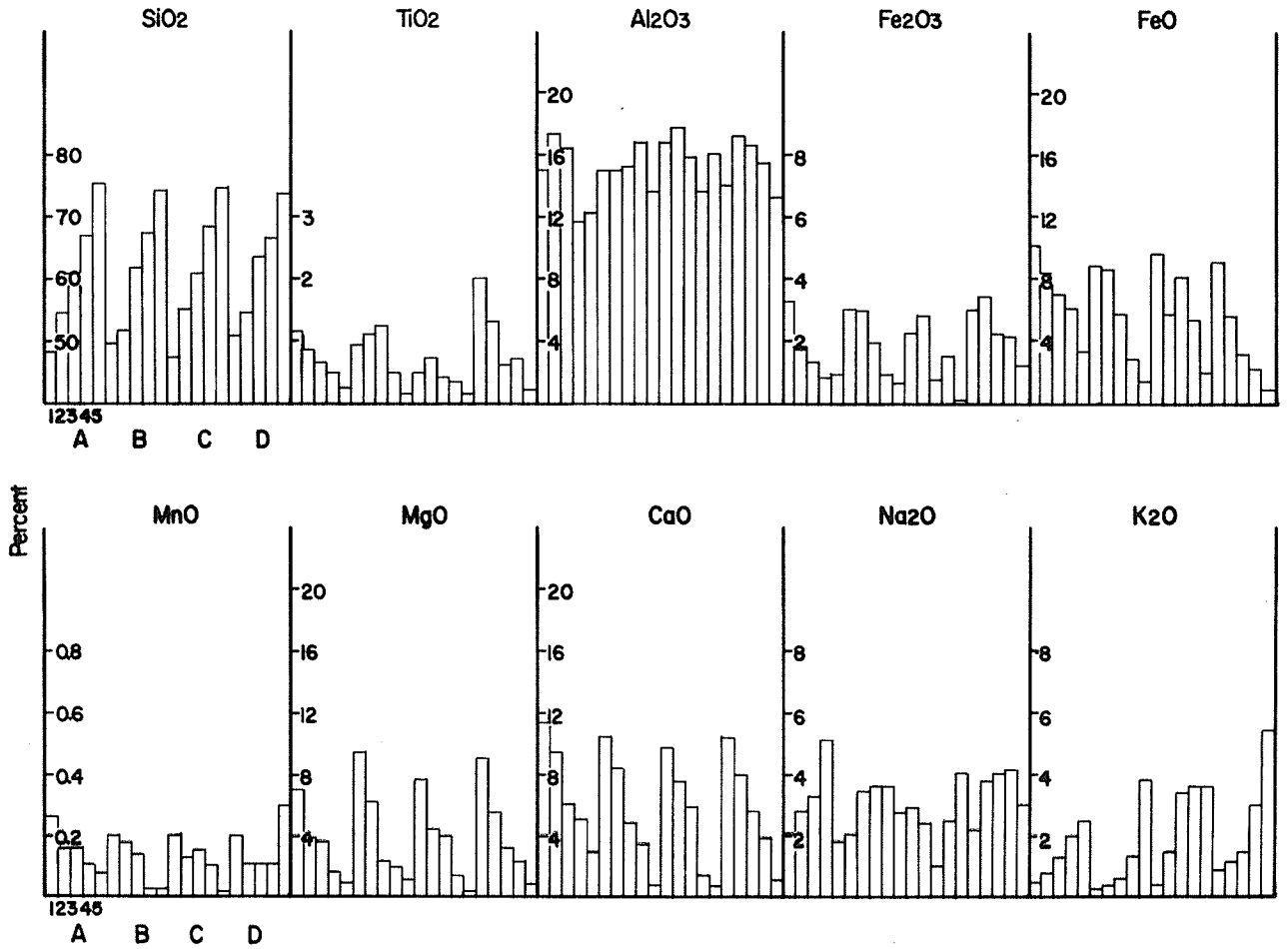

Figure 23. Mean Chemical Composition of PreCambrian to Recent Volcanic Rocks. A = Ruttan, B = Archean Superior Province (Goodwin, 1977). C = Snow Lake (Moore, 1977). D = Nockolds' Calc-Alkaline Series (1954). 1 = Basalt. 2 = Andesite. 3 = Dacite. 4 = Rhyodacite. 5 = Rhyolite.

TABLE IV. MEAN COMPOSITIONS OF PRECAMBRIAN TO RECENT VOLCANIC ROCKS.*

	PROTEROZOIC (RUTTAN)$_1$					PROTEROZOIC (FLIN-FLON-SNOW LAKE)$_2$				
n	BASALT 42	ANDESITE 10	DACITE 7	RHYODACITE 6	RHYOLITE 11	BASALT 7	ANDESITE 8	DACITE 4	RHYODACITE 7	RHYOLITE 8
SiO_2	48.05	54.29	60.91	66.11	75.18	49.06	53.25	59.00	67.09	75.04
TiO_2	1.16	0.81	0.62	0.47	0.21	0.61	0.56	0.66	0.54	0.20
Al_2O_3	15.11	17.22	16.31	11.21	12.22	17.30	15.38	16.23	14.06	12.39
Fe_2O_3	3.22	1.79	1.25	0.80	0.89	2.21	3.22	2.02	1.75	0.77
FeO	10.24	8.31	6.76	5.88	3.15	8.90	9.51	8.64	4.72	2.92
MnO	0.26	0.20	0.16	0.10	0.07	0.17	0.24	0.17	0.10	0.05
MgO	6.97	3.92	3.53	1.52	0.76	6.90	4.39	2.68	1.67	0.86
CaO	11.41	9.38	6.10	5.12	2.87	8.77	7.21	5.28	3.25	1.73
Na_2O	2.07	2.75	3.22	3.11	1.78	2.72	2.53	2.38	3.10	3.10
K_2O	0.40	0.71	1.16	1.95	2.43	0.54	0.68	1.73	1.68	1.68
P_2O_5	0.16	0.17	0.12	0.12	0.04	0.12	0.17	0.12	0.17	0.09
H_2O	1.68	1.21	1.02	1.15	0.85	2.63	2.10	1.92	1.46	1.12
CO_2	0.43	0.41	0.26	0.33	0.42	0.84	0.64	0.35	1.05	0.42

* values in weight percent

1 - This Study - Table II

2 - Stauffer, 1975; Moore, 1977

TABLE IV - continued

	ARCHEAN (SUPERIOR PROVINCE)[3]					NOCKOLDS' CALC-ALKALINE SERIES[4]				
n	BASALT 53	ANDESITE 20	DACITE 3	RHYODACITE 3	RHYOLITE 24	BASALT >100	ANDESITE >100	DACITE 50	RHYODACITE 115	RHYOLITE 22
SiO_2	49.83	51.83	61.74	67.16	74.11	50.83	54.20	63.58	66.27	73.66
TiO_2	0.94	1.11	1.22	0.46	0.14	2.03	1.31	0.64	0.66	0.22
Al_2O_3	14.64	14.53	15.17	16.73	13.59	14.07	17.17	16.67	15.39	13.45
Fe_2O_3	3.03	2.96	1.87	0.89	0.64	2.88	3.48	2.24	2.14	1.25
FeO	8.77	8.46	5.74	2.77	1.27	9.00	5.49	3.00	2.23	0.75
MnO	0.21	0.18	0.14	0.02	0.02	0.18	0.15	0.11	0.07	0.03
MgO	7.36	6.22	2.30	1.86	1.04	6.34	4.36	2.12	1.57	0.32
CaO	10.46	8.42	4.80	3.29	0.60	10.42	7.92	5.53	3.68	1.13
Na_2O	2.02	3.40	3.57	3.61	2.74	2.23	3.67	3.98	4.13	2.99
K_2O	0.23	0.29	0.54	1.31	3.82	0.82	1.11	1.40	3.01	5.35
P_2O_5	0.19	0.22	0.32	0.12	0.12	0.23	0.28	0.17	0.17	0.07
H_2O	1.81	1.56	1.87	0.86	0.90	0.91	0.86	0.56	0.68	0.78
CO_2	0.33	0.29	0.47	0.24	0.51					

3 - Wilson et. al., 1965.

4 - Nockolds, 1954.

TABLE IV - continued

	ISLAND ARCS (SOUTH PACIFIC)[5]					M.A.R.[6]	KEWEENAWAN[7]	HIGH ALUMINA BASALT[8]
	BASALT	ANDESITE	DACITE	RHYODACITE	RHYOLITE	BASALT	BASALT	BASALT
n	62	40	26	12	24	33	69	10
SiO_2	49.79	54.61	61.24	66.17	71.78	49.21	51.32	48.27
TiO_2	1.04	0.89	0.65	0.56	0.37	1.39	2.01	0.89
Al_2O_3	17.19	16.83	16.54	14.88	13.64	15.81	15.26	18.28
F_2O_3	3.40	3.55	2.86	1.81	0.88	2.21	5.57	1.04
FeO	6.71	5.81	3.66	3.30	1.79	7.91	6.67	8.31
MnO	0.18	0.17	0.14	0.13	0.09	0.16	0.20	0.17
MgO	6.42	4.53	2.50	1.47	0.44	8.53	5.73	8.96
CaO	11.41	8.58	5.77	4.06	1.60	11.14	8.38	11.32
Na_2O	2.30	2.84	3.59	4.09	4.88	2.71	2.96	2.80
K_2O	0.46	1.03	1.70	1.45	3.36	0.26	1.42	0.14
P_2O_5	0.16	0.24	0.19	0.13	0.07	0.15	0.28	0.07
H_2O	0.84	0.75	1.01	1.60	0.35			
CO_2	0.08	0.03	0.05	0.02	0.16			

5 - Mitchell et. al., 1971; Jakes and White, 1971; Bryan et. al., 1972; Miyashiro, 1974; MacKenzie, 1976; Ewart et. al., 1977; Dietrich et. al., 1978; Johnson et. al., 1978.

6 - Melson and Thompson, 1971.

7 - Annells, 1973.

8 - Yoder and Tilley, 1962.

TABLE IV - continued

	EAST PACIFIC RISE[9]			EAST AFRICAN RIFT[10]		
n	BASALT 1	KELANDITE 1	TRACHYTE 1	NEPHELINITE 1	PHONOLITE 1	TRACHYTE 1
SiO_2	48.45	55.34	66.87	48.90	56.13	61.09
TiO_2	3.39	1.93	0.66	1.00	1.07	0.91
Al_2O_3	13.75	14.02	12.55	17.60	16.13	16.64
F_2O_3	4.72	3.31	1.84	4.60	4.00	3.37
FeO	8.60	8.73	2.53	3.10	4.57	2.40
MnO	0.20	0.17	0.09	0.19	0.35	0.18
MgO	6.05	2.71	0.60	2.20	1.59	0.59
CaO	10.71	6.54	1.10	6.40	2.43	1.52
Na_2O	2.79	4.54	5.32	9.50	7.24	6.49
K_2O	0.50	1.33	3.08	3.40	4.99	5.89
P_2O_5	0.36	0.65	0.05	0.24	0.20	0.13
H_2O	0.38	0.82	4.99	2.80	1.21	0.96
CO_2						

9 - McBirney and Williams, 1969.

10 - Varne, 1968; Nash et. al., 1969.

Three assumptions must be made with regard to the data from Ruttan. Firstly, the volume frequency of lithologies represents a section through the flanks of a differentiated volcanic sequence, and may not be representative of the volcanic belt as a whole. Part of the mafic sequence may be missing due to intrusion, and the mafic volcanics may make up a higher proportion of rock types in the Rusty Lake belt as a whole, than they do in the Ruttan study area.

Secondly, the chemical analyses are assumed to be representative of the mafic-to-felsic cycle of volcanism at Ruttan.

Thirdly, a large proportion of the intermediate and felsic volcanic rocks are fragmental, which may fill the SiO_2 gap (64-71%) seen in some volcanic areas when only flows are represented in the analyses.

In Figure 21, the Proterozoic, Archean, and Nockolds' recent series of volcanic rocks show a similar differentiation trend from tholeiitic basalt to calc-alkaline andesite, dacite, rhyodacite, and rhyolite for mean chemical compositions. The Ruttan plot shows slighly more Fe enrichment and lower alkalis than the other volcanic suites, and is therefore somewhat displaced towards the tholeiitic field.

Figure 22 shows that Ruttan has a significantly higher proportion of dacite-rhyolite to andesite than do Archean and recent volcanic regimes. This is interesting because it may lend support to the idea that Proterozoic volcanism was different from Archean volcanism because more rhyolites and

dacites, and fewer andesites were erupted (Moore, 1977). Much more information from the Proterozoic and Archean is needed however before any reliable comparisons can be made between the two periods of volcanism. Nothing unusual is seen in the proportion of basaltic volcanics at Ruttan in Figure 22. They fall within the range of other ancient and more recent volcanic sequences.

In Figure 23 and Table IV, the mean composition of Ruttan volcanics is compared with mean compositions from such diverse associations as the Archean, South Pacific Island Arcs, the mid-Atlantic ridge, alumina-basalts, Keeweenawan flood basalts, and alkaline rocks from the East African Rift. The notable differences in major element geochemistry between Ruttan and these regimes are listed below.

Al_2O_3 - Lower than High Alumina basalts, East African Rift

total Fe - higher than Island Arcs, Keeweenawan basalts, the East Pacific Rise, the mid-Atlantic Ridge, High Alumina basalts.

TiO_2 - Lower than Nockolds' Series, Keweenawan basalts, East Pacific Rise

MgO - higher than Island Arcs, Keweenawan basalts, East African Rift

K_2O - lower than Nockolds' Series, Island Arcs, Keweenawan basalts, East African Rift

Na_2O - lower than Island Arcs, Mid-Atlantic Ridge, Keweenawan basalts, High Alumina basalts, East Pacific Rise, East African Rift.

CaO - higher than Keweenawan basalts, East African Rift

P_2O_5 - lower than Keweenawan basalts, East Pacific Rise, East African Rift

From the above data it is obvious that the Ruttan volcanic sequence most closely resembles Proterozoic and Archean volcanic sequences listed in Figure 23 and Table IV.

With respect to the more modern volcanic regimes, the Ruttan volcanics are similar only to island arcs in major element geochemistry. The major contrasts between these 2 are , 1) higher total Fe and MgO at Ruttan, which is interpreted as being related to Fe enrichment and Mg metasomatism of rocks in the Ruttan area, and 2) lower Na_2O and K_2O at Ruttan, which is interpreted as resulting from normal Pre-Cambrian alteration effects and leaching of alkalis due to alteration at Ruttan.

The results are consistent with the concept that differentiated mafic-to-felsic volcanic sequences in the PreCambrian may have developed in circumoceanic arc systems similar to modern island arc regimes.

5. VARIATION DIAGRAMS

Variation of Major Oxides with Stratigraphic Height

Major oxides are plotted in weight percent against stratigraphic height in the Ruttan volcanic pile (Figure 24).

As differentiation proceeds from basalt to rhyolite, there is an increase in SiO_2, Na_2O, and K_2O, and a decrease

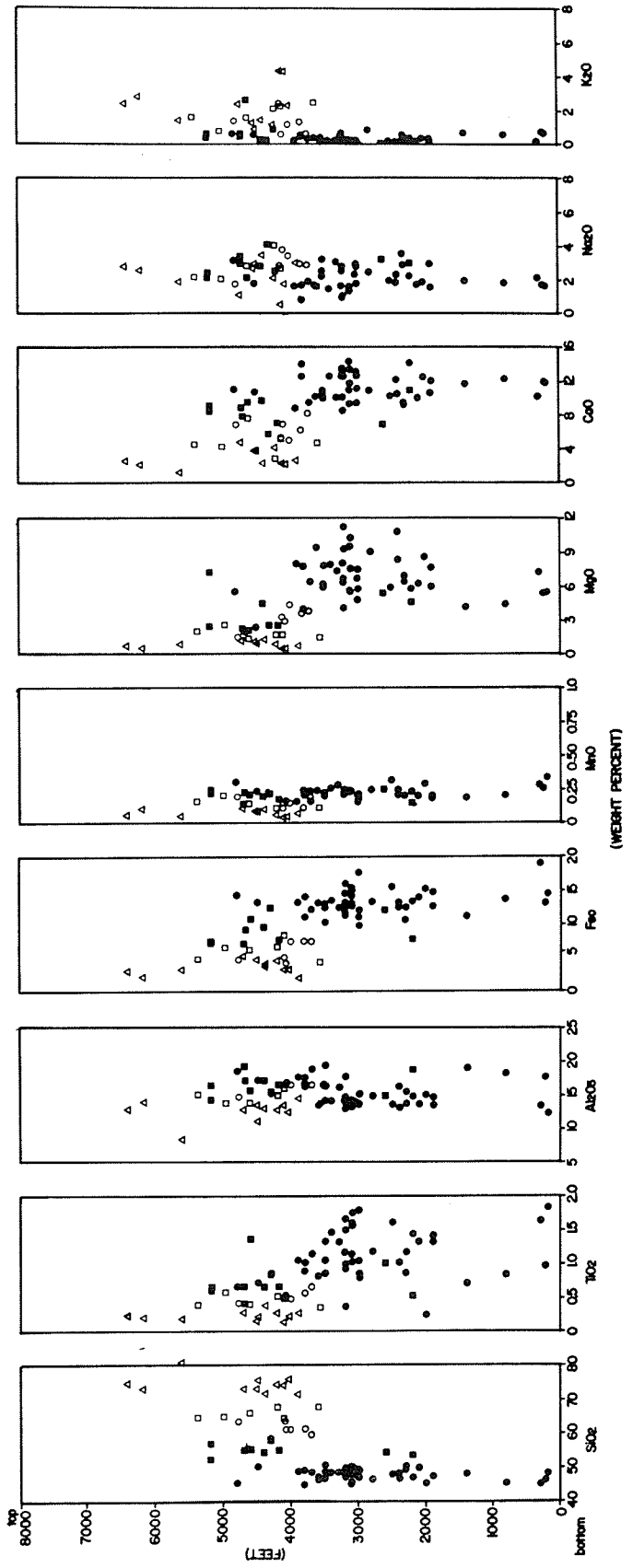

Figure 24. Variation of Major Element Oxides with Stratigraphic Position in the Ruttan Volcanic Sequence. Legend Same as in Figure 25.

in FeO and MgO. Fe enrichment is shown towards the base of the pile where basalts reach about 16% FeO. Titanium and Magnesia decline upwards in the sequence. Alumina increases steadily from 12.5% at the base to about 20% towards the stratigraphic top. These trends in major oxide variation largely reflect changes in lithology and differentiation upwards in the pile from basalt to andesite to dacite to rhyodacite to rhyolite. Some trends however, appear to reflect stratigraphic height rather than rock type. For example, basalts become increasingly richer in SiO_2, Al_2O_3, and Na_2O stratigraphically higher in the mafic sequence, approaching basaltic andesites in composition. This may be caused by compositional changes in the source magma with prolonged volcanism (Yoder and Tilley, 1962; Baragar, 1968), or it may be related to local alteration which has silicified the "footwall" rocks at the Ruttan orebody.

AFM

On an AFM diagram (Figure 25) basalts plot as tholeiites with a strong, distinct, Fe-enrichment trend. Andesites, dacites, rhyodacites, and rhyolites overlap the tholeiitic and calc-alkaline fields, and plot successively closer to the alkali apex. The apparent tholeiitic trend of some felsic volcanics is probably related to alkali depletion and Fe enrichment at Ruttan, rather than a primary characteristic. This fractional crystallization path is also illustrated by plotting SiO_2 against FeO/MgO (Figure 26). The dual tholeiitic-

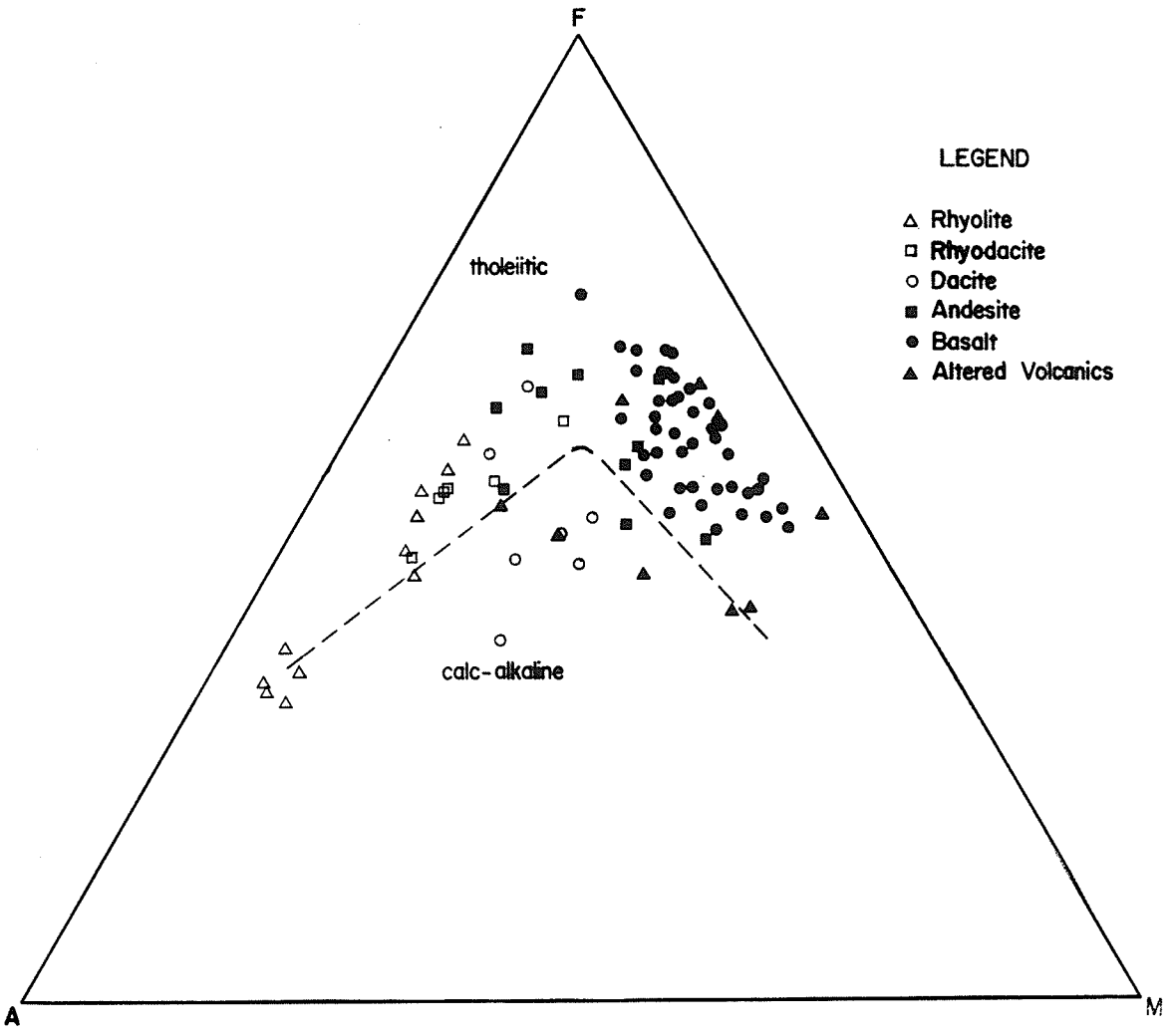

Figure 25. AFM Plot of Volcanics at Ruttan. Dividing Line Between Calc-Alkaline and Tholeiitic Fields after Irvine and Baragar (1971). A = K_2O + Na_2O, F = FeO + 0.8998 Fe_2O_3, M = Mgo (Expressed in Weight Percent). Classification Based on SiO_2 Content (After Goodwin, 1968).

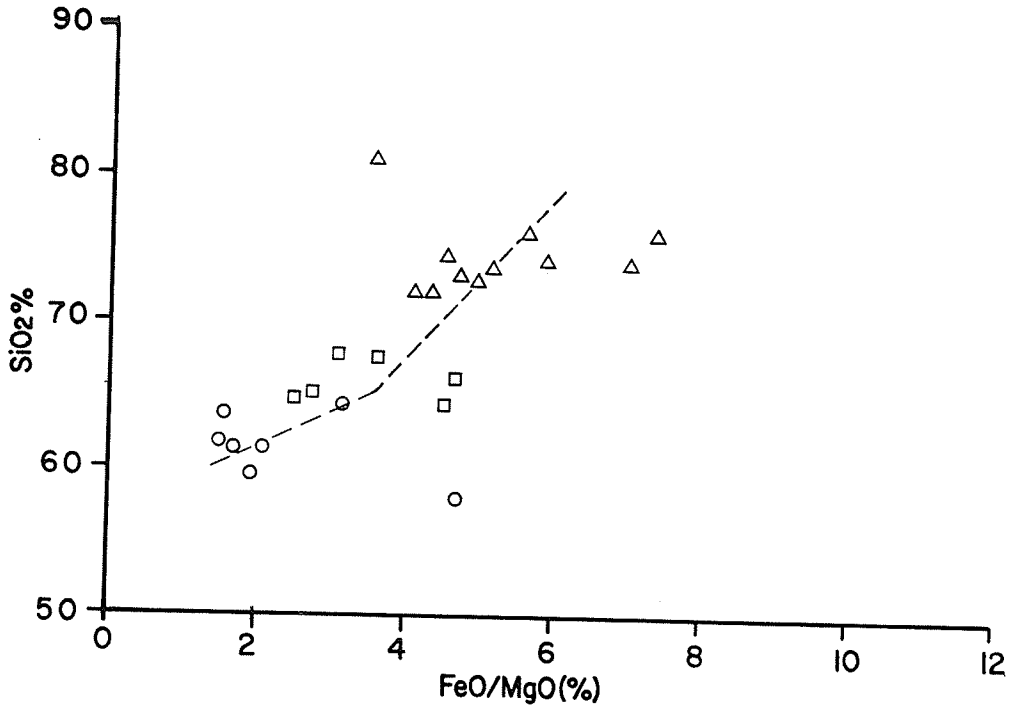

Figure 26. SiO_2 v.s. FeO/MgO Ratio For Dacitic to Rhyolitic Volcanics at Ruttan. Dashed Line is Differentiation Trend. Legend Same as in Figure 25. Oxides expressed in Weight Percent.

calc-alkaline nature is a common feature of many individual volcanoes (Kuno, 1950).

SiO_2 v.s. $Na_2O + K_2O$

Figure 27 shows the subalkaline nature of the rocks.

K_2O v.s. SiO_2

The low K_2O content of rocks (Figure 28) suggests that they could have an island arc-tholeiite affinity as easily as a calc-alkaline affinity because the points overlap equally in both fields, unlike most true calc-alkaline suites (Jakes and Gill, 1970). The analogy between PreCambrian and recent geochemistry is questionable here however (see Table IV), because low K_2O has been documented as being a typical feature of PreCambrian volcanic rocks (Wilson et. al., 1965; Goodwin, 1967; and others).

Q - Ab - Or

Figure 29 reflects the low concentration of alkalis and the normative feldspar composition in part (see also Figure 20). High SiO_2 (and normative quartz) in felsic rocks is shown by a progression towards the Q apex. The intermediate and felsic volcanics also plot closer to the Q apex, and farther from the Ab apex, than most unaltered volcanic rocks according to a comparison with Nockold's series. The diagram shows the progressive enrichment in silica and potash from basalt through rhyolite, and a progressive decrease

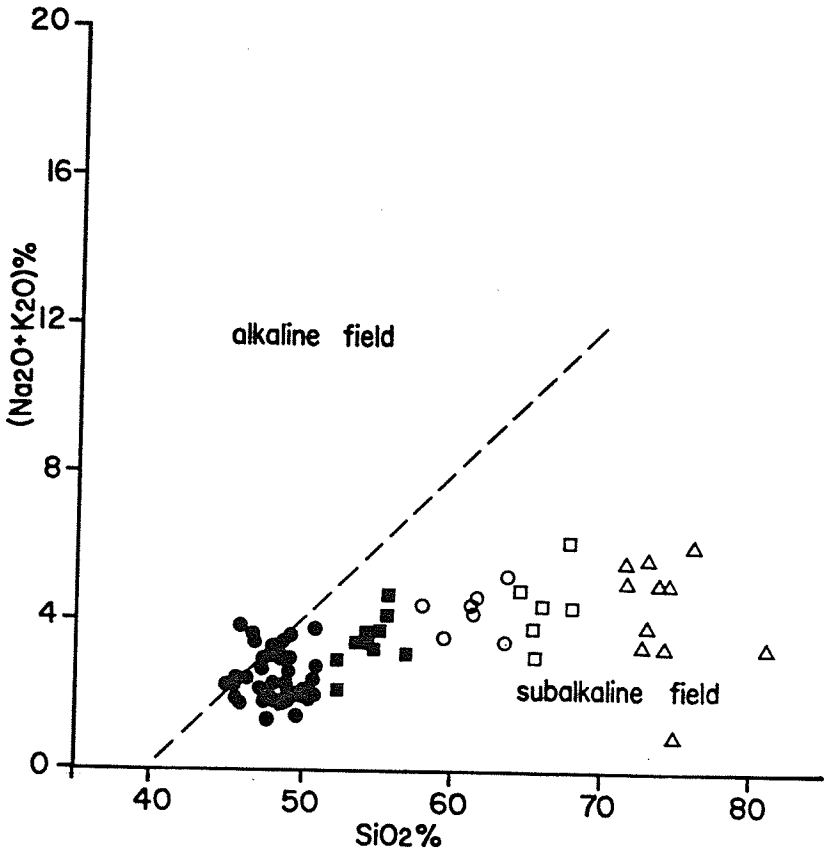

Figure 27. $Na_2O + K_2O$ v.s. SiO_2 Plot for Volcanics at Ruttan (Dividing Line from MacDonald and Katsura, 1964). Legend Same as in Figure 25. Oxides Expressed in Weight Percent.

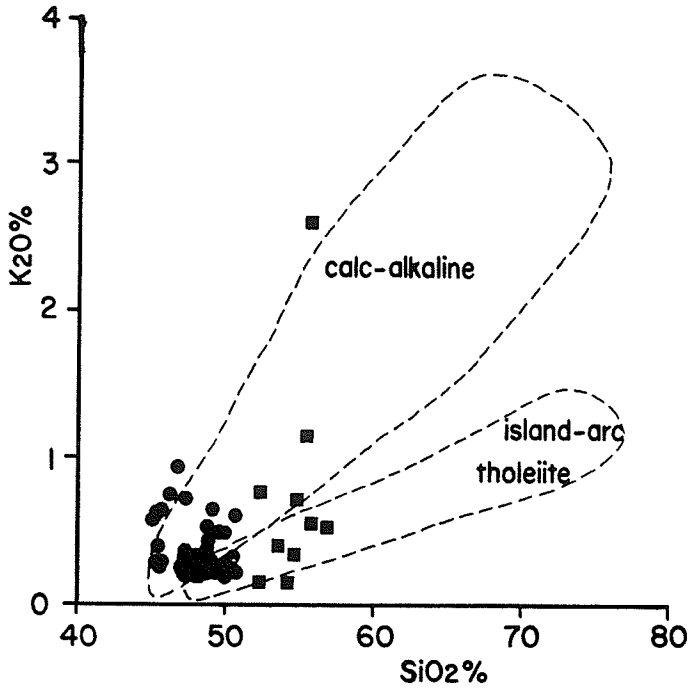

Figure 28. K_2O v.s. SiO_2 Plot for Mafic Volcanics at Ruttan (Fields After Jakes and Gill, 1970). Legend Same as in Figure 25. Oxides Expressed in Weight Percent.

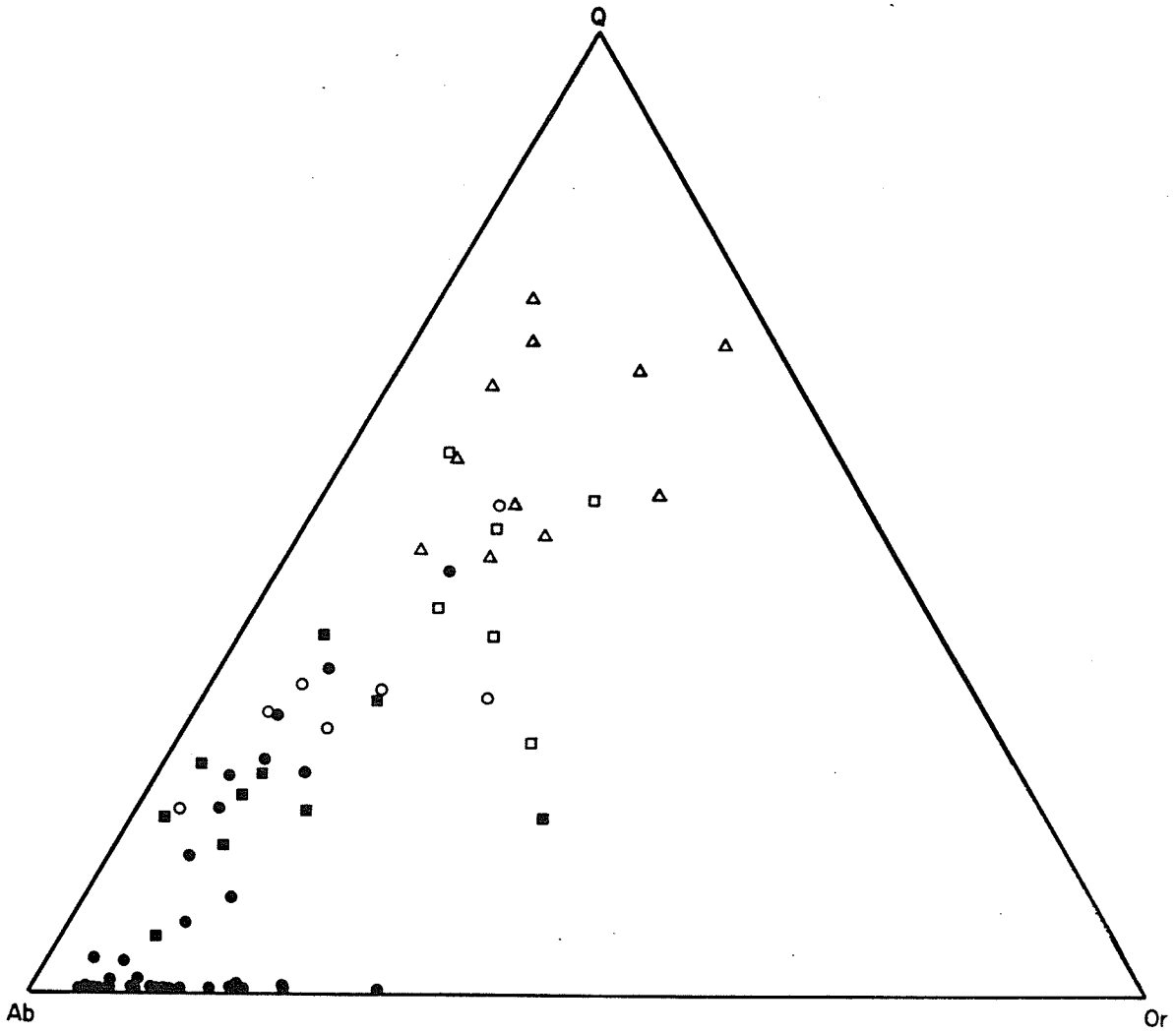

Figure 29. Normative Q - AB - OR Diagram of Volcanics at Ruttan. Q = Quartz, AB = Albite, OR = Orthoclase. Legend Same as in Figure 25.

in soda. This could represent metasomatic trends involving depletion of Na and enrichment of K at Ruttan.

An - Ab - Or

This diagram shows the normative composition of feldspar (Figure 20). The scatter of points may be interpreted as varying degrees of feldspar alteration. As differentiation proceeds from mafic to felsic rock types, the Ab/Or (and Na/K) ratio decreases with increasing alteration of feldspar. For example, the group of rhyolites that form a near linear path in Figure 20, with constant An content, show increasing alteration from the Ab apex towards the Or apex. Sample no. 20-2 is the closest point to the Or apex, and also shows the strongest evidence of alteration among these rhyolites (ie. - low Na_2O and high K_2O, significant sericite + chlorite + carbonate + pyrite; see Tables II and III). Figure 20 also brings out the low potash content of the Ruttan volcanics, especially the mafics which cluster along the An-Ab join.

Peraluminous Nature?

Volcanic rocks that are considered to be high in alumina are those with $Al_2O_3 > 17\%$ (Carmichael, Turner, Verhoogen, 1974), or those rocks with $Al_2O_3 < CaO + Na_2O + K_2O$ (Spitz and Darling, 1975). Figure 30 shows that the mafic volcanics are not high alumina basalts, but that 6 of 10 andesites and 3 of 7 dacites are peraluminous. The

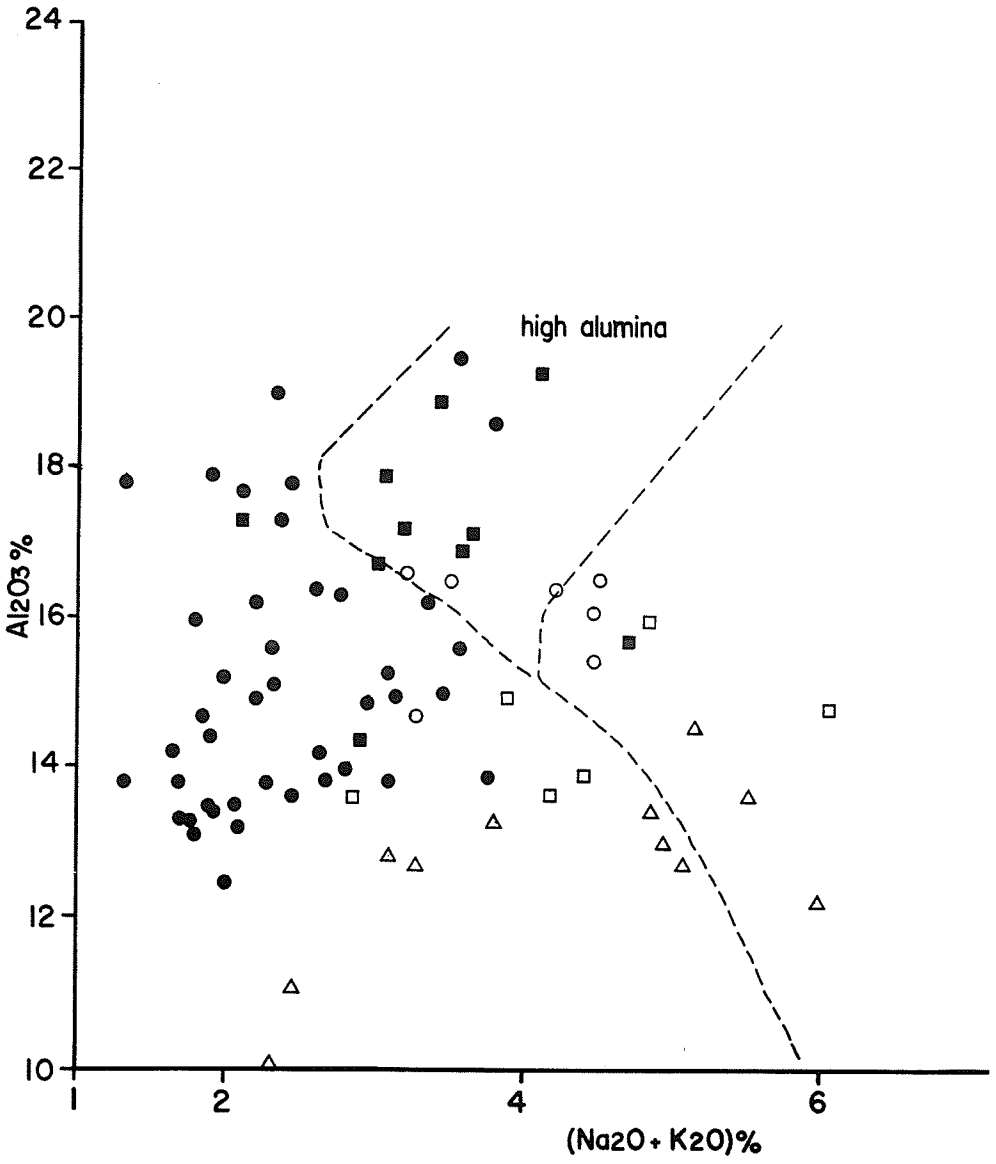

Figure 30. Al_2O_3 v.s. Na_2O + K_2O Plot for Volcanics at Ruttan. Legend Same as in Figure 25. Oxides Expressed in Weight Percent.

apparent peraluminous nature is probably not real because the alkalis are low in relation to alumina (rather than alumina being high), and because felsic and intermediate rocks are normally more aluminous than mafics in the PreCambrian (Wilson et. al., 1965). If these rocks were peraluminous, the mafic volcanics would also overlap the alumina field.

6. ORIGIN OF BASALTS

The variation from olivine normative to quartz normative basalts is taken by some authors as indicating a progression away from the abyssal sea floor (where basalts are rarely quartz normative) towards the island arc environment (where basalts are commonly quartz normative; from Descarreaux, 1973). Olivine and quartz normative basalts are both common in the Ruttan sequence (see Table III). K_2O content of the Ruttan basalts shows that they are oceanic, rather than continental, when compared with tholeiitic basalts of Engel et. al. (1965; Figure 31). TiO_2 content further classifies the basalts as having a circumoceanic rather than an oceanic affinity (Figure 32) when compared with tholeiitic basalts of Chayes (1964). This is consistent with the concept of development in a circumoceanic arc system. The geochemistry strongly favours an island arc tholeiite versus a seafloor origin for the Ruttan tholeiitic basalts.

7. CONCLUSIONS

The major element geochemical trends are consistent

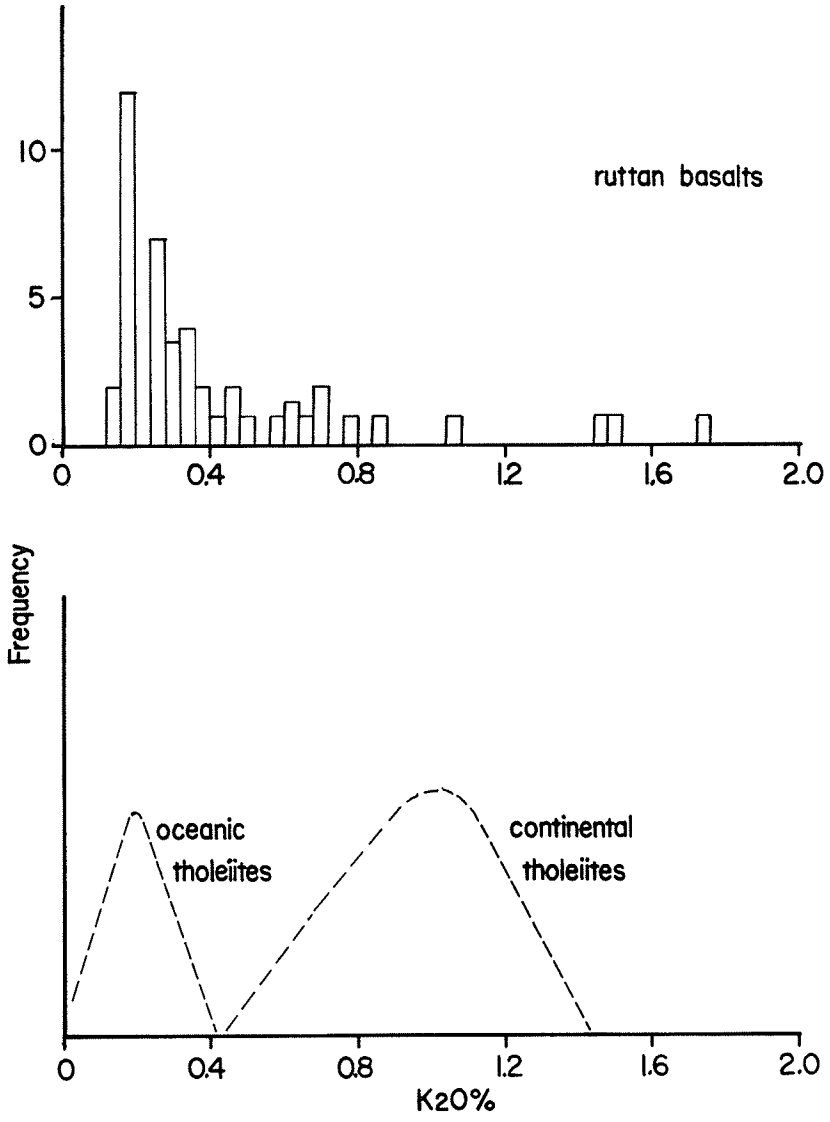

Figure 31. K_2O v.s. Frequency Diagram for Ruttan Basalts - Compared with Oceanic and Continental Tholeiites (Fields after Engels et. al., 1965). K_2O Expressed in Weight Percent.

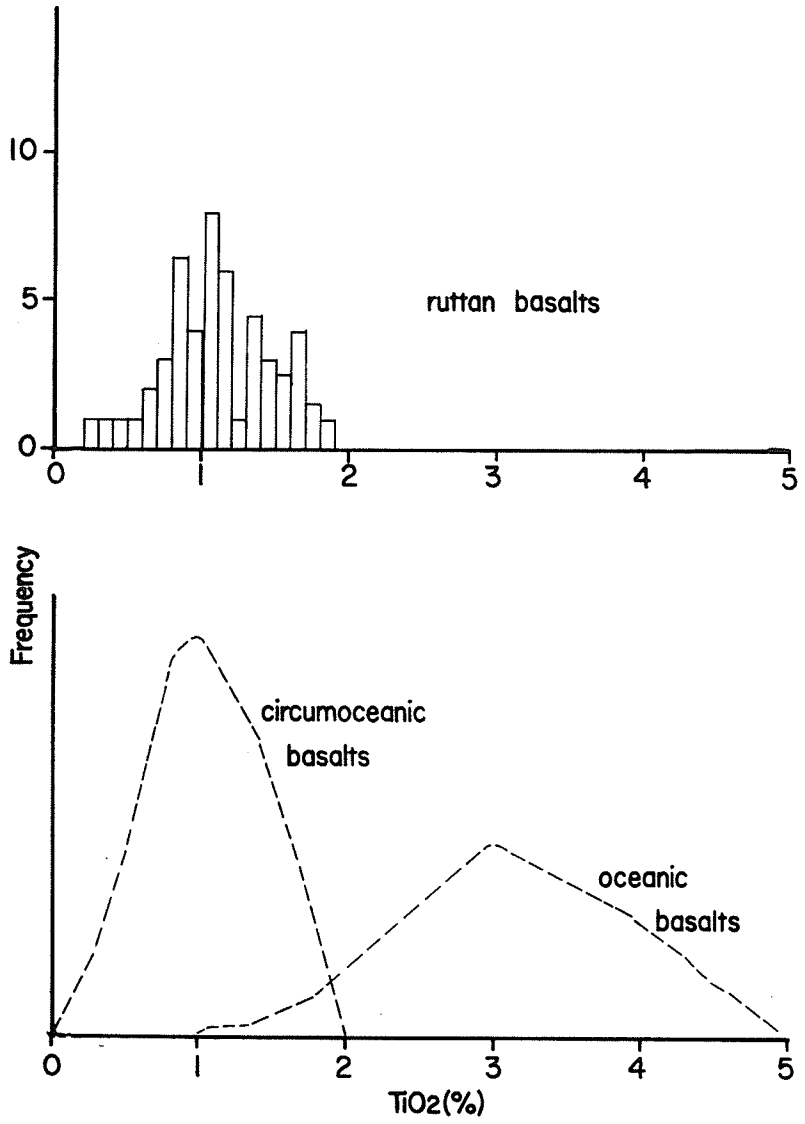

Figure 32. TiO_2 v.s. Frequency Diagram for Ruttan Basalts - Compared with Oceanic and Circumoceanic Basalts. (Fields after Chayes, 1964). TiO_2 Expressed in Weight Percent.

with the model of a differentiated mafic to felsic strato-volcano, which may be applicable to the classic island arc model of basalt-andesite-dacite-rhyolite volcanism. Contrasts in major oxide contents between Ruttan and recent island arcs (higher total Fe and MgO, lower Na_2O and K_2O at Ruttan) are interpreted as being related to alteration associated with mineralization at Ruttan (Fe enrichment, Mg metasomation, leaching of alkalis) and effects of Pre-Cambrian alteration (lower alkalis than in more recent rocks). Also, the proportion of dacite-rhyolite to andesite composition volcanics is higher at Ruttan, than in Archean volcanic sequences.

Much more detailed work from the PreCambrian needs to be documented before the differences and similarities between Proterozoic and Archean volcanism, and between Pre-Cambrian and recent volcanism can be properly evaluated. The use of trace elements, especially Nb, Zr, Y (relatively inert elements) may further refine the geochemical trends.

CHAPTER X

ALTERATION GEOCHEMICAL PATTERNS

1. INTRODUCTION

Exploration in PreCambrian volcanic belts has been based on geological mapping, geophysical interpretation, and diamond drill core data, but more recently attention has been given to geochemical methods of exploration (Nichol, 1969; Garrett, 1972; Descarreaux, 1973; Govett and Goodfellow, 1975; and others). Rock geochemistry is still a relatively underdeveloped exploration technique compared with the widespread use of soil, stream, and lake sediment geochemistry. However, lithogeochemical methods may become more important in the future as exploration for deeply buried mineralization becomes more complex.

In this study, patterns of alteration and anomalous geochemistry are examined in relation to patterns observed at the Ruttan orebody, as an exploration technique for the mapped area. Plots of Cu, Zn, S distribution (Figures 33, 34, 35) sulphide distribution (Figure 36), chlorite + sericite distribution (Figure 37), and Na/K ratio (Figure 38) outline these trends in the mapping area (see backflap inserts).

2. ALTERATION PATTERNS AT THE RUTTAN OREBODY

The sulphide zone at Ruttan is highly chloritized, sericitized, and silicified (Newmont Geochem. Expl. Report, 1977) and appears to be typical of most volcanogenic massive Cu-Zn deposits in the PreCambrian Shield. Significant features are:

1. Chloritization - retrograde alteration of chlorite replacing hornblende and biotite. At the orebody this is closely associated with sulphide mineralization. Alteration is more extensive and intensive in the footwall than in the hangingwall.
2. Sericitization - retrograde alteration of sericite after plagioclase is apparently an important indication of mineralization. Alteration is most intense in the footwall.
3. Silicification - quartz occurs as pods and veins and is closely associated with Fe rich, biotite rich alteration veinlets along foliation.
4. Mg Metasomatism - Above average grain sizes and Mg - rich assemblages (ie. - cordierite + tremolite + phlogopite) are closely associated with mineralization. MgO is typically $> 10\%$ and associated FeO is $\geq 25\%$.
5. Na Depletion - This corresponds to increased sericitization towards the ore zone.
6. S Enrichment - This is directly related to sulphide mineralization.

These features of alteration and anomalous geochemistry

from the Ruttan orebody are contrasted with those on strike to the orebody in order to attempt to detect similar trends of anomalous geochemistry.

3. ALTERATION TYPES IN THE RUTTAN MAP AREA

1. Sheared mafic volcanics rich in epidote - quartz-calcite-hematite pods and veinlets (see shear zone in Figures 2 and 3 in vicinity of samples C-74, 12-9, 12-10, 12-11)
2. Mild chloritization (in vicinities of samples 12-12, C-13, C-17, C-48, C-67 in Figure 3. See also Figure 37)
3. Silification and quartz veining (location as in "1")
4. Pyrite-Pyrrhotite Mineralization (in vicinities of samples 13-4, 25-1, 28-1, 43-1, C-10, C-13, C-39, C-50, C-55, C-74; See also Figure 36)
5. Sericitization (in vicinities of samples 12-12, 13-1, 14-3, 20-2, C-50. See also Figure 37)

The alteration is most intense in the vicinity of the altered, sheared fault zones (see shear zones on Figures 2 and 3) within the mafic volcanics, and within the felsic fragmentals at a few localities (see Figures 33-38 for location of anomalous zones). The stratigraphic location of alteration trends is consistent with those at the Ruttan orebody and with Sangster's (1972) concept of alteration beneath volcanogenic orebodies.

Two geochemical patterns are evident from the geochemistry (Table II) and from the alteration patterns shown in

Figures 33-38. One represents primary unaltered, and the other represents the effects of shearing, hydrothermal alteration, and mineralization. With increasing alteration there is a decrease in SiO_2, Na_2O and an increase in Al_2O_3, FeO + MgO, CaO, K_2O, Cu, Zn, S. (Figures 33-38).

The zone of alteration associated with massive sulphide mineralization would be expected to be fairly extensive because of the permeability and porosity within the felsic pyroclastic-volcaniclastic sediment pile and because of shearing and fracturing. According to Spitz and Darling (1975) however, the chemical halo of alteration around many massive sulphide deposits is 100 to 700 metres.

Na/K Ratio

A geochemical feature that may be detected in felsic volcanics near massive sulphide deposits is the removal of Na_2O and addition of K_2O, which may therefore be a useful tool in geochemical exploration for massive sulphide deposits (Descarreaux, 1973; Govett et. al., 1974). Negative Na anomalies are generally more detectable than positive K anomalies since they extend farther out from massive sulphide bodies into country rock (Gjelsvik, 1968).

In the study area there are anomalous Na/K zones from surface sampling that seem to correspond with:

1. Shear zones
2. Felsic volcanic units where they have stratigraphically thinned out and are weakly altered and mineralized.

3. Felsic volcanic units where they are stratigraphically thickest and nearest to the Ruttan orebody (See Figure 38). Also, the Na/K ratios are very low (<0.25) adjacent to the orebody in drill core (Chornoby, pers. comm.)

For the Ruttan area, there appears to be a strong negative correlation between Na and K, and anomalies occur at a number of localities (Figure 38, Table II).

Distribution of Major Elements

The distribution of major elements is complex. On log cumulative frequency plots most elements display one or more inflection points, or have a sigmoidal distribution. This indicates two or more populations are represented. Perhaps the major element sample size is not large enough for distribution analysis for the intermediate and felsic volcanics. However, the mafics are amply represented and the complex distribution pattern persists. The bimodality is interpreted to be caused by alteration.

Distribution of Cu, Zn, S and Statistical Treatment

The advantages of lithogeochemistry versus soil or stream sediment geochemistry are:

1. the effects of secondary environment redistribution need not be considered (Garrett, 1972)
2. the results represent the immediate area rather than regional dispersion (Nichol, 1969)

3. deeper trends can be detected (Govett and Goodfellow, 1975).

The set of data studied here are multimodal. That is, a variety of rock types with varying geochemical characteristics such as primary emplacement, PreCambrian alteration effects, metamorphism, and hydrothermal alteration. The former and latter parameters are the principal ones of concern here. The multimodality of these data rules out the usefulness of regional geochemical survey tools such as trend surface analysis, rolling mean tests, and trend fitting analyses. (Nichol, 1969; Garrett, 1972). A basic law of statistics states that regression analysis assumes a normal distribution (Nichol, 1969). The anomalous values of these data are not normally distributed.

Histogram plots of Cu, Zn, and S for mafic, intermediate, and felsic composition volcanics (Figure 39) show that Cu and S are strongly positively skewed and that Zn has a normal distribution.

"Anomalous" and "background" populations of Cu, Zn, and S have been determined by log cumulative frequency plots (Figures 40, 41, 42). Log transformed data were grouped into class intervals, transformed to the cumulative scale, and then plotted on log probability - cumulative frequency paper (after Lepeltier, 1969). On these plots, Zn is almost normally distributed, whereas Cu and S show distinct bimodal distributions. Anomalous values are those that are greater than a distinct break from the background values at an inflection

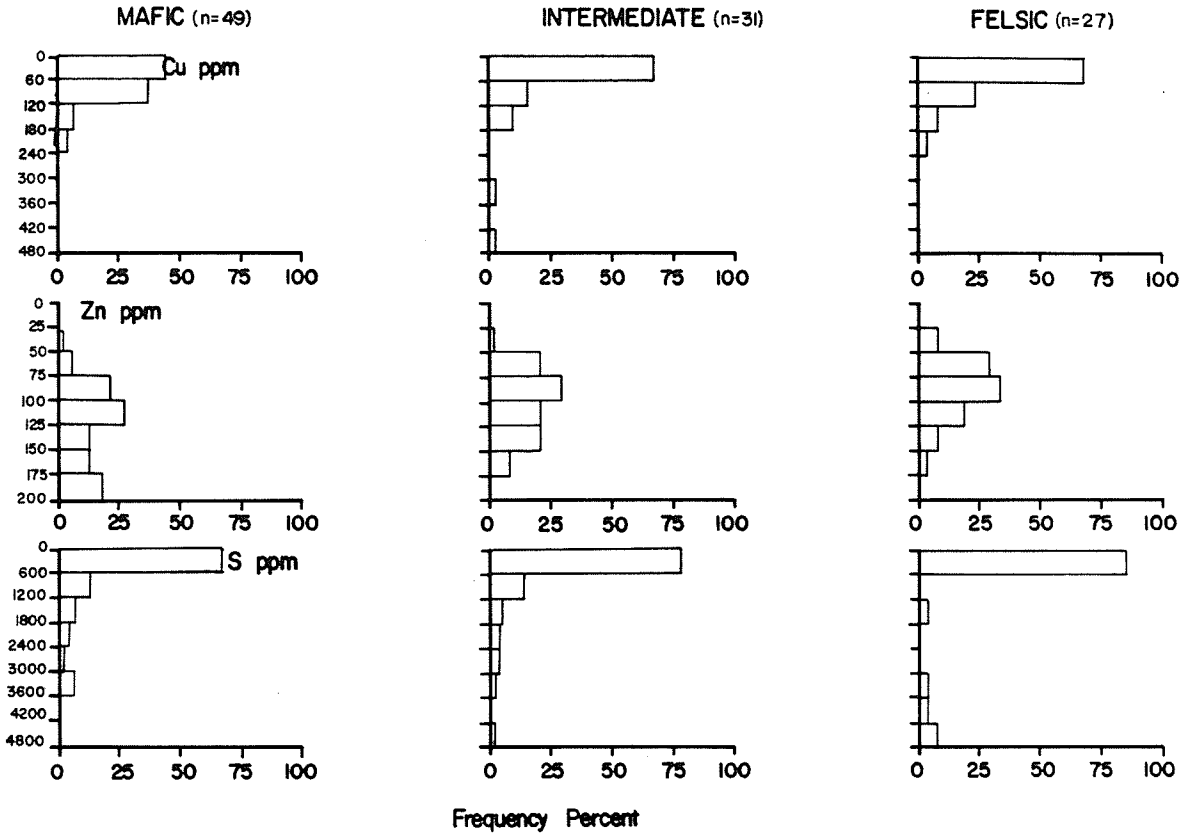

Figure 39. Histogram Plot (Frequency Distribution) of Copper, Zinc, and Sulphur Content of Volcanic Rocks in Ruttan area.

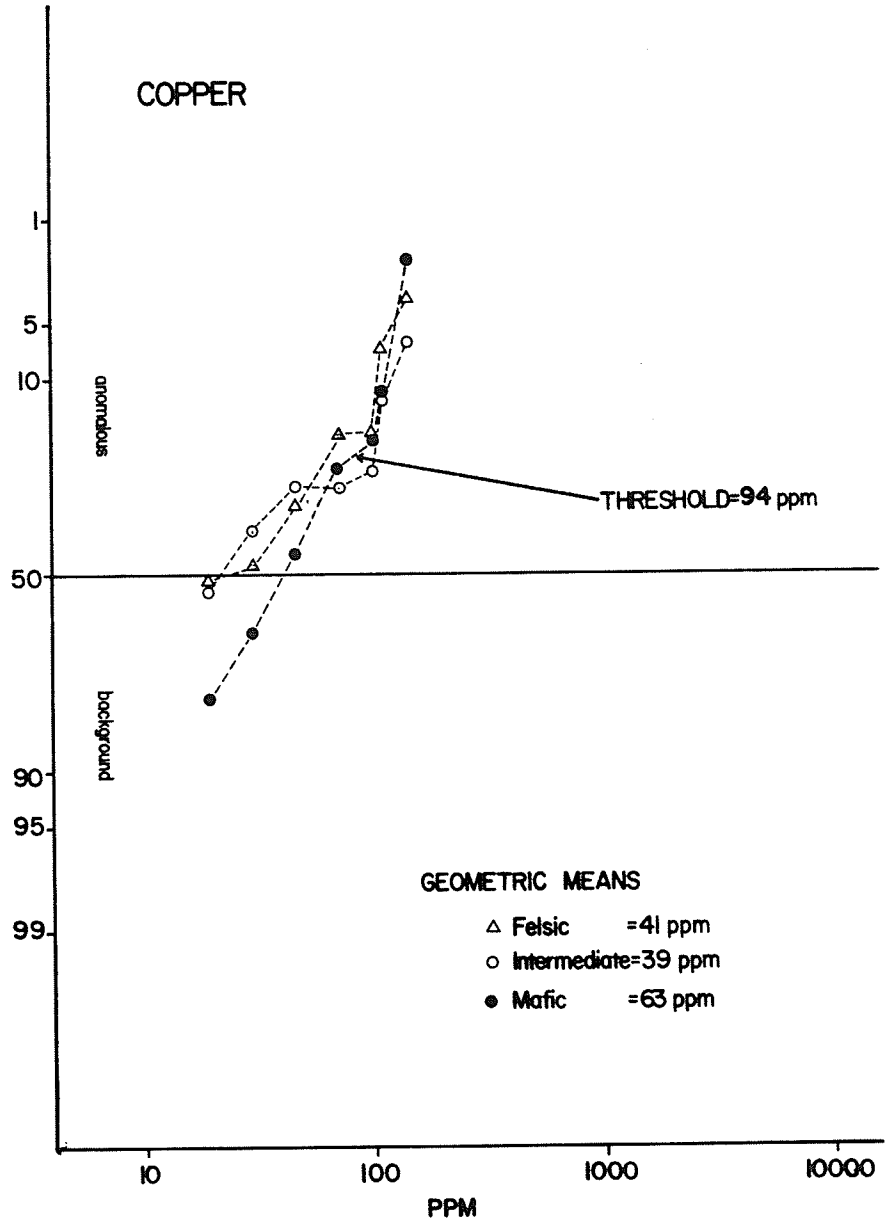

Figure 40. Log-Probability Plot of Copper Content of Volcanic Rocks in Ruttan Area.

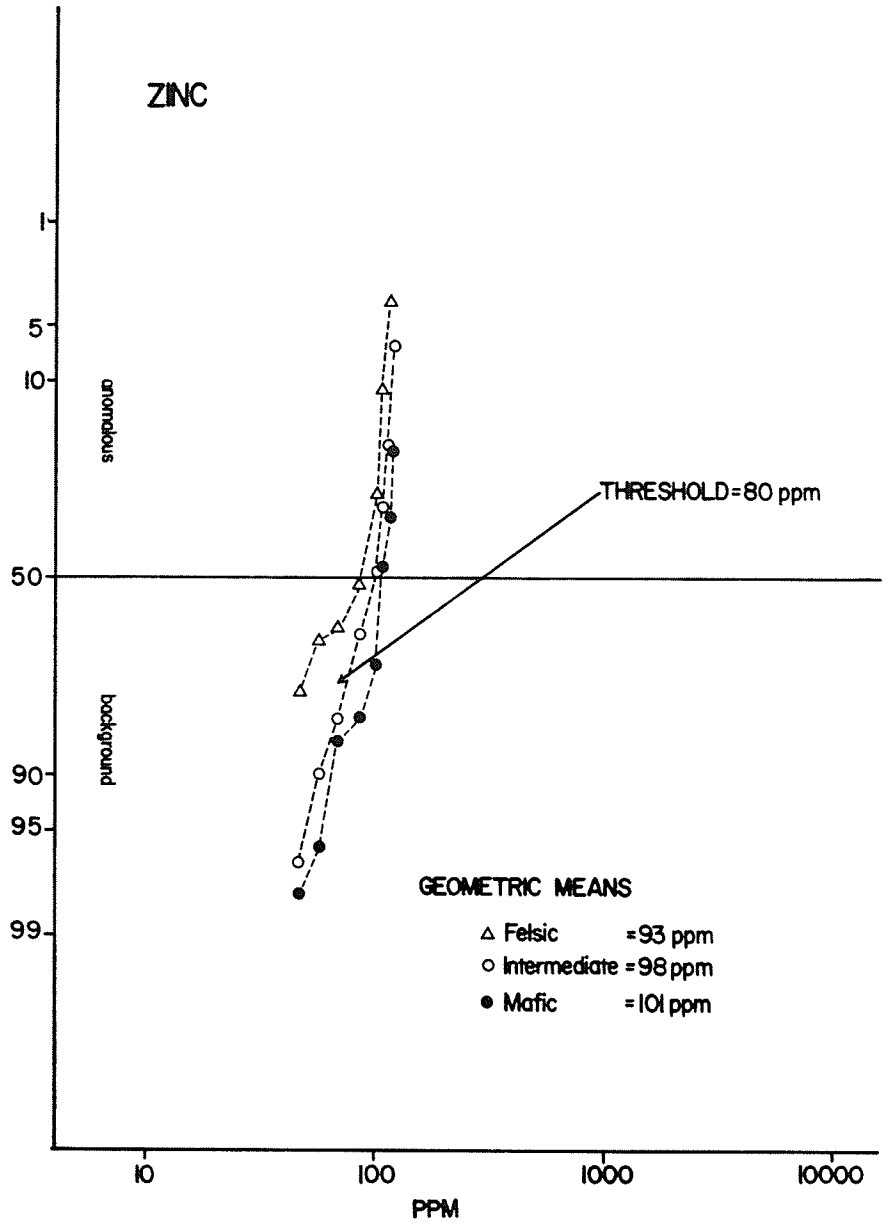

Figure 41. Log-Probability Plot of Zinc Content of Volcanic Rocks in Ruttan Area.

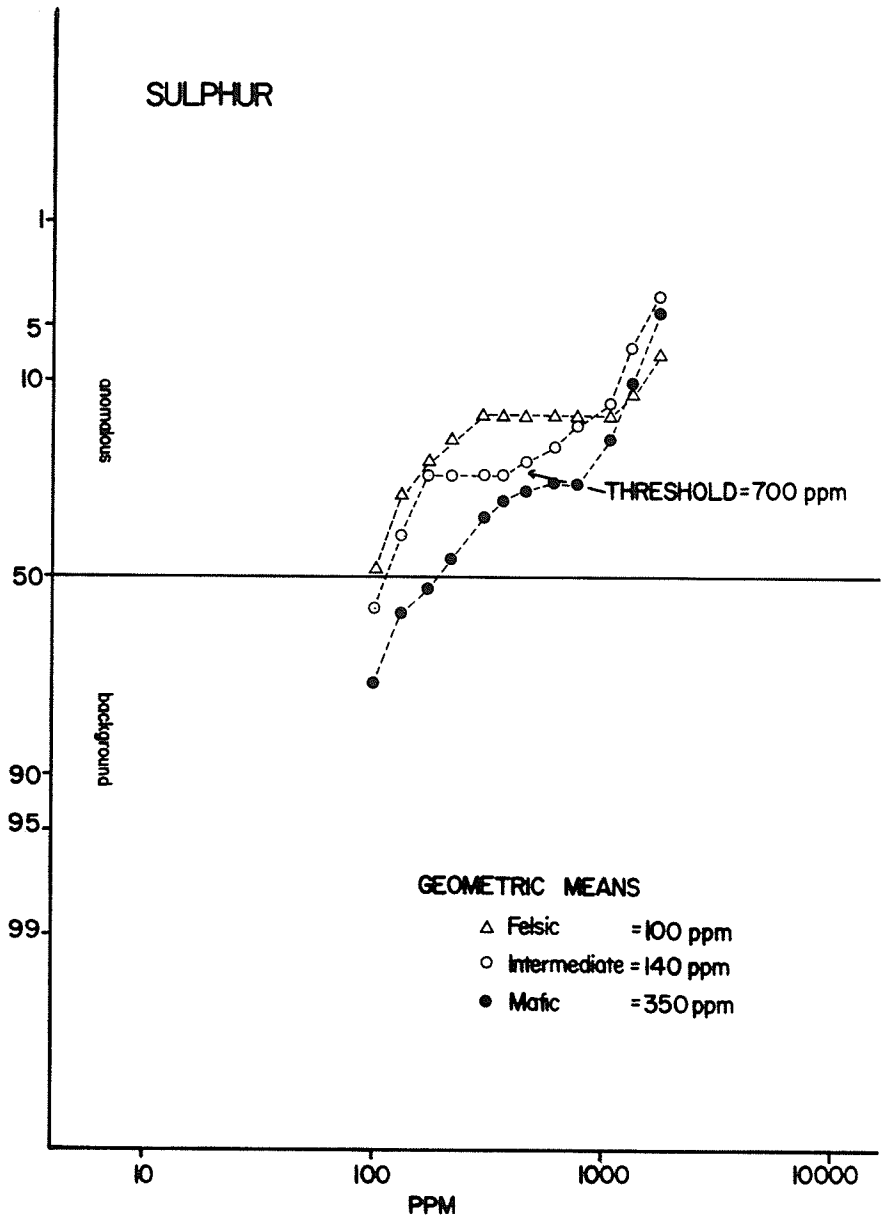

Figure 42. Log-Probability Plot of Sulphur Content of Volcanic Rocks in Ruttan Area.

point. The populations for Cu, Zn, S distributions are (in ppm):

Cu - from 0-94 (background); greater than 94 (anomalous, 20%)
Zn - from 0-80 (background); greater than 80 (anomalous, 70%)
S - from 0-700 (background); greater than 700 (anomalous, 20%)

A large proportion of the values are anomalous (especially Zn values - see Figure 34) and the map area is anomalous as a whole. The Cu and S anomalous readings correspond well with each other, representing the area of shearing (2 shear zones shown in Figure 3) and localized areas of disseminated sulphide mineralization in the intermediate to felsic volcanics (See Figures 33 and 35). The Cu and S anomalies also correspond with ground magnetic anomalies that also favour the 2 sheared or faulted zones, and localized areas within the felsic to intermediate volcanics (see Figure 18).

In conclusion, the bimodality of Cu, Zn, S indicates 2 events:

1. primary emplacement
2. signature of mineralization.

4. ALTERATION PATTERNS AT OTHER VOLCANOGENIC DEPOSITS

Some of the geochemical characteristics of Archean rocks related to massive sulphide deposits are reviewed to compare with the results from Ruttan.

(1) In a number of cycles of basaltic to rhyolitic volcanism,

generally only one cycle is anomalous in geochemistry and is mineralized (Descarreaux, 1973; Spence and DeRosen-Spence, 1975). The basaltic to rhyolitic cycle of volcanism at Ruttan is anomalous in geochemistry, and it is mineralized. It is not known whether this is the only cycle in the area that is anomalous.

(2) All basalt to rhyolite piles that contain massive sulphide deposits in the Abitibi belt are of calc-alkaline affinity (Descarreaux, 1973). The Ruttan volcanics show the same tholeiitic to calc-alkaline differentiation trend that is typical of other mineralized volcanics.

(3) The tectonic environment of massive sulphide deposits in the Archean is proximal volcanogenic facies and most closely resembles the island arc type volcanic regime. The same holds true for the Ruttan volcanic sequence.

(4) Ores occur in characteristic groups of individual deposits clustered in specific favourable areas and spaced roughly according to size (Sangster, 1972). Only one deposit is known in the Ruttan area.

5. CONCLUSIONS

From the reviewed data above it appears that:

Exploration for massive sulphide deposits in the Rusty Lake greenstone belt should be concentrated within differentiated basaltic to rhyolitic volcanic sequences of the proximal volcanogenic facies, having a calc-alkaline affinity and island arc characteristics, and having similar

lithological and geochemical characteristics as the rocks at Ruttan.

CHAPTER XI

SUMMARY AND CONCLUSIONS

(1) The rocks adjacent to the Ruttan orebody are a metamorphosed sequence of mafic, intermediate and felsic volcanics and derived volcaniclastic sediments. The felsic volcanic units are thickest towards the orebody and thin rapidly towards the northeast.

(2) Textures, structures, and stratigraphic relationships between the felsic volcanics and volcaniclastic sediments indicate a relatively proximal facies volcanic environment. The mafic to felsic volcanic sequence represents a geologically short-lived, single stage evolution from an effusive basaltic shield volcano to an explosive rhyolitic stratovolcano.

(3) Rocks were mapped in the field according to colour index, texture, structure, and stratigraphic relationships. Chemically, the rocks were classified by SiO_2 content.

(4) Chemostratigraphy indicates a sequence of tholeiitic basalts that differentiated with time to produce intermediate to felsic volcanics. The differentiation trend overlaps tholeiitic and calc-alkaline affinities. Major element geochemistry is consistent with the concept of a mafic-to-felsic stratovolcano complex similar to island arc

type volcanic regimes.

(5) The Ruttan volcanic sequence is geochemically similar to other Proterozoic and Archean volcanic assemblages in major element concentrations. However, the proportion of dacite-rhyolite to andesite volcanics is higher at Ruttan than in Archean volcanic sequences.

(6) Bimodal distributions for Cu, Zn, S indicate 2 events: primary emplacement and the signature of mineralization. A high proportion of Cu, Zn, and S concentrations are anomalous in the Ruttan area.

(7) Distribution Maps of Cu, Zn, S, sulphides, sericite + chlorite, Na/K, and ground magnetics outline a few anomalous zones. These are: the 2 shear/fault zones, localized areas within the Intermediate and Felsic Metavolcanic Formations, and the stratigraphically thickest section of the Felsic Metavolcanic Formation nearest to the Ruttan orebody.

(8) Exploration for massive Cu-Zn sulphide deposits should be concentrated within differentiated basalt-to-rhyolite volcanic cycles having similar lithological and geochemical characteristics as those at Ruttan.

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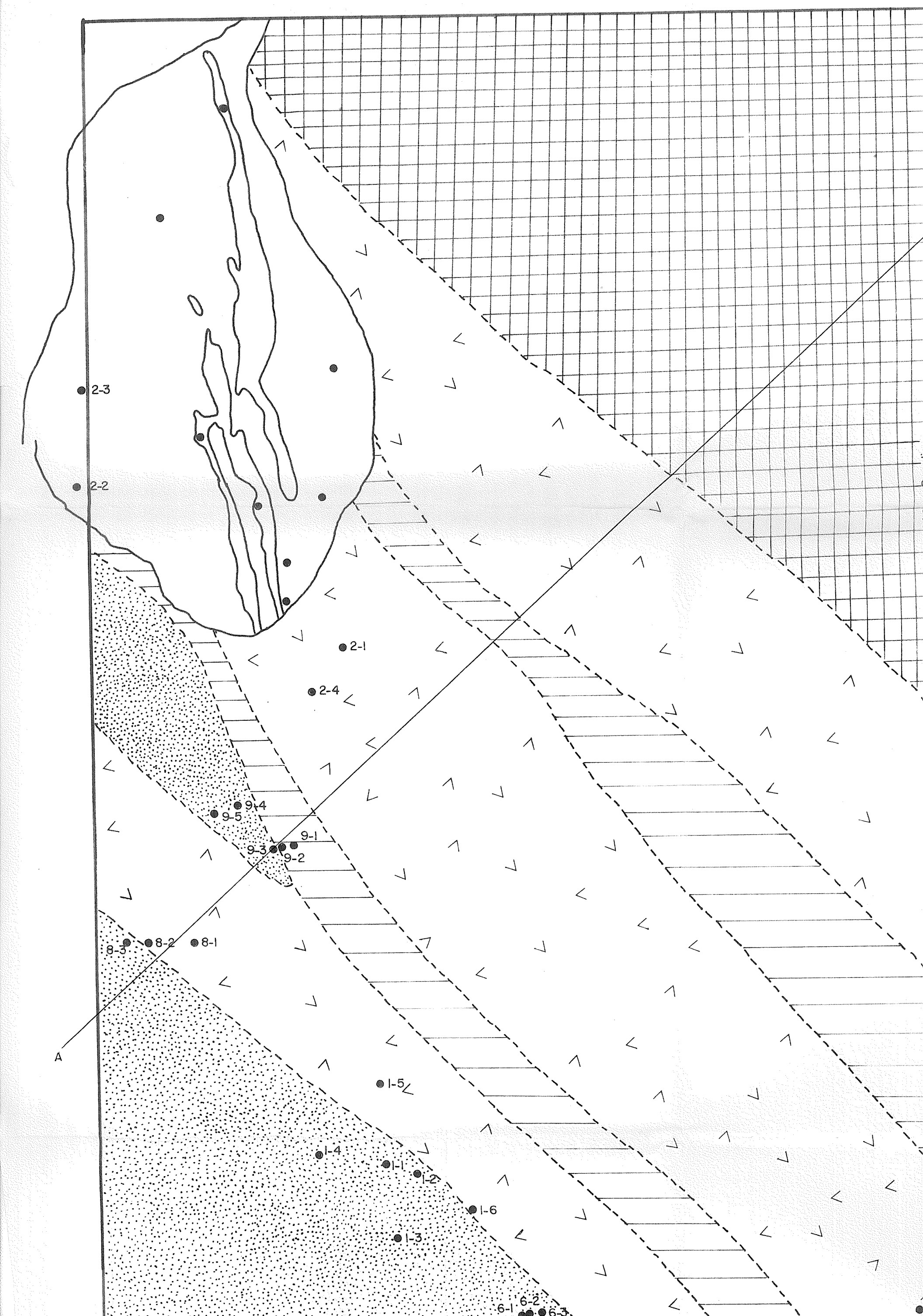
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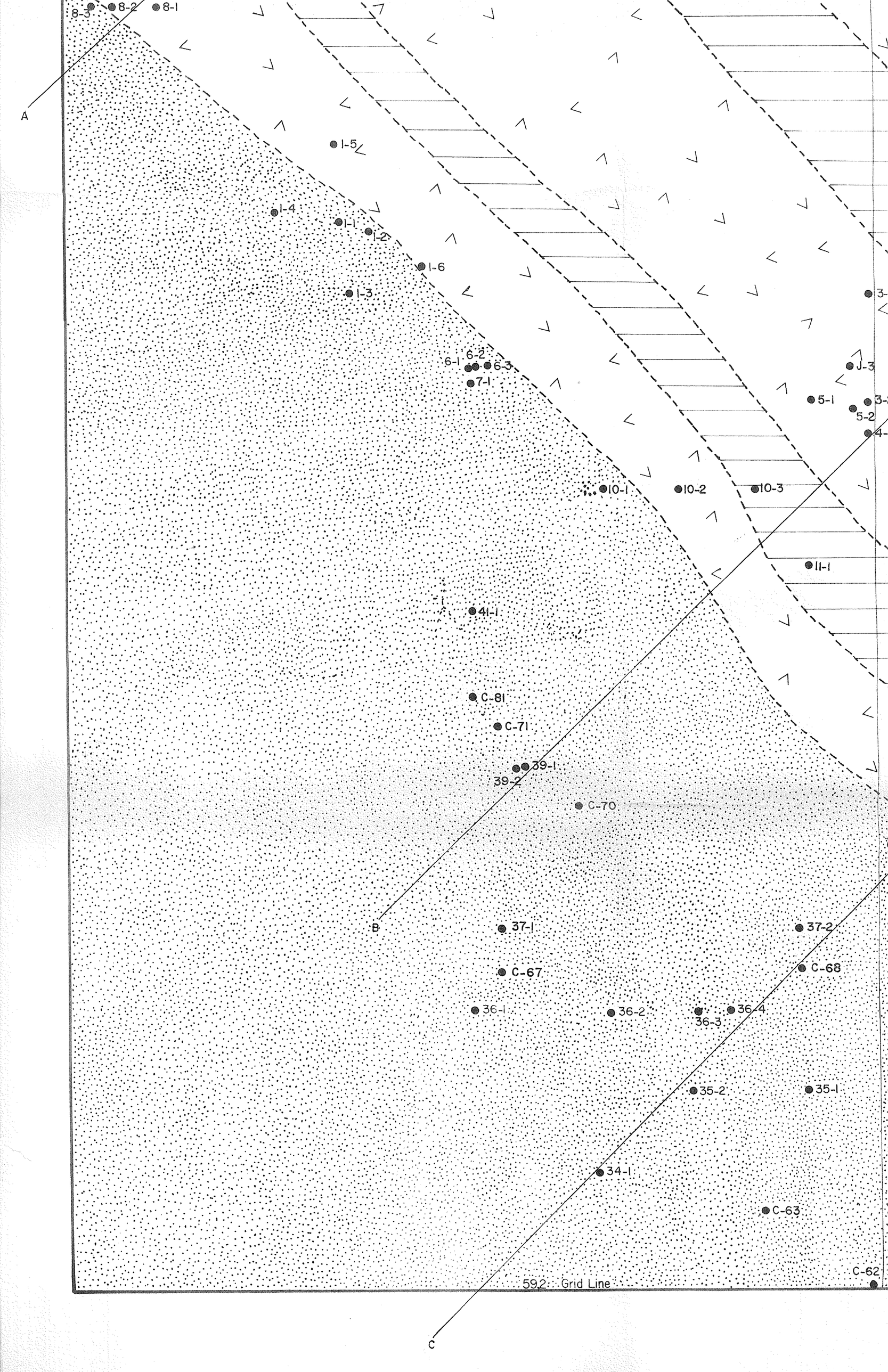
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10-2
10-3
11-1
41-1
C-81
C-71
39-1
39-2
C-70
B
37-1
37-2
C-67
C-68
36-1
36-2
36-3
36-4
35-2
35-1
34-1
C-63
C-62
59.2 Grid Line
C

160 Baseline

12-5

C-7

12-4

12-3

12-2

12-1

180 Baseline

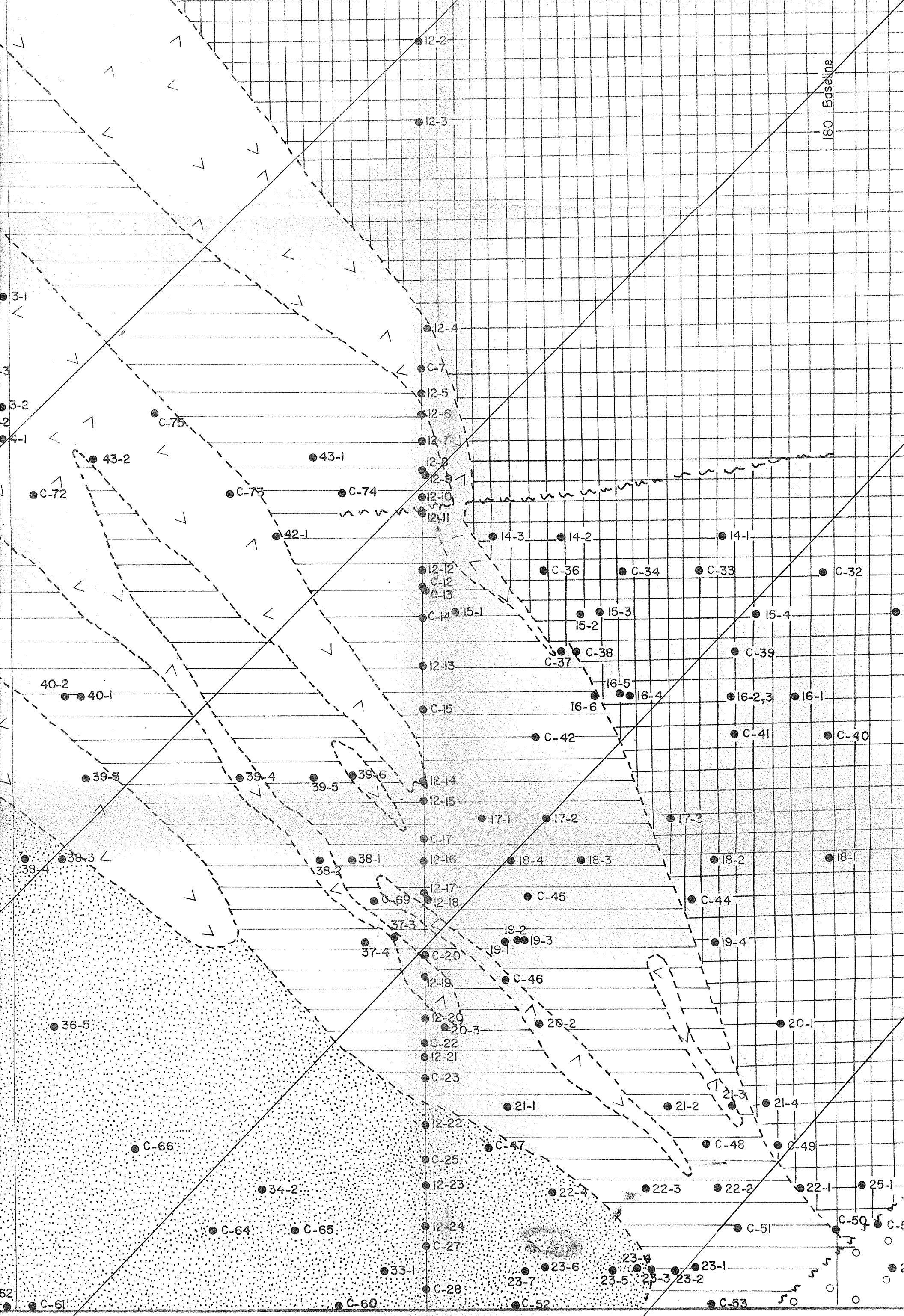


FIGURE 3- STRATIGRAPHY AND SAMPLE LOCATION MAP

LEGEND

Volcaniclastic Sediments

Felsic Volcanics

Intermediate Volcanics

Mafic Volcanics and Granite

Sediments and Mafic Volcanics

Fault

Ruttan Orebody

● 4-1

Sample Site

0 1000 2000 feet

200 400 m.

180 Baseline

180 Baseline

14-1

13-4 13-3 13-2 13-1

C-33 C-32

15-4 32-1 32-2

C-39

16-2,3 16-1 31-3 31-2 31-1

C-41 C-40

30-1

18-2 18-1 28-1

C-44

19-4 29-1

20-1

27-1 27-2

C-57

21-3 21-4

26-2 26-1

C-48 C-49 C-56

22-2 22-1 25-1 25-2 25-3,4 25-5 25-6

C-50 C-55

STRATIGRAPHY AND SAMPLE LOCATION

LEGEND

Volcaniclastic Sediments

Felsic Volcanics

Intermediate Volcanics

Mafic Volcanics and Granite

Sediments and Mafic Volcanics

Fault

Ruttan Orebody

● 4-1

Sample Site

N

0 1000 2000 feet

200 400 m.

180 Baseline

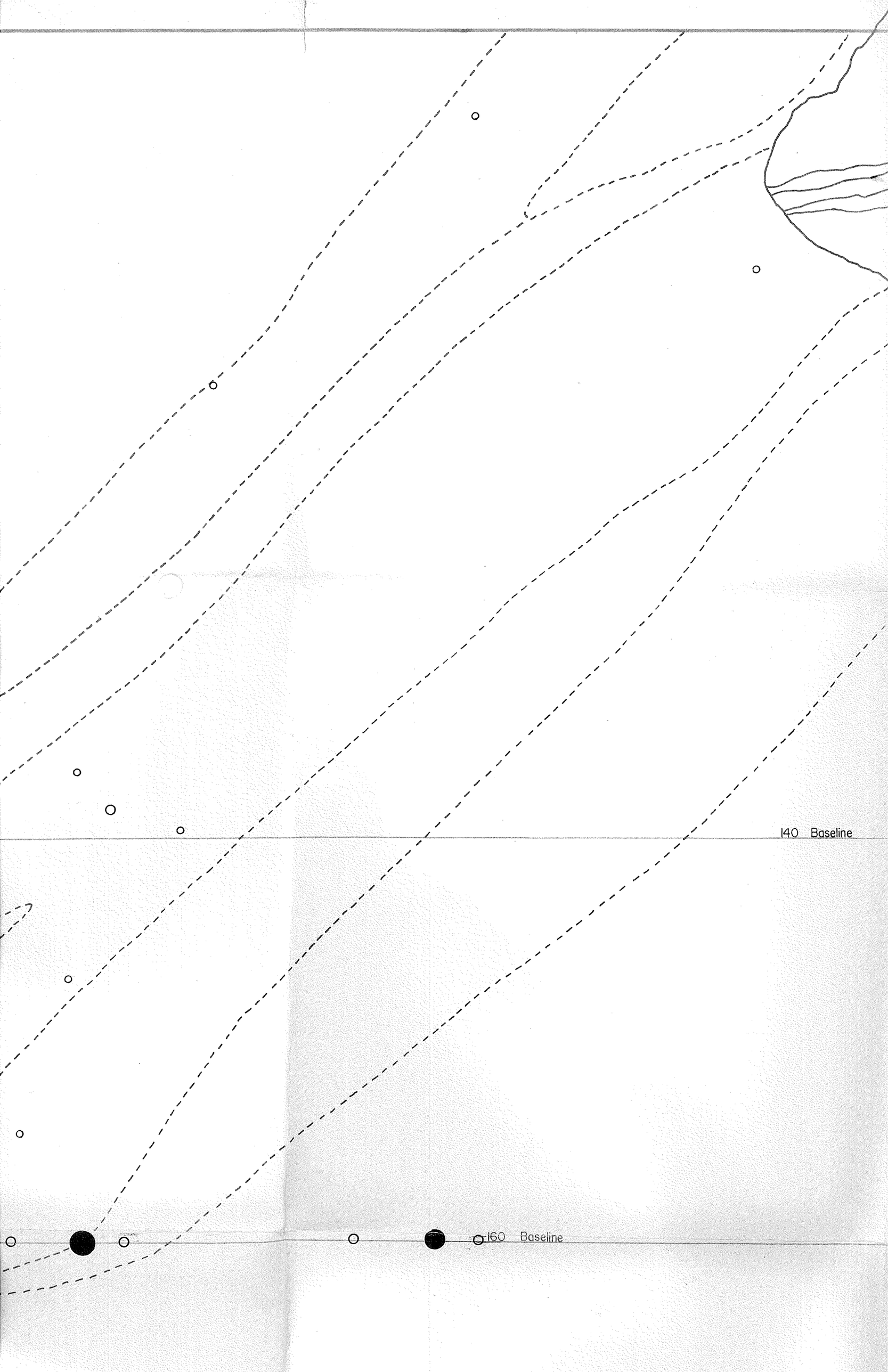
180 Baseline

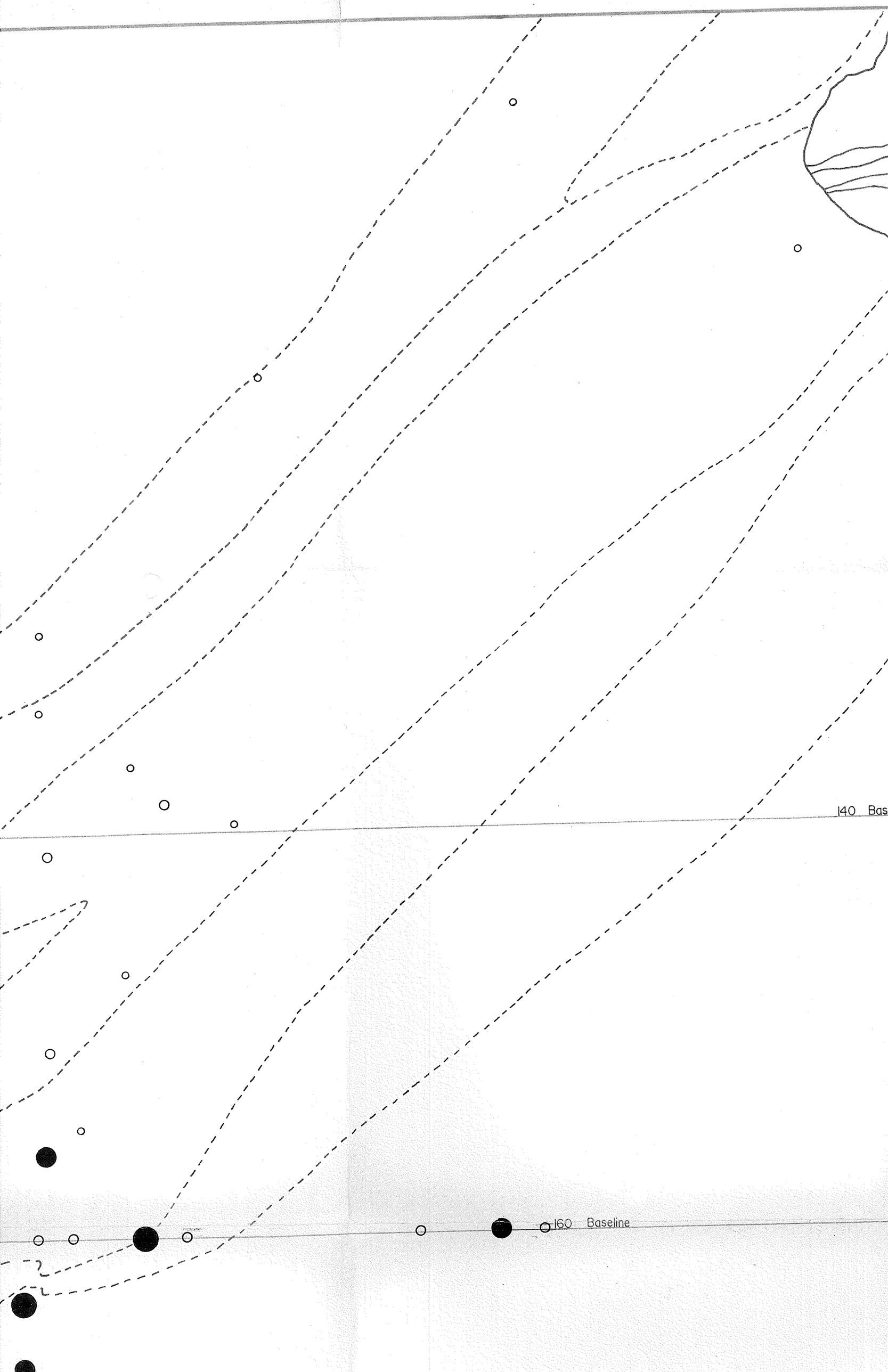
13-4
13-3
13-2
13-1
C-32
15-4
32-1
32-2
C-39
16-2,3
16-1
31-3
31-2
31-1
C-41
C-40
30-1
18-1
28-1
29-1
20-1
27-1
27-2
C-57
21-4
26-2
26-1
C-49
C-56
22-1
25-1
25-2
25-3,4
25-6
25-5
C-51
C-50
C-55
24-1

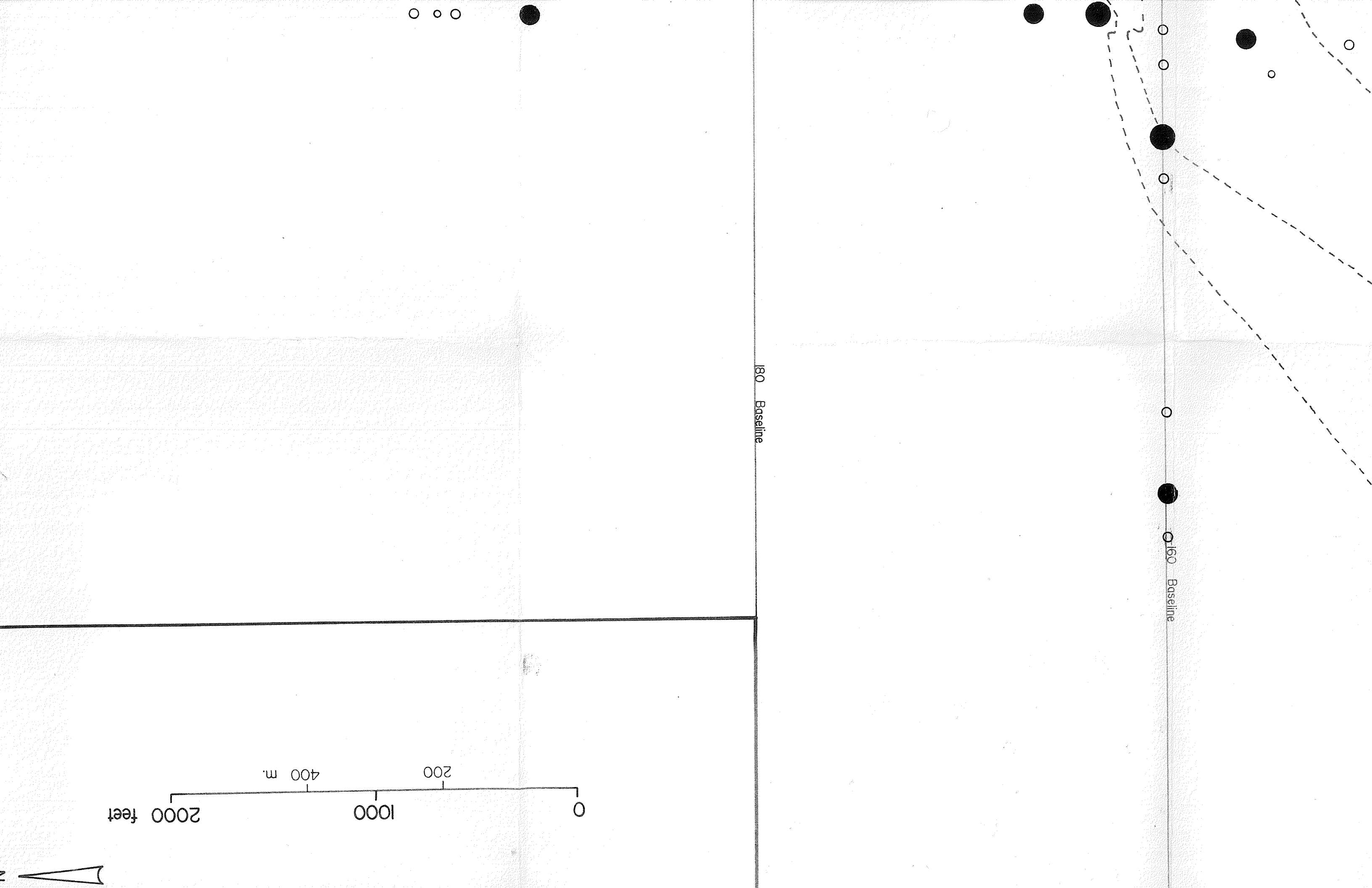
592 Grid Line

FIGURE 33- CU DISTRIBUTION

- CU DISTRIBUTION


140 Baseline
160 Baseline


140 Bas
160 Baseline


I80 Baseline
0160 Baseline
0
1000
2000 feet
200
400 m.


140 Baseline
160 Baseline

CU, ZN, S DISTRIBUTIONS (ppm)

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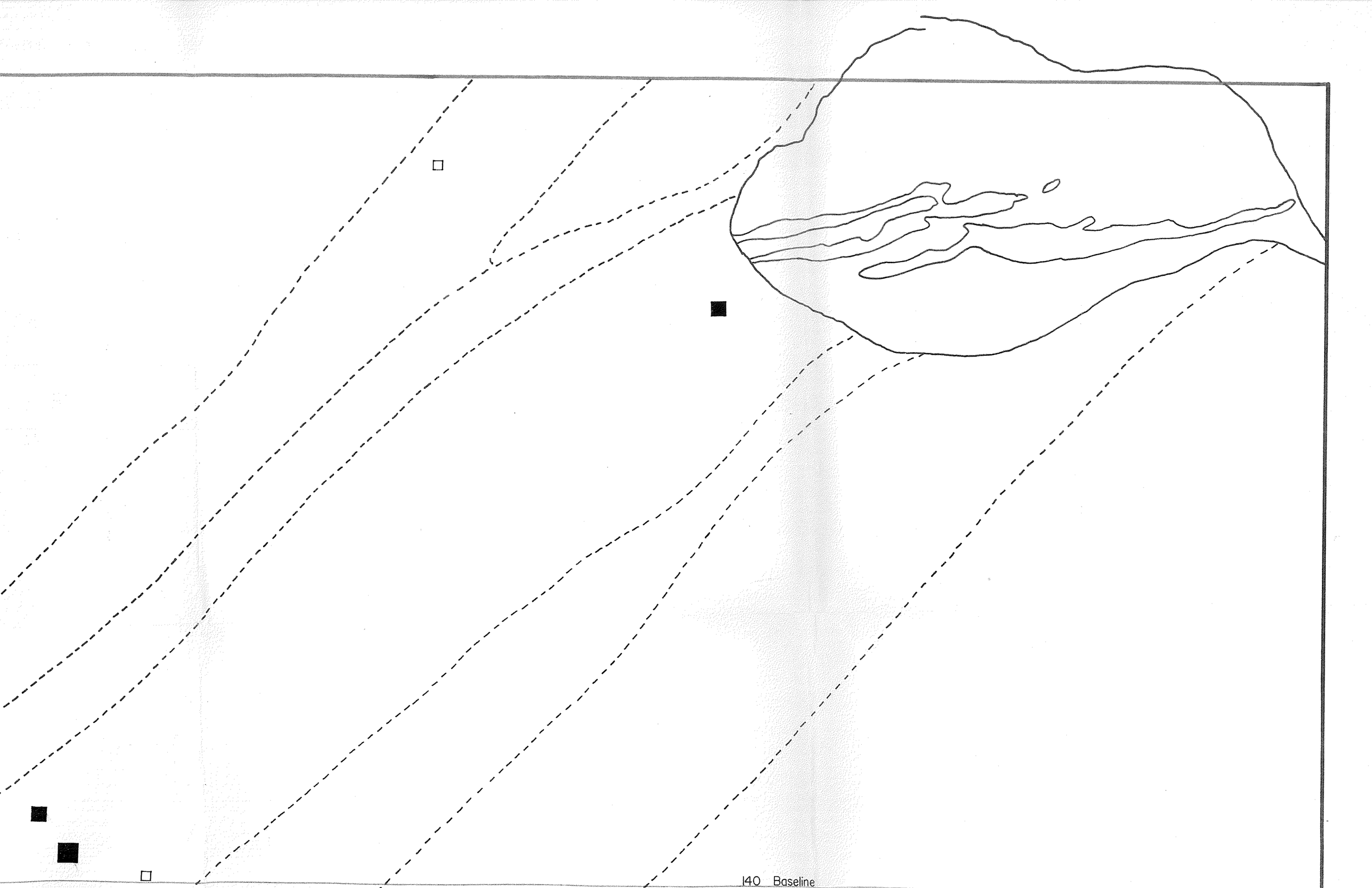
COPPER		ZINC		SULPHUR	
○	0 to 50	□	0 to 40	△	0 to 500
○	50 to 100	□	40 to 80	△	500 to 1000
●	100 to 150	■	80 to 120	▲	1000 to 1500
●	150 to 200	■	120 to 160	▲	1500 to 2000
●	greater than 200	■	greater than 160	▲	greater than 2000

N

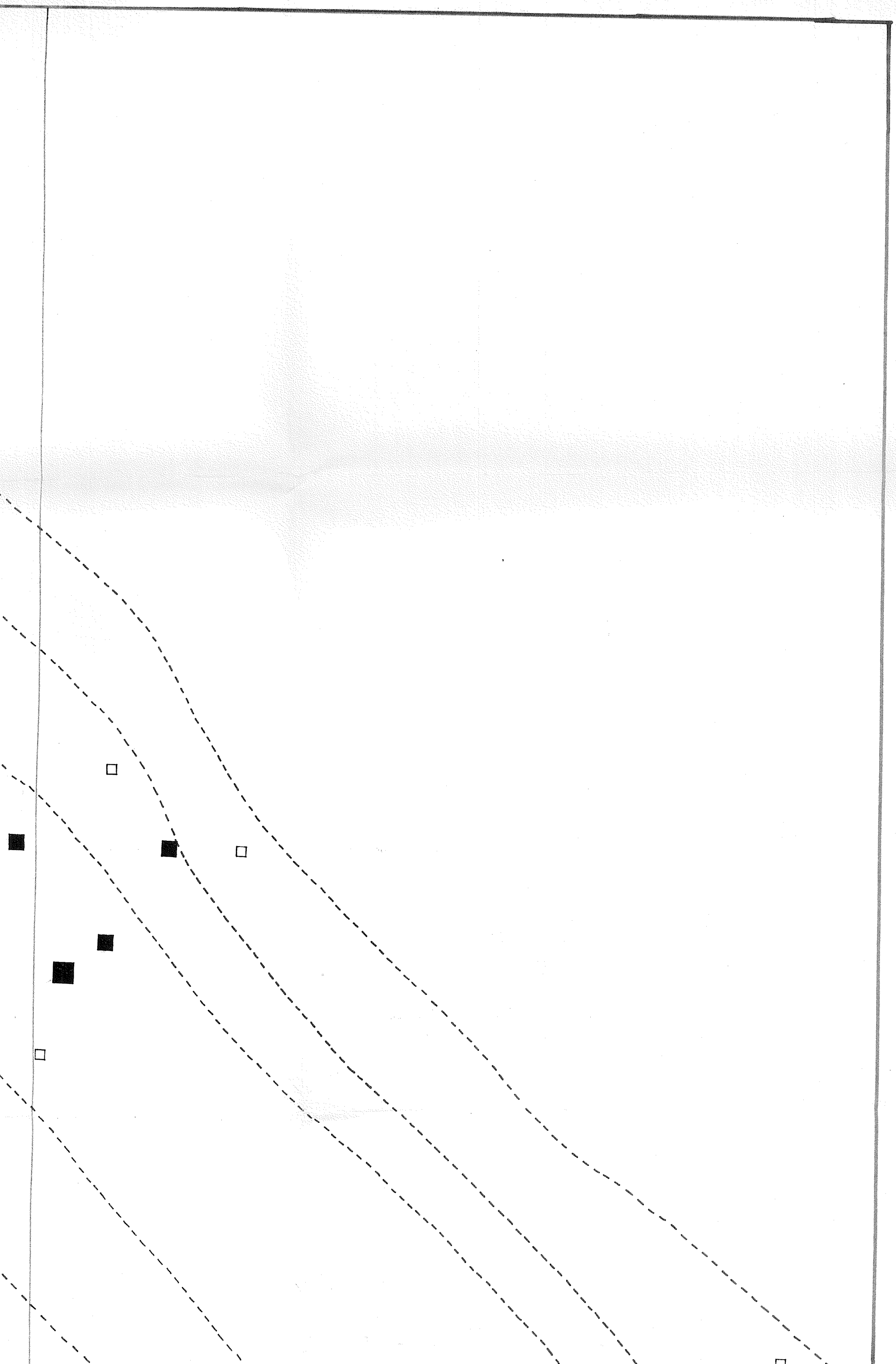
0 1000 2000 feet

200 400 m.

160 Baseline



140 Baseline



140 Baseline

60 Baseline

180 Baseline



FIGURE 34- ZN DISTRIBUTION

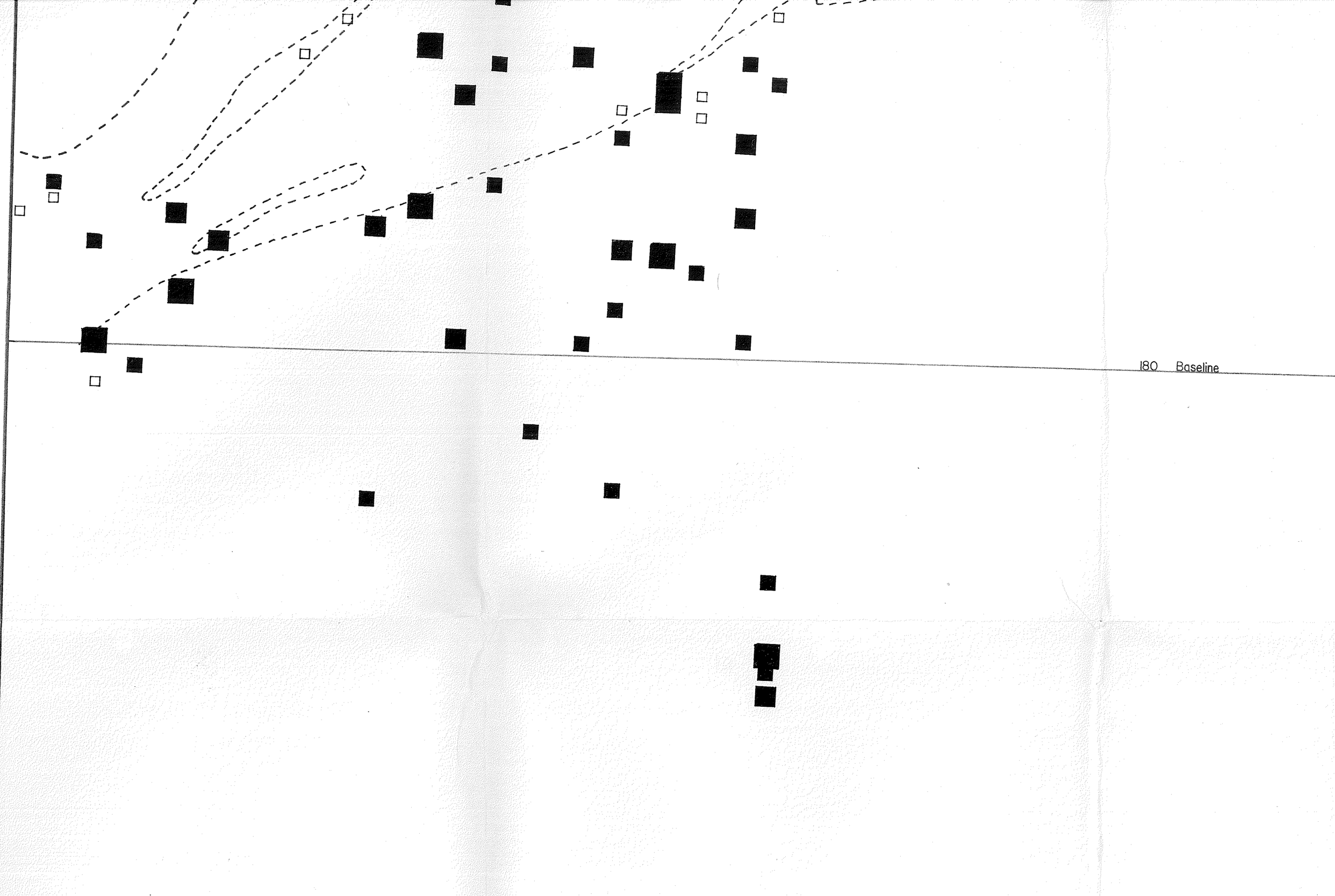
CU, ZN, S DISTRIBUTIONS (ppm)

COPPER		ZINC	
○	0 to 50	□	0 to 40
○	50 to 100	□	40 to 80
●	100 to 150	■	80 to 120
●	150 to 200	■	120 to 160
●	greater than 200	■	greater than 160

0 1000

200 400 m.

180 Baseline


180 Baseline

ZINC DISTRIBUTION.

CU, ZN, S DISTRIBUTIONS (ppm)

COPPER		ZINC		SULPHUR	
○	0 to 50	□	0 to 40	△	0 to 500
○	50 to 100	□	40 to 80	△	500 to 1000
●	100 to 150	■	80 to 120	▲	1000 to 1500
●	150 to 200	■	120 to 160	▲	1500 to 2000
●	greater than 200	■	greater than 160	▲	greater than 2000

N

0 1000 2000 feet

200 400 m.

180 Baseline

180 Baseline

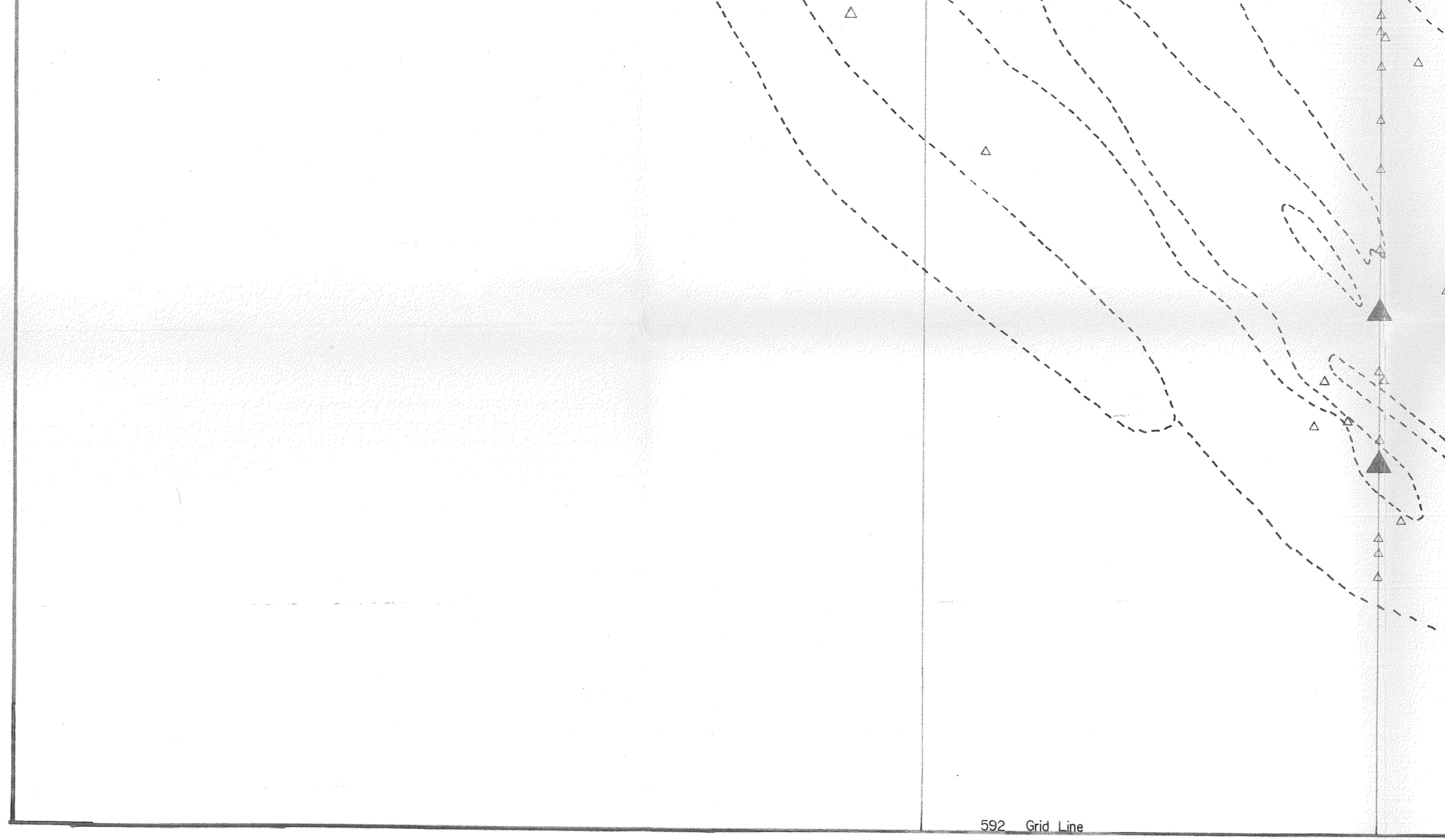
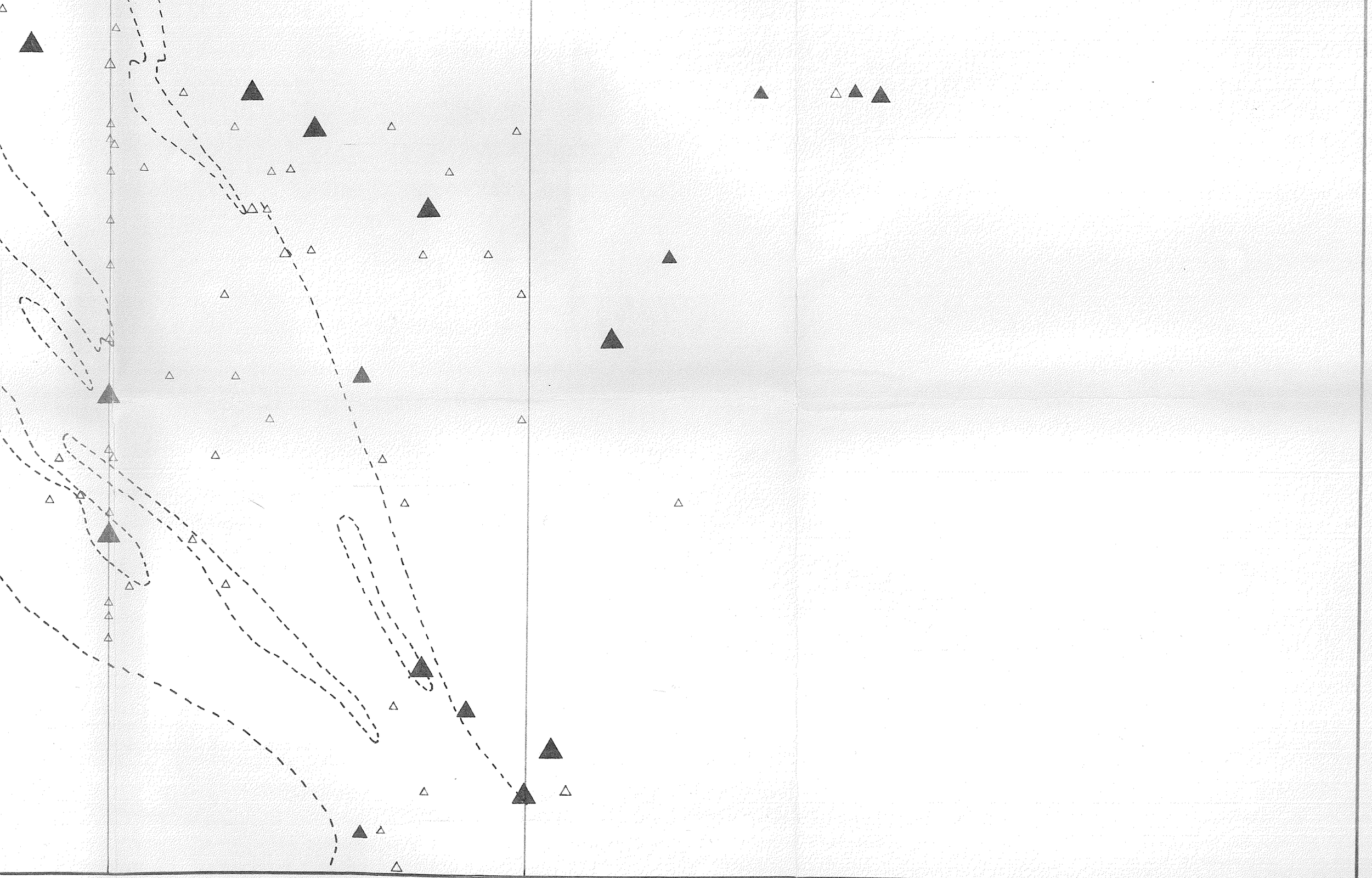
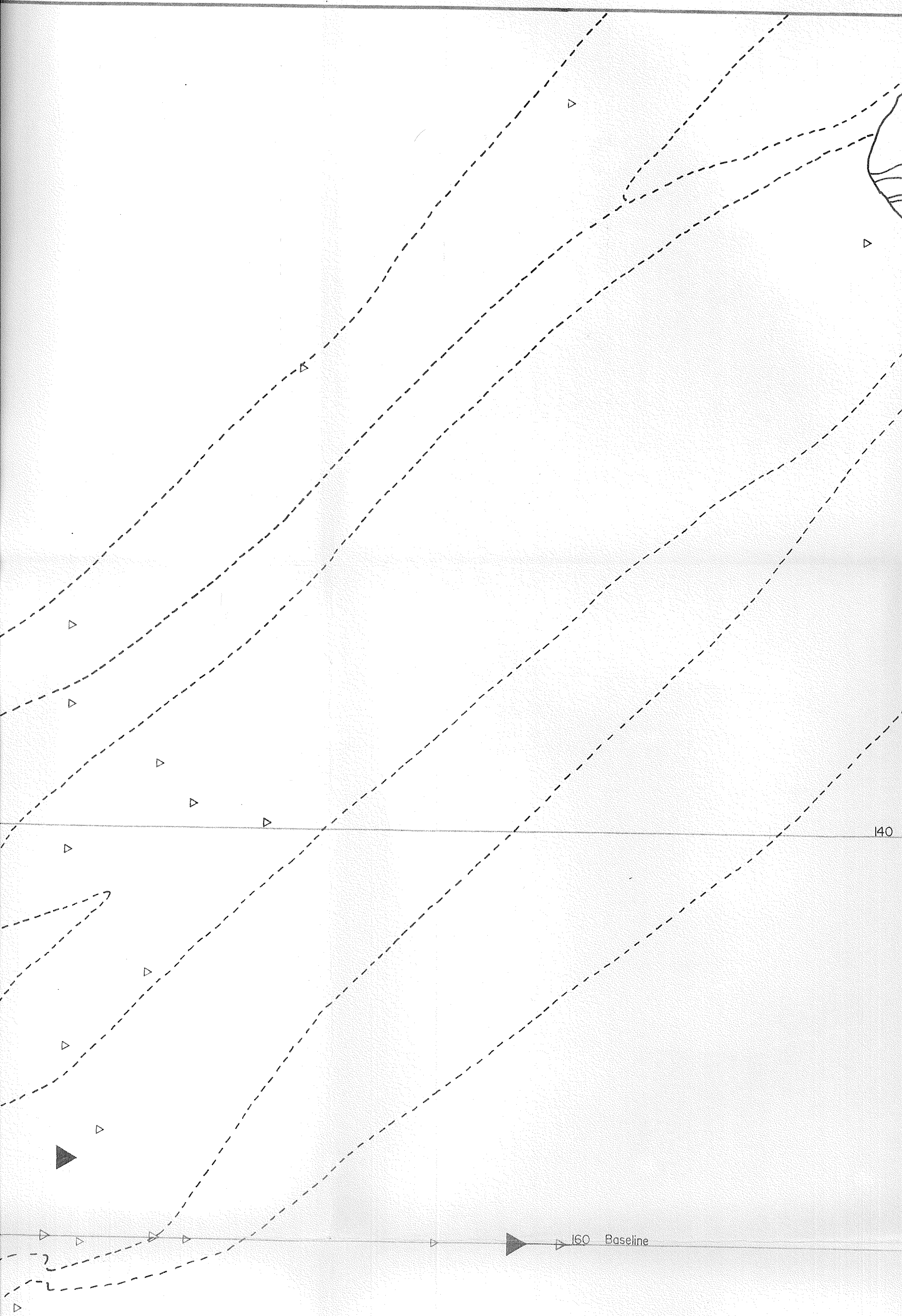


FIGURE 35- S DISTRIBUTION



S DISTRIBUTION


140
160 Baseline

N

0 1000 2000 feet

200 400 m.

160 Baseline

180 Baseline

FIGURE 35.
SULPHUR DISTRIBUTION.

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CU, ZN, S DISTRIBUTIONS (ppm)

COPPER	ZINC	SULPHUR
○ 0 to 50	□ 0 to 40	△ 0 to 500
○ 50 to 100	□ 40 to 80	△ 500 to 1000
● 100 to 150	■ 80 to 120	▲ 1000 to 1500
● 150 to 200	■ 120 to 160	▲ 1500 to 2000
● greater than 200	■ greater than 160	▲ greater than 2000

N

0 1000 2000 feet

200 400 m.

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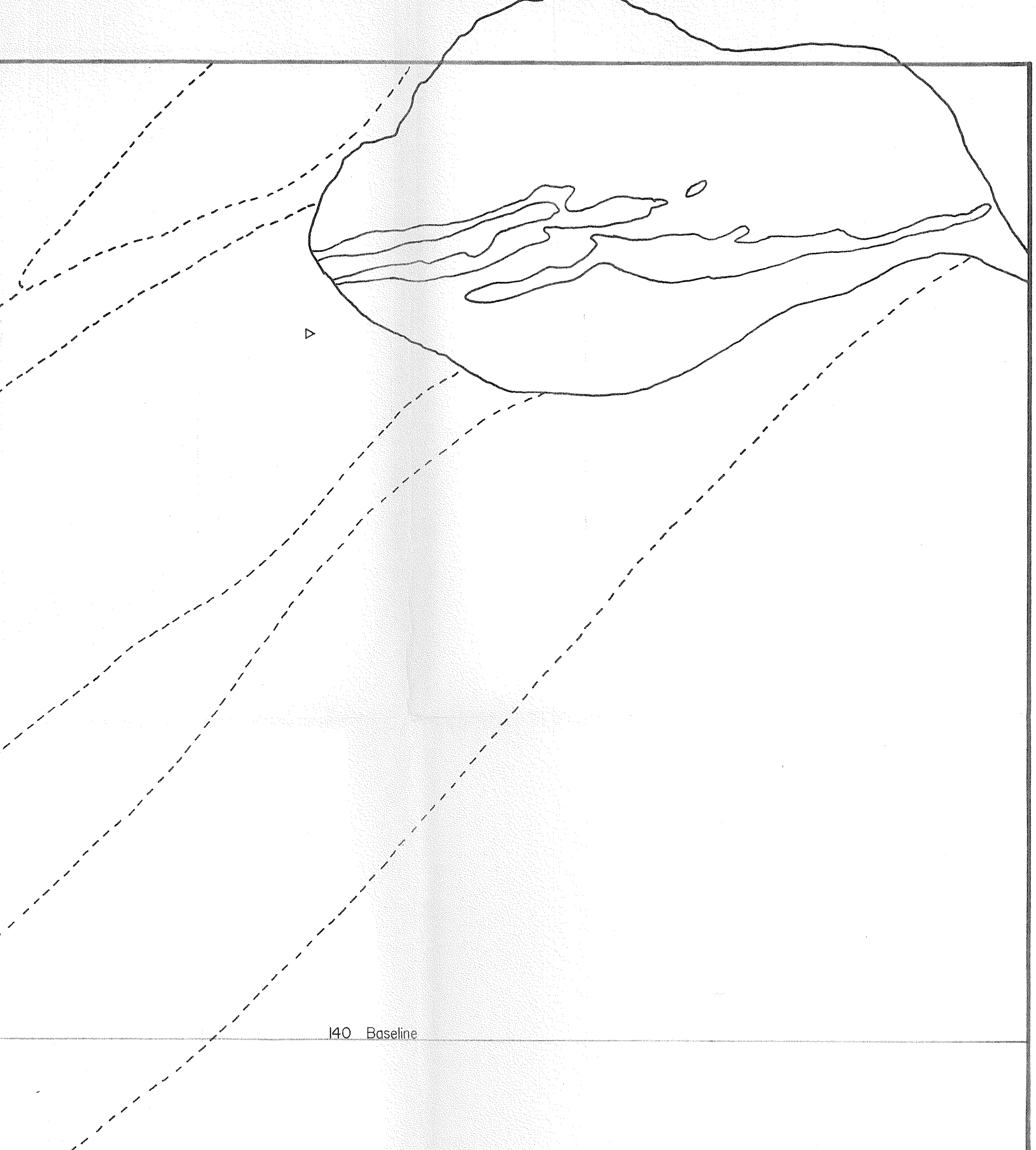
140 Baseline
Baseline

FIGURE 38.
Na/K DISTRIBUTION.

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LIBRARIES

Na/K.

- 0 to 0.5
- 0.5 to 1
- 1 to 2
- 2 to 3
- 3 to 4
- 5 and above

N

0 1000 2000 feet

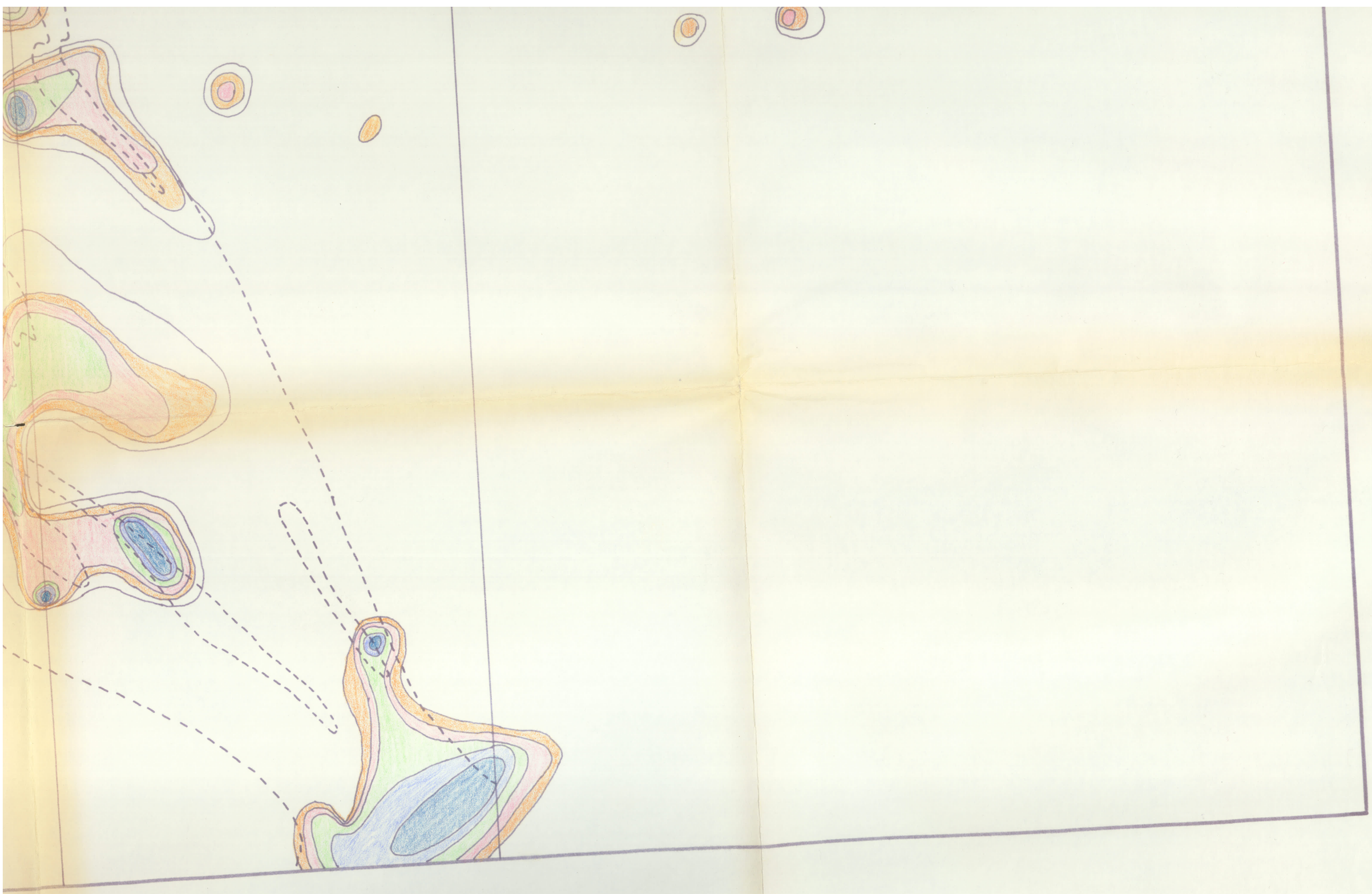
200 400 m.

140 Baseline

160 Baseline

180 Baseline

160 Baseline



/K DISTRIBUTION

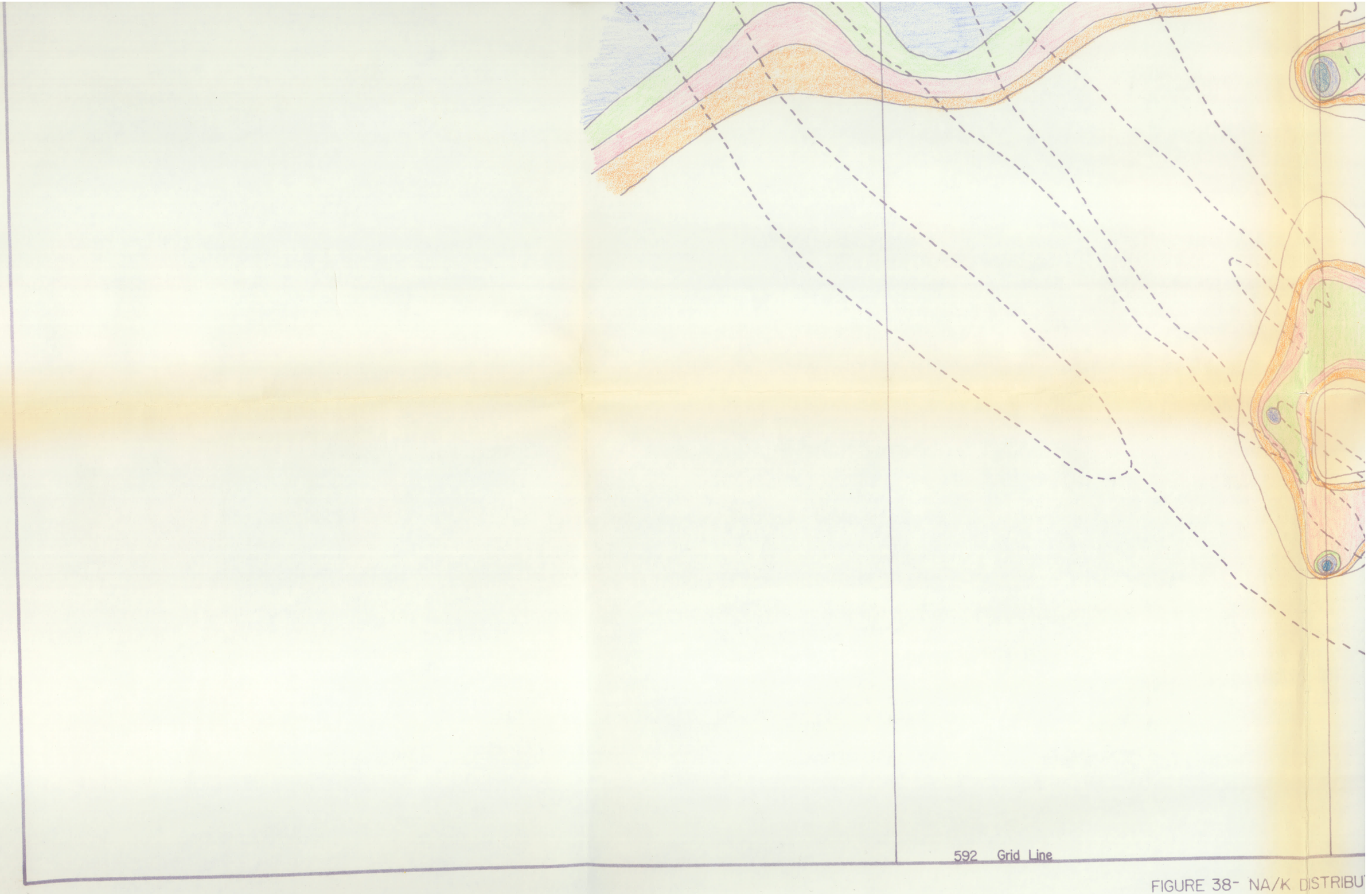


FIGURE 38- NA/K DISTRIBU

FIGURE 37.
SERICITE + CHLORITE DISTR.

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SERICITE + CHLORITE DISTRIBUTION (%)

- 0 to 5
- 5 to 10
- 10 to 15
- 15 to 20
- 20 to 25
- greater than 25

N

0 1000 2000 feet

200 400 m.

140 Baseline

160 Baseline

180 Baseline

160 Baseline

RICITE + CHLORITE DISTRIBUTION

592 Grid Line

FIGURE 37- SERICITE + CHL

FIGURE 36.
SULPHIDE DISTRIBUTION.

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OF MANITOBA
LIBRARIES

SULPHIDE DISTRIBUTION (%)

- 0 to 5
- 5 to 10
- 10 to 15
- 15 to 20
- 20 to 25
- greater than 25

N

0 1000 2000 feet

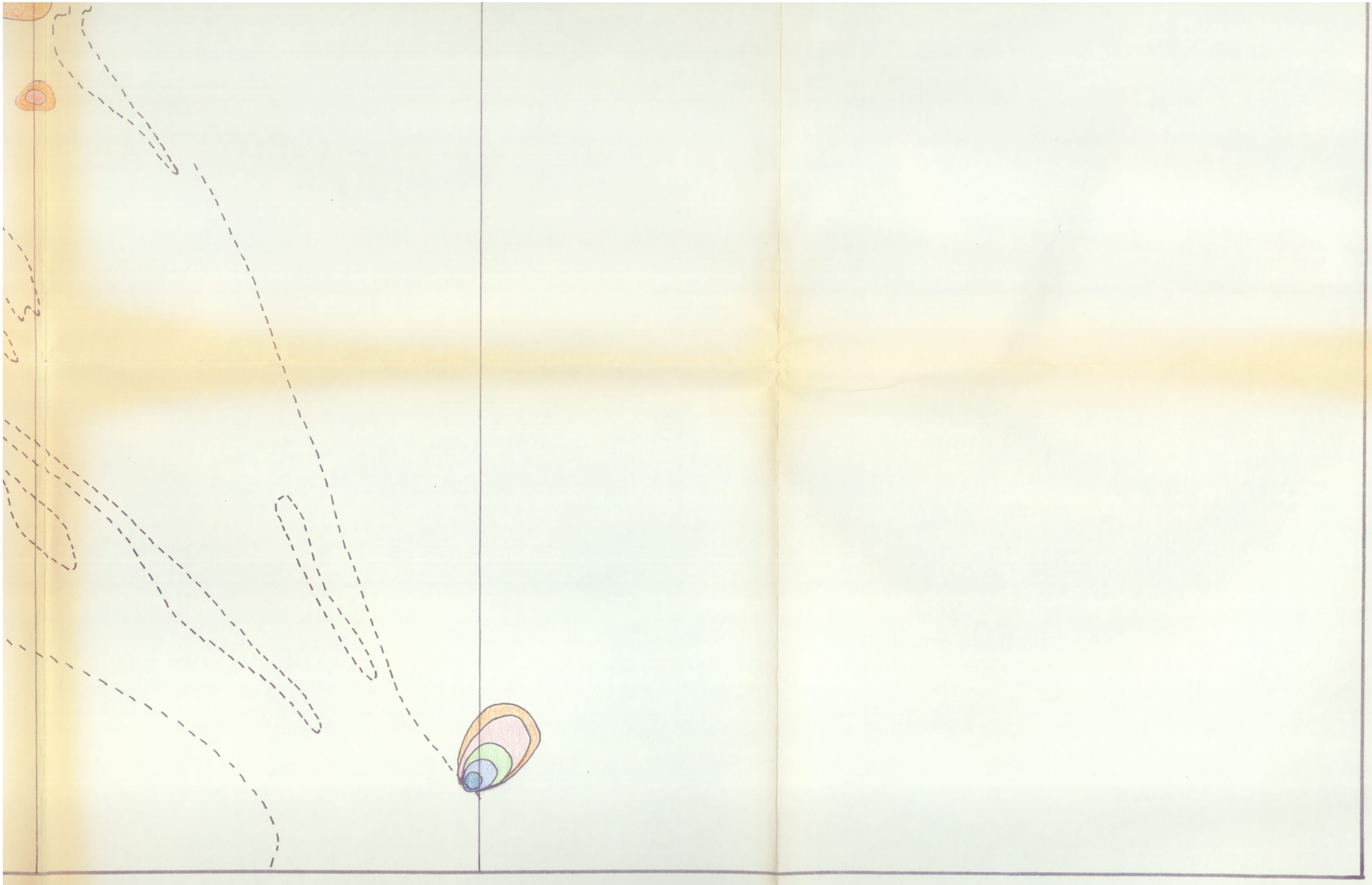
200 400 m.

140 Baseline

160 Baseline

180 Baseline

160 Baseline



E DISTRIBUTION

59.2 Grid Line

FIGURE 36- SULPHIDE DISTRIBUTIO

FIGURE 18.
GROUND MAGNETIC MAP.

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GAMMAS

- 0 to 500
- 500 to 1000
- 1000 to 3000
- 3000 to 5000
- 5000 to 7000
- 7000 and above

N

0 1000 2000 feet

200 400 m.

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2700

2900

2500

3150

6350

2020

6400

5800

2550

140 Baseline

3670

160 Baseline

180 Baseline

2630

2210

2085

2230

2805

2430

9585

2400

5140

2840

2125

5360

3530

2855

2800

5160

4540

7860

2110

160 Baseline

2630

2210

2740

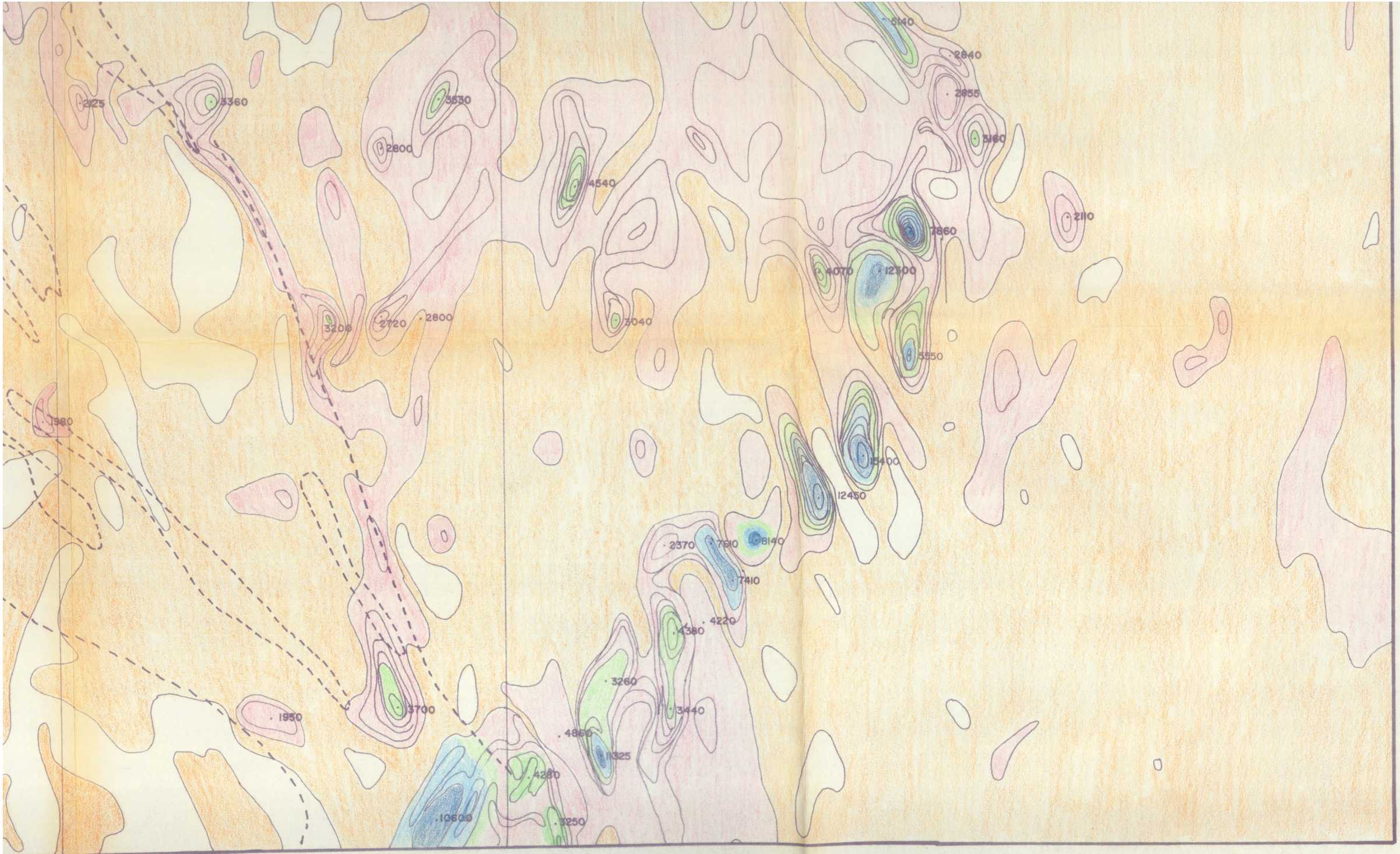
3085

2230

2805

2125

6260



UND MAGNETIC MAP

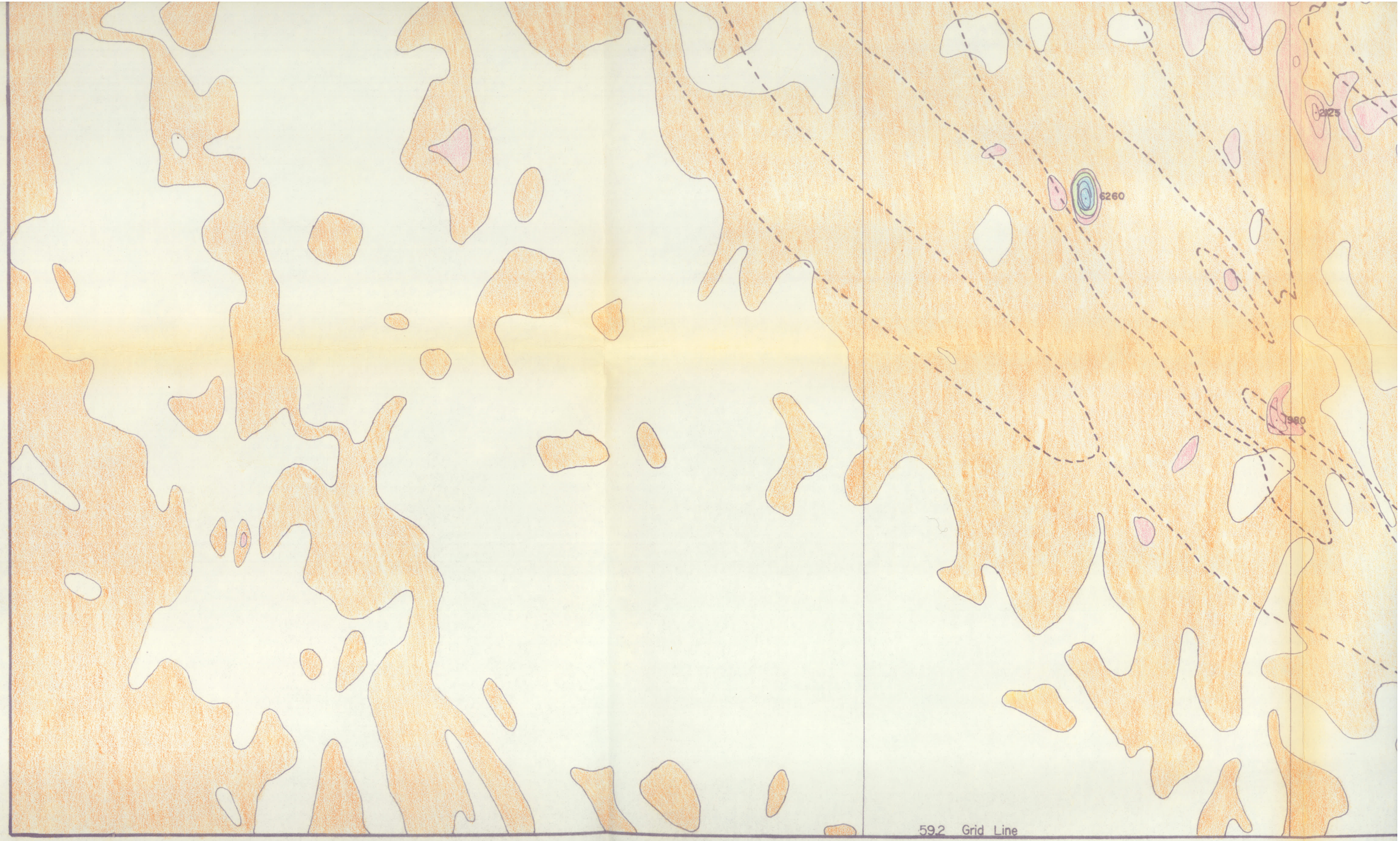


FIGURE 18- GROUND MAGNETIC MAP

FIGURE 2.
DETAILED GEOLOGICAL MAP.

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JACKSON, M.R.
(3)

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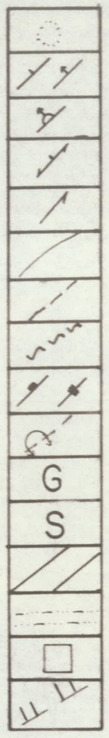
SYMBOLS



Area of Bedrock Outcrop
Bedding; top unknown, top from graded beds
Lava Flow; top from pillows shape and packing
Schistosity and Foliation
Lineation
Geological Boundary, observed
Geological Boundary, position interpreted
Fault, Shear zone
Jointing; inclined, vertical
Anticline, overturned
Gossan
Disseminated Sulphides
South Bay Road
Trail, Winter Road
Building
Power Line

SOURCES OF INFORMATION

Geology by M. Jackson and J. Chornoby, 1977
Geology tied to surveyed lines on Ruttan Mine grid
Drafting by M. Jackson
Magnetic Declination about 13° W

N

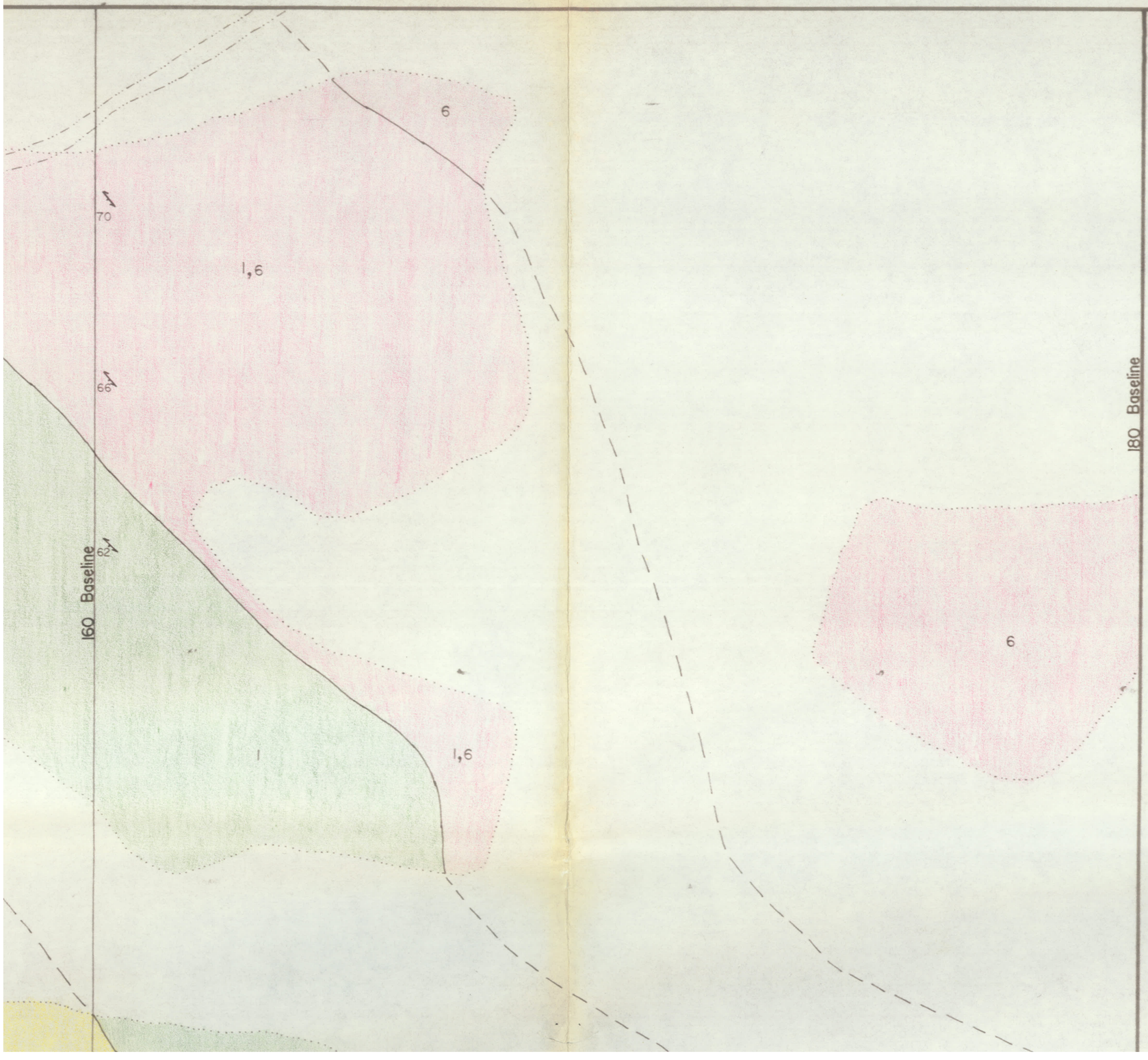
NTS

ntermediate composition
ate to mafic composition

Agglomerate

e
S

ff
l Agglomerate



LEGEND

PRECAMBRIAN

PROTEROZOIC (APHEBIAN)

GRANITIC BATHOLITH

6 — 6 Undifferentiated

INTRUSIVE CONTACT

DIORITE and GABBRO

5 — 5 Undifferentiated

INTRUSIVE CONTACT

VOLCANICLASTIC METASEDIMENTS

4 — 4 Undifferentiated

4a Sandstone and Siltstone; felsic to interm

4b Sandstone and Siltstone; intermediate to

4c Pebble and Cobble Conglomerate

4d Mixed Fragmental Breccia

FELSIC METAVOLCANICS

3 — 3 Undifferentiated

3a Felsic Flows

3b Tuff and fine grained Lapilli Tuff

3c Coarse grained Lapilli Tuff and Agglon

3d Flow Breccia

3e Quartz-Feldspar Porphyry Intrusive

INTERMEDIATE METAVOLCANICS

2 — 2 Undifferentiated

2a Intermediate Flows; amygdaloidal

2b Porphyritic Flows

2c Flow Breccia

2d Tuff and fine grained Lapilli Tuff

2e Coarse grained Lapilli Tuff and Agg

MAFIC METAVOLCANICS

1 — 1 Undifferentiated

140 Baseline

160 Baseline

70

66

62

79

85

74

3b,3c

140 Baseline

3b,3c

79

85

74

f and Agglomerate

0 500 1000 feet

100 200 m.

80 67 1,5,6

86 6 77 6

1,5,6

80

6

G

S G

1a,1b,5,6

1,5,6

71 65 85

1,5,6

G

71 80

S 1,5,6

1,5,6

2e Coarse grained Lapilli Tuff and Agglomerate

MAFIC METAVOLCANICS

I

I Undifferentiated

Ia Thick Mafic Flows

Ib Pillowed Flows

Ic Porphyritic Flows

Id Flow Breccia

Ie Tuff

3b,3c

2d,2e

3b

2d,2e

3b

2d,2e

3c,3d,3e

3b

2d

3b

2d,2e

2e

2d,2e

2d

1

1a,1c


3e
71
64
4a
4a
70
72
4a
4a
74
4a
3e
64
62
74
67
66
2d,2e
4a
70
4a,4d
63
73
79
70
69
69
69
76
82
80
64
64
62
76
82
88
66
3b,3c
62
78
88
64
66
65
2d
3c,3d,3e
3b

71 80 1,5,6 1,5,6 1,6 80 80 4b

G G G G

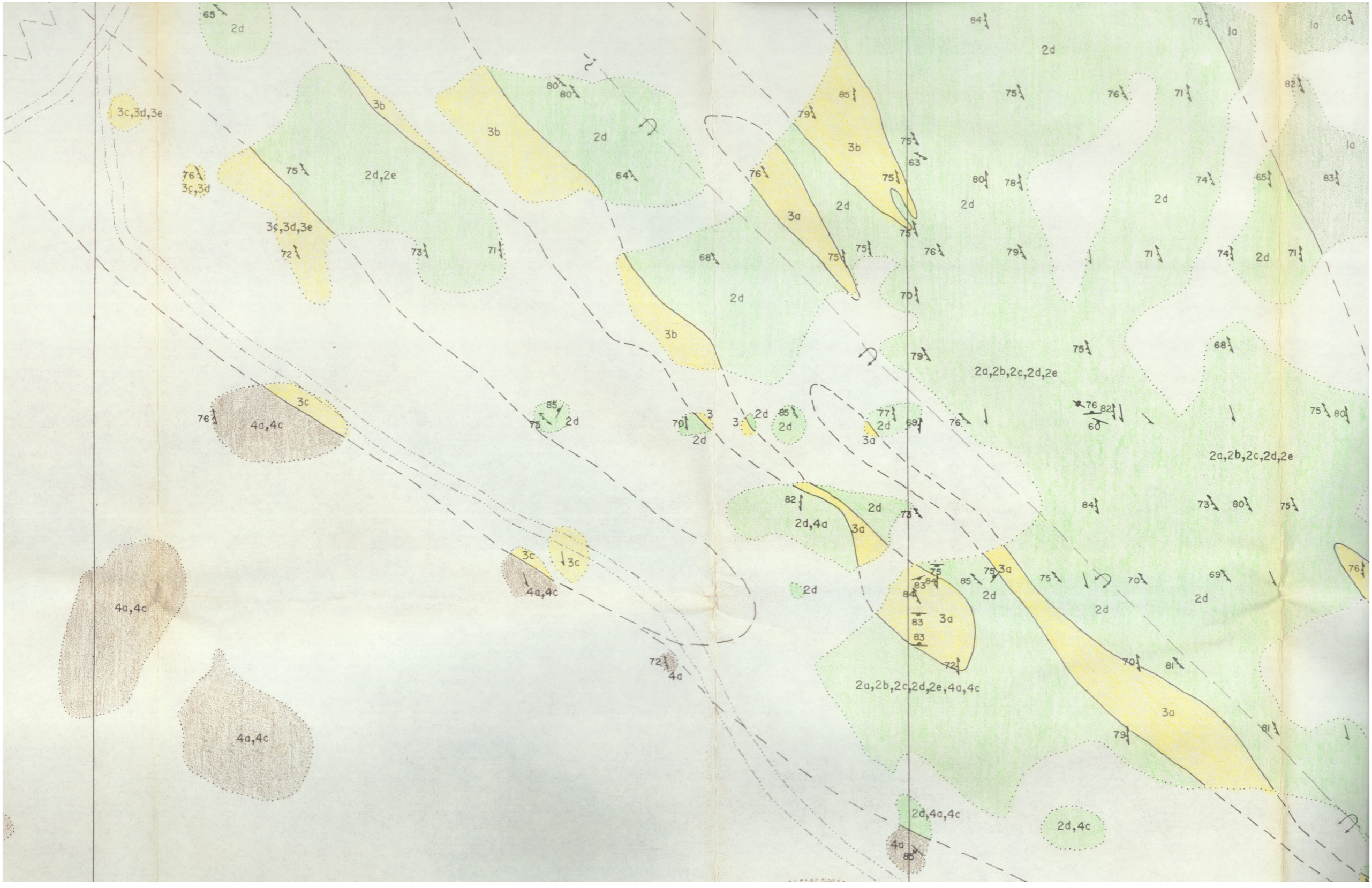
1a,1c G G 74 88 4b 70 4b G 84 4b

G 80 4b 67 4b 82 65 74 4b

82 70 71 82 68 4b,4c 83 4b

G 76 1c 70 80


2a,2b,2c,2d,2e
2d
3a
4a
4a,4c
2d,4c
2e,4a,4c
1a
1a,1c
1a,1b,1c
G
S
4b
1c


65
2d
3c,3d,3e
3b
80
80
2d
3b
64
76
3c,3d
75
2d,2e
3c,3d,3e
72
73
71
68
2d
3b
85
79
3b
75
63
76
3a
2d
75
75
75
76
79
71
74
2d
71
70
79
2a,2b,2c,2d,2e
75
68
84
76
1a
1a
60
2d
75
76
71
82
1a
80
78
74
65
83
2d
2d
76
82
60
75
80
3c
76
4a,4c
85
75
2d
79
3
2d
3
2d
85
2d
77
2d
69
3a
76
2a,2b,2c,2d,2e
84
73
80
75
82
2d
2d,4a
3a
73
3c
3c
4a,4c
75
85
75
3a
2d
84
83
84
83
3a
83
72
2d
70
81
2a,2b,2c,2d,2e,4a,c
3a
79
81
4a,4c
4a,4c
72
4a
2d,4a,4c
4a
85
2d,4c


73
79
70
4a
71
4d
72
74
74
84
81
80
70
5
72
4a
73
70
4d
5
4a
75
82
75
4a
75
4a,5
5
68
84
5
78
83
85
74
77
4a,4c
83
76
4a,4c
82
85
65
2d
3c,3d,3e
3b
76
3c,3d
75
2d,2e
3c,3d,3e
72
73
3c
76
4a,4c
4a,4c
70
4a
4a
4a,4c
4a,4c


G
Ia,Ic
G
G
74
88
4b
70
4b
G
84
4b
G
80
4b
67
82
4b
65
74
4b
82
70
71
82
68
4b,4c
G
76
Ic
80
70
83
4b
78
84
4b
Ic
Ic,4b
4b
Ib
80
74
4b
Ib
79
Ic

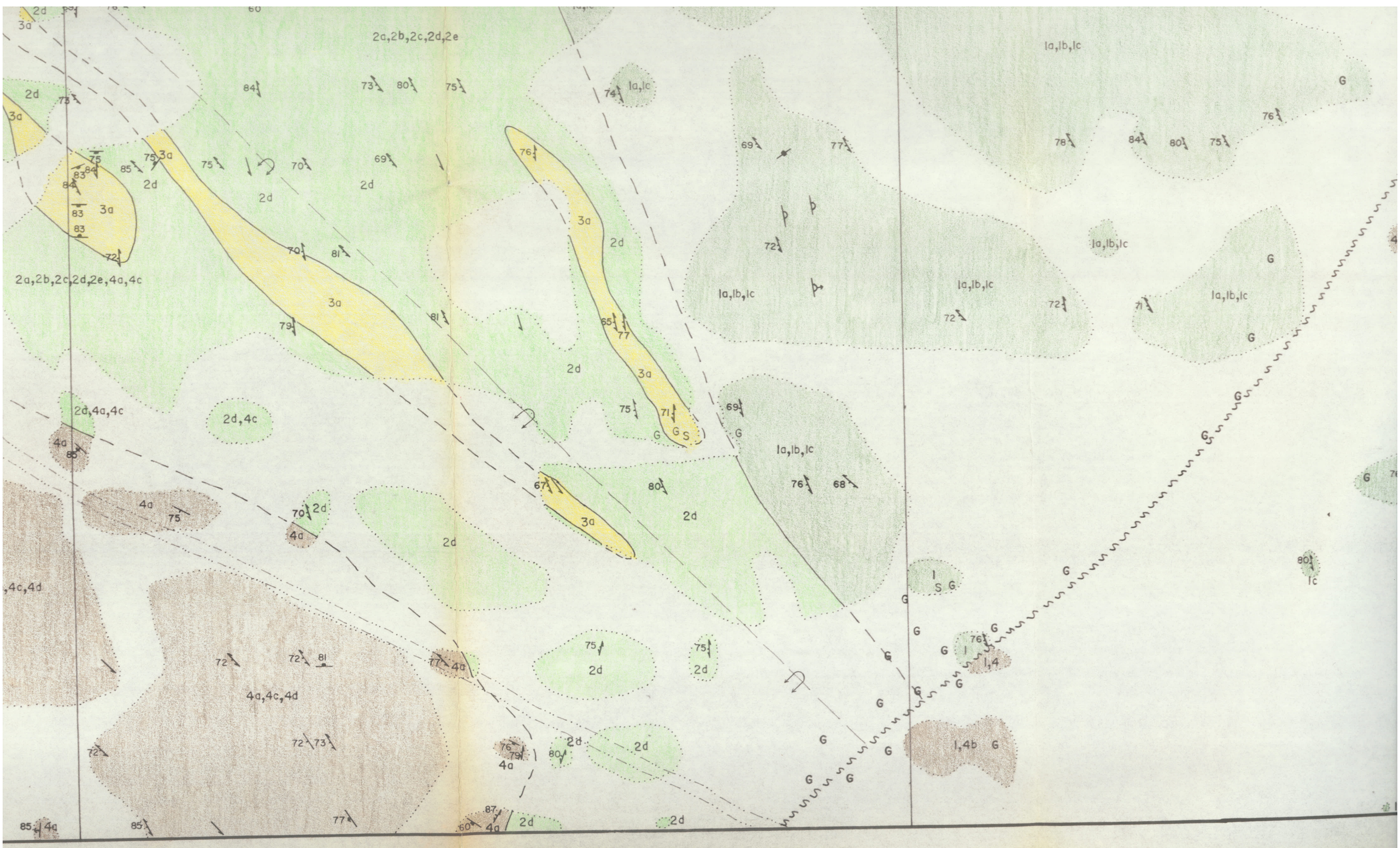
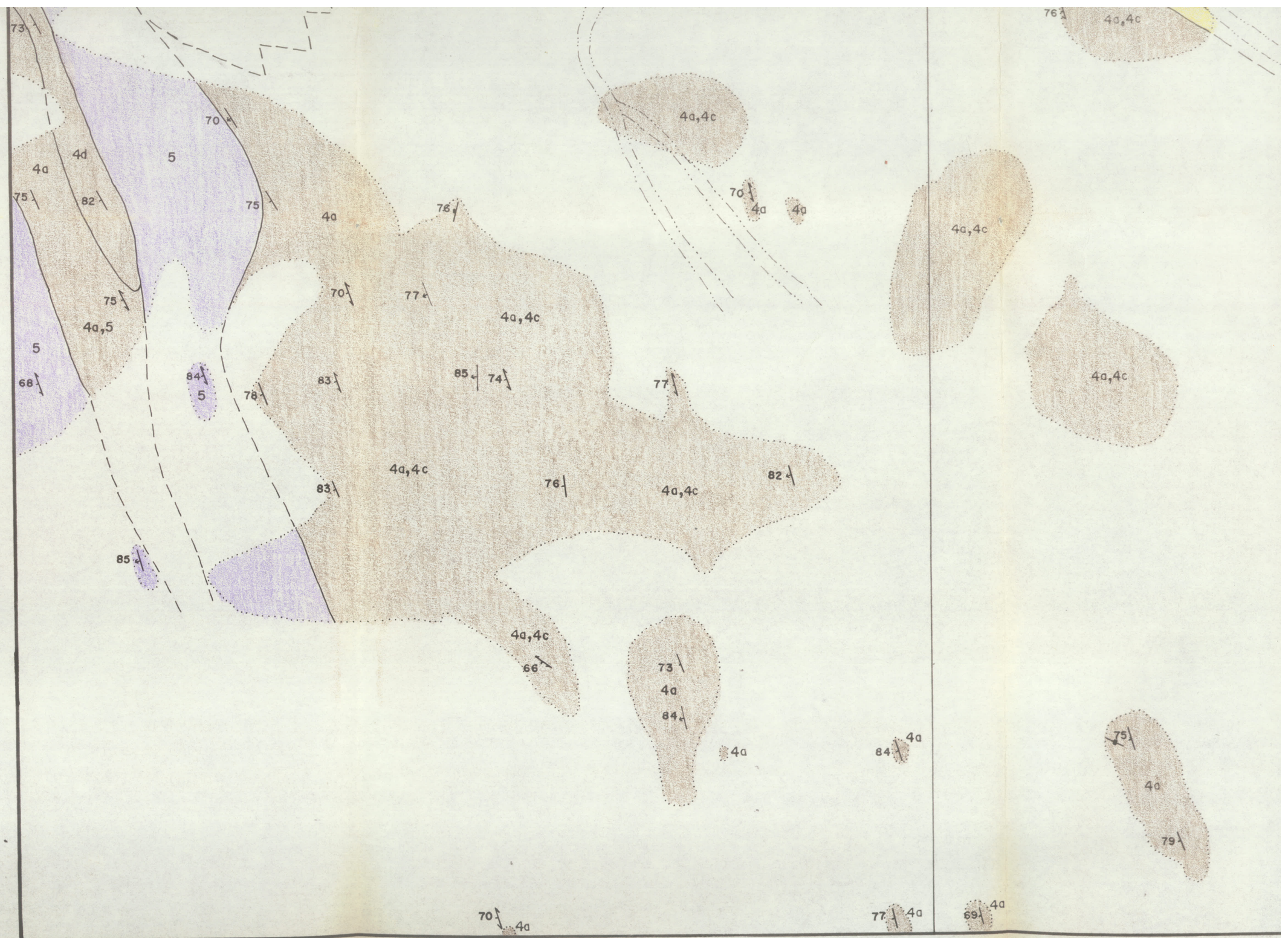


FIGURE 2- DETAILED GEOLOGICAL MAP


2a,2b,2c,2d,2e
2d
2d,4a
3a
2d,4a,4c
2d,4c
4a,4c
4a
3c
2a,2b,2c,2d,2e,4a,4c
4a,4c,4d
4a,4c,4d
4a,4c,4d
4a
2d
4a
4a
4a


73
70
4d
4a
5
75
82
75
4a
76
4a,4c
70
4a
4a
4a,4c
75
70
77
4a,5
4a,4c
5
68
84
5
78
83
85
74
77
4a,4c
83
76
4a,4c
82
85
4a,4c
66
73
4a
84
4a
84
4a
75
4a
79
70
4a
77
4a
69
4a