THE ENVIRONMENT OF DEPOSITION OF THE BOOSTER LAKE CONGLOMERATE AND GREYWACKE

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By

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ABSTRACT

The Booster Lake area forms part of a greenstone belt of deformed and metamorphosed volcanic and sedimentary rocks in the Superior Province of the Precambrian shield, at Bird Lake, southeastern Manitoba, Canada. A sequence of volcanogenic epiclastic sedimentary rocks, consisting of a cobble to coarse pebble, polymictic, extraformational orthoconglomerate, interbedded with massive feldspathic and pebbly greywacke rocks, forms the eastern part of this belt.

This conglomerate and greywacke mark the initiation of major uplift and tectonic activity in the Bird River greenstone belt. The provenance for the clasts in the conglomerate is a volcanic-subvolcanic complex within the greenstone belt. Minor clastic material may have been derived from other volcanic and sedimentary rocks in the belt, but the plutons which border the belt do not appear to have contributed detrital fragments.

Primarily on the basis of geometry, stratigraphy and sedimentary structures, the environment of deposition is proposed to be that of a near-shore subaqueous fan of resedimented conglomerate and greywacke. Clastic material, apparently derived from the volcanic-subvolcanic complex of Bernic Lake and transported by fluvial systems, was initially accumulated on a narrow shelf in a littoral to neritic zone. After further rounding and sorting, orogenic activity or rapid influxes of sediment remobilized this sediment. The gravel and sand (lithified equivalents being the conglomerate and greywacke) were transported

by subaqueous sedimentary gravity flow mechanisms into a near shore-marine transitional environment of a submarine fan by way of feeder channels and upper fan channels.

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INTRODUCTION

1) Introductory Comment on the Scope and Results of the Study

The Booster Lake conglomerate lies in the eastern portion of the Bird River greenstone belt, as shown in Figure 1. It is interbedded with greywacke and pebbly greywacke and these sedimentary rocks are important in the interpretation of the orogenic development of the belt. Study of the structures and sedimentary petrography of this conglomerate has demonstrated the provenance of the clasts to be the volcanic-subvolcanic complex of the Bernic Lake area. Minor contributions of detritus may have come from the mafic and felsic volcanic rocks and volcanogenic sedimentary rocks of the Bird River greenstone belt, but not from the adjacent granitic plutons.

The depositional environment that is proposed, as evidenced by the diversity of clast concentrations, sedimentary textures and internal organizations, is that of near-shore subaqueous fan of a resedimented conglomerate. From the sequence of uplift, successive unroofing and exposure of different source materials of the Bernic Lake volcanic-subvolcanic complex, a provenance can be inferred on the basis of concentrations of petrographic types in the conglomerate. After reworking of the gravel, final deposition of the conglomerate occurred in the feeder and upper channels of a submarine fan. Transportation into this near shore-marine transitional environment was by processes of subaqueous sedimentary gravity flow mechanisms such as debris and grain flows.

"Greywacke" is used in the text as a purely petrographic term for a biotite schist, that can be interpreted in the field

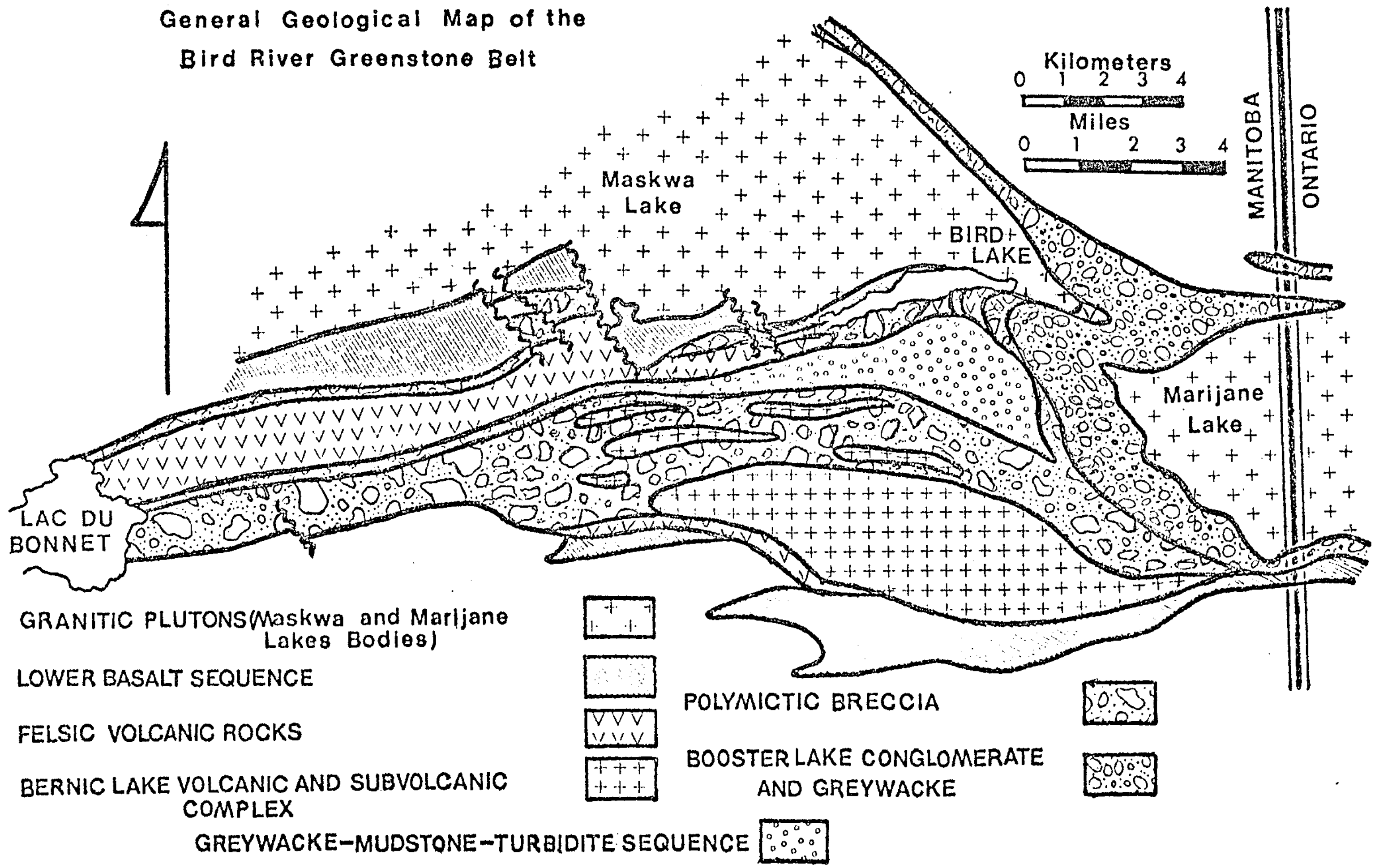

FIGURE 1 - GENERAL DISTRIBUTION OF LITHOLOGICAL UNITS OF THE BIRD RIVER GREENSTONE BELT (AFTER TRUEMAN, 1976).

as a metasediment that was derived from a high-matrix volcanogenic sandstone. Minor original clastic material was recognizable, but recrystallization was extensive and thus concise classification was impossible. The presence of metamorphic biotite or hornblende was used to distinguish two types of greywacke (based on the dominant mafic mineral), presumably of differing original bulk rock chemical compositions.

2) Present Geological Investigations

Detailed geological field mapping was carried out in an area east of Bird Lake, between Booster, Starr and Davidson Lakes, approximately 130 miles (210 km) northeast of Winnipeg, Manitoba as shown in Map 1.

To establish a suitable provenance the following methods were used: megascopic modal point counts of clast types; determination of the clast to matrix ratio; lateral and vertical variations in clast concentrations; and regional plots of the dimensions in outcrop of the maximum Y axes (ellipsoidal strain axes: $X<Y<Z$). Microscopic modal point counts and distinctive mineralogies were also used for making correlations of petrographic types.

Sedimentary structures, internal sedimentary organizations and variations in clast concentrations were used to propose a depositional environment and transportational mechanism for the conglomerate and greywacke.

To examine the polydeformational events, structural data were collected in the field, i.e. foliations, top directions (cross and graded bedding), surface axial planar traces, lin-

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eations and the plunge and trend of fold axes. To qualitatively determine the type of strain that affected the conglomerate, ellipsoidal strain axes ratios were measured. Few outcrops were amenable to measurement of all three ellipsoidal strain axes and thus the range of the minimum to intermediate (X:Y) axes ratios were determined by using the "down plunge" method.

3) Previous Geological Investigations

The Bird River area has been the target of geological mapping and mineral exploration since 1912, when E. S. Moore carried out a reconnaissance survey along the main water routes in the Cat Lake-Winnipeg River areas for the Geological Survey of Canada. In 1920, H. C. Cooke mapped the Rice Lake and Bird River areas specifically examining the base metal sulphide occurrences. During 1922-1929, J. F. Wright mapped the area for the Geological Survey of Canada, and found occurrences of base metals and rare-earth pegmatites. G. M. Brownell and J. D. Bateman investigated chromite deposits northwest of Bird Lake in 1943. G. D. Springer mapped the area from Cat Lake to the Winnipeg River for the Manitoba Mines Branch in 1948 and 1949. J. F. Davies mapped the Bird Lake and Booster Lake areas for the Manitoba Mines Branch during the field seasons of 1951, 1954 and 1955.

K. Dwibedi (1965) described specimens from the Bird River greenstone belt for his Ph. D. thesis on the petrography of the English River gneissic belt. The character of metamorphism that affected the greenstone belt was the topic of a M. Sc. thesis by S. B. Butrenchuk (1970). W. D. McRitchie (1971) reported on the granitic rocks of southeastern Manitoba. D. L. Trueman (1976) has examined in detail the geology of the Bird River greenstone belt for a Ph. D. thesis.

An incomplete list of literature that has dealt with investigations of Archean conglomerates in the Canadian Shield are as follows: Campbell, (1971); Donaldson and Jackson, (1965); McLimans, (1972); Mukherjee, (1971); Ojakangas, (1972); Pettijohn, (1943, 1957, 1975); Pettijohn and Walker, (1971); Stauffer, (1974); and Turner and Walker (1973).

REGIONAL GEOLOGY OF THE BIRD RIVER GREENSTONE BELT

A detailed discussion of the geology of the Bird River greenstone belt is the topic of a Ph. D. thesis by Trueman (1976). A brief lithological description of the rock units and geological history of the Bird River greenstone belt follows.

Archean metamorphosed volcanic and sedimentary rocks occupy a greenstone belt that trends east-west in southeastern Manitoba, near the Manitoba-Ontario Interprovincial boundary as shown in Figure 1. Granitic plutons flank the belt, and several mafic to felsic stocks and plutons intrude the volcanic and sedimentary pile. With increasing metamorphic grade to the east, the volcanic and sedimentary rocks change gradually into gneisses and schists of the English River gneissic belt in Northwestern Ontario.

The Maskwa Lake and Marijane Lake plutons (Figure 1) are adjacent to the Bird River greenstone belt. The Maskwa Lake pluton is composed of several compositional phases that range from quartz monzonite to quartz diorite. The Marijane Lake pluton is quartz monzonite in composition. There are clasts in the conglomerate of tonalitic composition, but none of the clasts fall within the range from quartz monzonite to quartz diorite, which would match these plutons. Therefore, these plutons were not exposed as a source region, for the Booster Lake conglomerate.

The Lower Basalt sequence (Figure 1) consists of pillowed basalts, porphyritic flow basalts, hyaloclastic breccias, tuffs, and amygdaloidal flow basalts, (Trueman, 1976). This

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sequence is cut by several stocks and sills of gabbro. At the top of the sequence is the Bird River Sill, a differentiated chromite-bearing layered sill of ultramafics, gabbros, anorthosites and granophyres. No Bird River Sill detritus has been recognized as clasts in the Booster Lake conglomerate, though the Lower Basalts may have been the source for mafic schist clasts.

The overlying 'rhyolitic' felsic volcanic rocks (see Fig. 1) occur as breccias, tuff, flow-banded rhyolites and quartz porphyry. Interbedded in this unit is minor oxide facies iron formation. This unit does not appear to be a major contributor of fragments as the felsic volcanogenic clasts in the Booster Lake conglomerate are either volcanic sandstone or shallow intrusive porphyritic quartz-feldspar clasts. The source volcanic center for the Lower Basalt and rhyolitic volcanism is situated somewhere northwest of Bird Lake (D. L. Trueman, pers. comm. , 1976).

The volcanic-subvolcanic complex near Bernic Lake is a volcanic pile consisting of several elongate mafic-to-felsic intrusive bodies. These range in composition from gabbro, meladiorite, leucodiorite, quartz-diorite, tonalite to quartz-feldspar porphyry. The mafic intrusions are characterized by moderate quartz content and slate-grey to blue pleochroic, poikiloblastic tourmaline. The felsic intrusions grade from quartz diorite and tonalite, to shallow intrusive porphyritic quartz-feldspar rocks.

A polymictic breccia occurs in the volcanic pile of the greenstone belt west of the Booster Lake conglomerate, as shown

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in Figure 1. It lies above the Lower Basalt and felsic volcanic rocks, and the Bernic Lake volcanic-subvolcanic complex, and it contains detritus from these rocks plus detrital chromite of the Bird River Sill (D. L. Trueman, pers. comm., 1976). It is associated with andesitic flows.

The Booster Lake conglomerate and greywacke are exposed only in the eastern part of the Bird River greenstone belt, approximately 15 miles (24 km) northeast of the source volcanic-subvolcanic complex at Bernic Lake. The conglomerate and greywacke occupy an area of over 120 square miles (310 sq. km); the distribution of these two epiclastic units are illustrated in Figure 1 and Map 2.

Uplift and faulting of the volcanic pile produced clastic material for the Booster Lake conglomerate and greywacke from the Bernic Lake volcanic-subvolcanic complex and the Bird River greenstone belt. The cobble to coarse pebble conglomerate and feldspathic greywacke were deposited disconformably on the underlying felsic volcanic and volcanogenic sedimentary rocks.

The youngest lithological unit of the Bird River greenstone belt (Figure 1) is a greywacke-mudstone turbidite sequence which was deposited unconformably over the underlying rocks. This unit displays both normal and inverse graded bedding, as well as load casts and flame structures. It also contains abundant cordierite and garnet, and sulphide facies iron formation has been locally recognized.

The conglomerate and greywacke have been affected by superimposed deformations (see: Structural Geology). Interpretation of the type of folding that has affected these clastic rocks has been based on the distribution of the units, clast elongations and orientations. A north-trending D_1 synformal axis passes through the upper greywacke bed (see: Geometry of the Sedimentary Units and Generalized Section) as shown in Map 3. Several east-west trending D_2 axes can be delineated since this second deformational episode has refolded the earlier D_1 synformal fold axis (Map 3). The result of the refolding is a tight similar fold that is overturned to the north, moderately plunging to the southeast with steeply inclined axial planes.

From structural data and top indicators (graded bedding and cross bedding) it is possible to determine stratigraphic tops. Proximal and transitional facies of environment could be interpreted from the information based on: maximum clast sizes, lateral variation in clast concentrations, clast to matrix ratios, sedimentary structures, and internal organizations. The proximal facies is characterized by high clast to matrix ratios (88 - 95% clasts), poor sorting, massive to poor bedding, normal and reverse grading, internal disorganization of bedding, large clast sizes, and thus it is thought to have been deposited nearest the source area in the higher parts, or feeder channels, of a submarine fan. The transitional facies has relatively lower clast to matrix ratios (44 - 68% clasts), moderate sorting, normal graded beds, conglomerate interbedded with cross-stratified greywacke and smaller clast sizes. The transitional facies represents the sediments deposited in the upper parts of the submarine fan, but further downslope than the proximal facies. A distal facies, presumably represented by fine grained, well bedded sedimentary rocks of a 'turbidite' association that was deposited further into the sedimentary basin, was not identified. The above descriptive terms are illustrated in Figure 2.

From the detailed mapping of exposures outlined in Figure 2, it was possible to produce a generalized section of the conglomerate and greywacke succession at Booster Lake. This section is illustrated in Figure 3, and is described in detail later in the text (see: Geometry of the Sedimentary Units and Generalized Section).

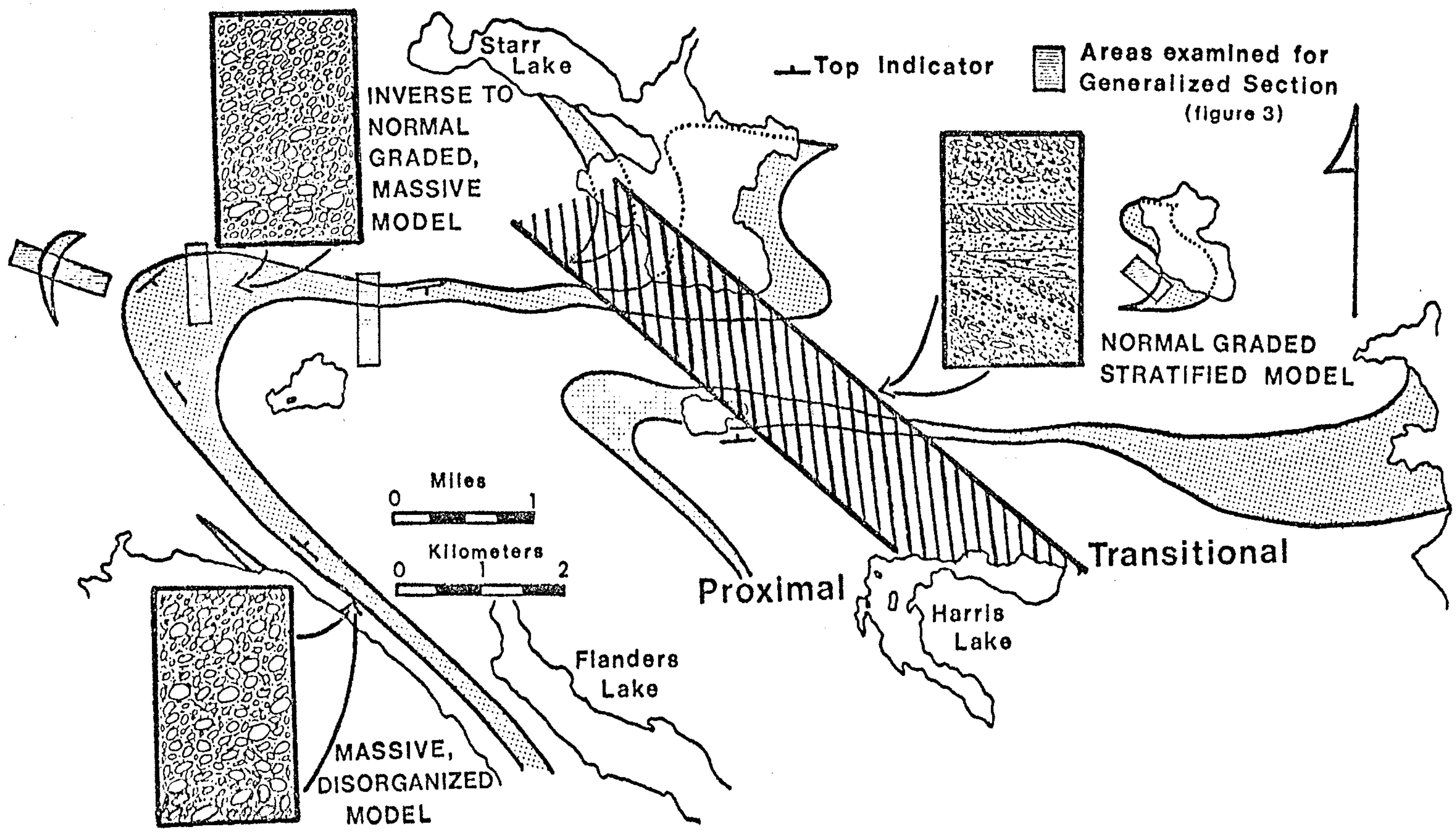

FIGURE 2a - DIAGRAM ILLUSTRATING THE INTERPRETATIVE GRADATIONAL BOUNDARY BETWEEN PROXIMAL AND TRANSITIONAL FACIES OF ENVIRONMENT, TOP INDICATORS (CROSS AND GRADED BEDS) AND INTERNAL ORGANIZATIONS (FACIES MODELS AFTER WALKER, 1975, 1976) ALONG THE LATERAL EXTENT OF THE CONGLOMERATE. ALSO AREAS EXAMINED FOR THE GENERALIZED STRATIGRAPHIC SECTION OF FIGURE 3 ARE SHOWN.

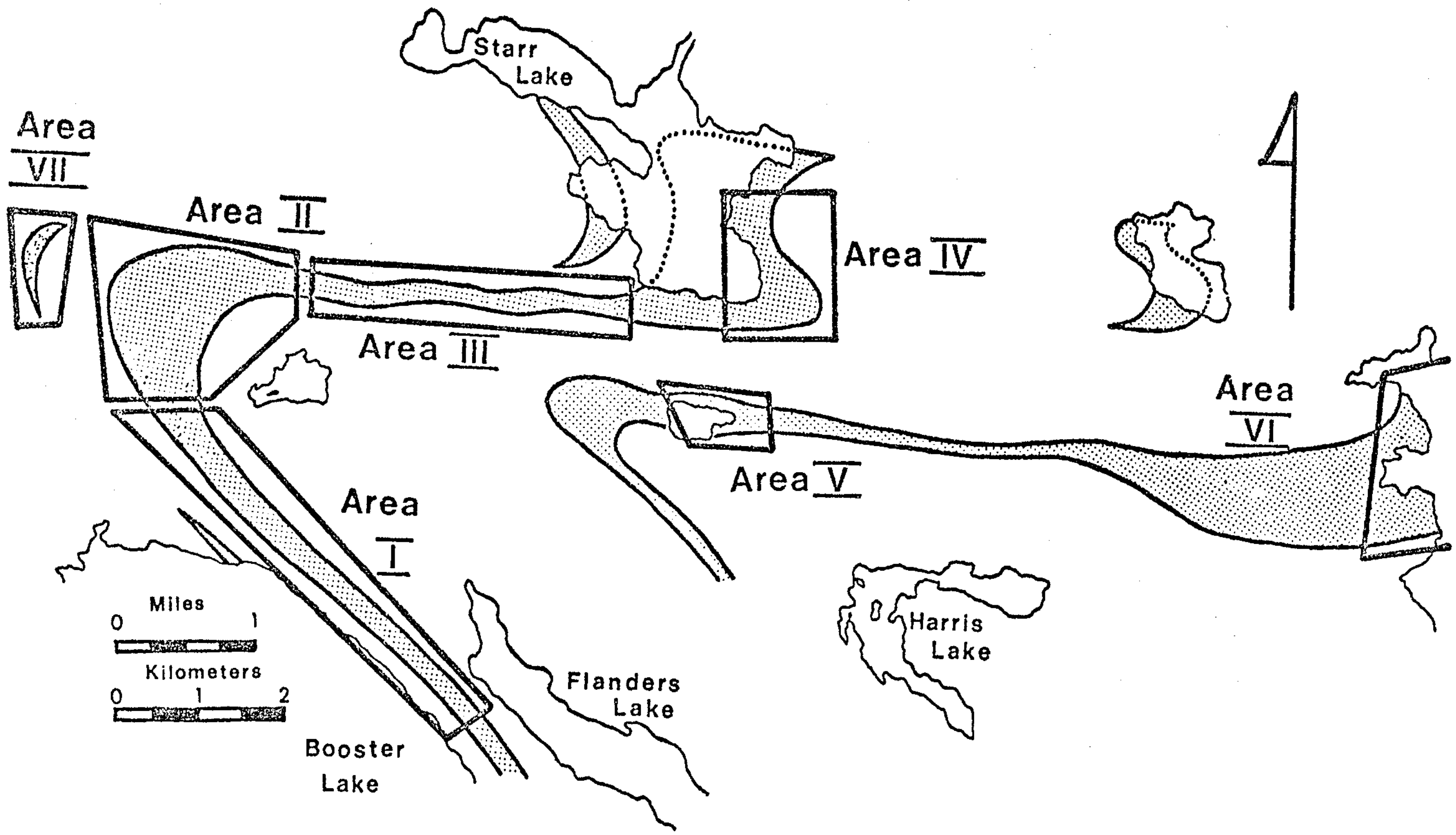

FIGURE 2b - THE 7 DEFINED AREAS OF DISTINCTIVE CLAST CONCENTRATION VARIATIONS.

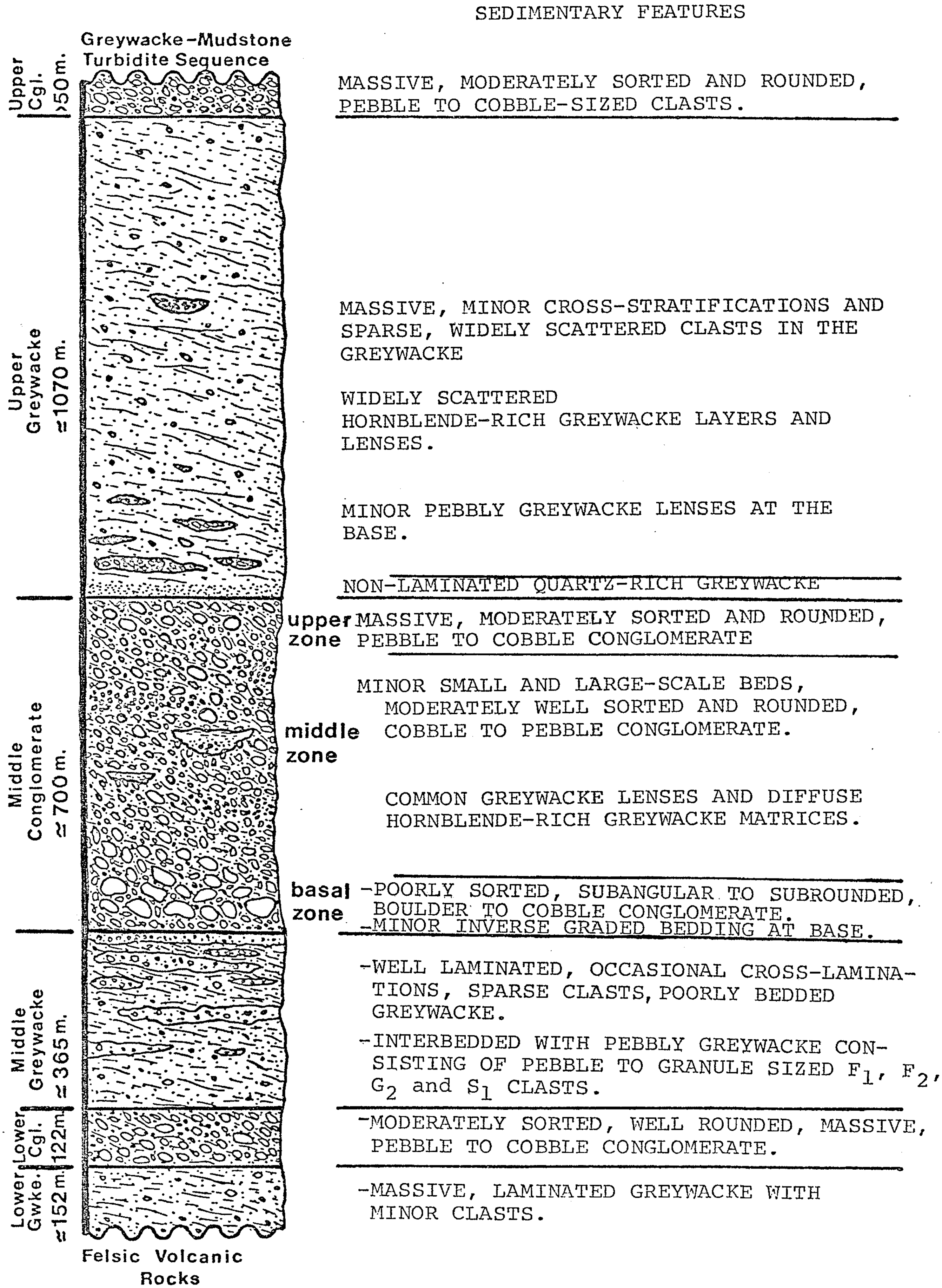

FIGURE 3 - A GENERALIZED SECTION OF THE CONGLOMERATE, GREYWACKE AND PEBBLY GREYWACKE SUCCESSION AT BOOSTER LAKE. (COMPLETED FROM SECTIONS ILLUSTRATED IN FIGURE 2a).

PETROGRAPHIC DESCRIPTION OF THE BOOSTER LAKE CONGLOMERATE AND GREYWACKE

1) Clast Types in the Conglomerate

The Booster Lake conglomerate is polymictic and divisible into six major lithological groups (and 16 types and 2 variants) as shown in Table 1. Figures 4 to 11 illustrate typical examples of the clast types. A detailed petrographic description of the clast types in the conglomerate is given in Appendix I.

2) Conglomerate Matrix

The matrix of the conglomerate is a fine grained recrystallized biotite-rich greywacke which is similar petrographically to the associated and interbedded greywacke.

3) Greywacke and Pebbly Greywacke

These rocks are characterized by fine grain size, light to dark grey weathered surface and moderate to well developed foliation. Bedding, developed on a fine scale of 1 - 5 mm, is expressed by differences in grain size and mineral content. No large scale bedding, nor graded bedding, was observed, and the rock appears massive in outcrop. Rare low angle cross-stratifications were found. Discontinuous laminations are common. Near the Manitoba-Ontario Interprovincial boundary (see Figure 1), the grain size increases to medium grain, bedding becomes obscure, higher grade metamorphic indicators develop, blastesis and local partial anatexis occurs.

TABLE ONE

LIST OF CLAST GROUPS, TYPES AND SUBTYPES IN THE BOOSTER LAKE CONGLOMERATE

FELSIC VOLCANIC CLASTS	GROUP F
Volcanic Sandstone Clasts	Type F_1
Porphyritic Felsic Volcanic Clasts	Type F_2
INTERMEDIATE VOLCANIC CLASTS	GROUP $\overline{\underline{I}}$
Dacitic Volcanic Clasts	Type $\overline{\underline{I}}_1$
Andesite Porphyry Clasts	Type $\overline{\underline{I}}_2$
MAFIC INTRUSIVE CLASTS	GROUP M
Fine Grained Granoblastic Leucodiorite Clasts	Type M_1
Medium Grained Blastic Leucodiorite Clasts	Type M_2
Meladiorite Clasts	Type M_3
Zoned Meladiorite Clasts	Subtype M_{3-1}
Melagabbro Clasts	Type M_4
FELSIC INTRUSIVE CLASTS	GROUP G
Fine Grained Tonalite Clasts	Type G_1
Medium Grained Tonalite Clasts	Type G_2
Coarse Grained Tonalite Clasts	Type G_3
Hornblende Tonalite Clasts	Type G_4
CLASTS OF SEDIMENTARY ROCKS	GROUP S
Biotite Schist Clasts	Type S_1
Blastic Hornblende Biotite Schist Clasts	Subtype S_{1-1}
Greywacke Clasts	Type S_2
MISCELLANEOUS CLASTS	GROUP X
Iron Formation Clasts	Type X_1
Tourmaline Sandstone Clasts	Type X_2

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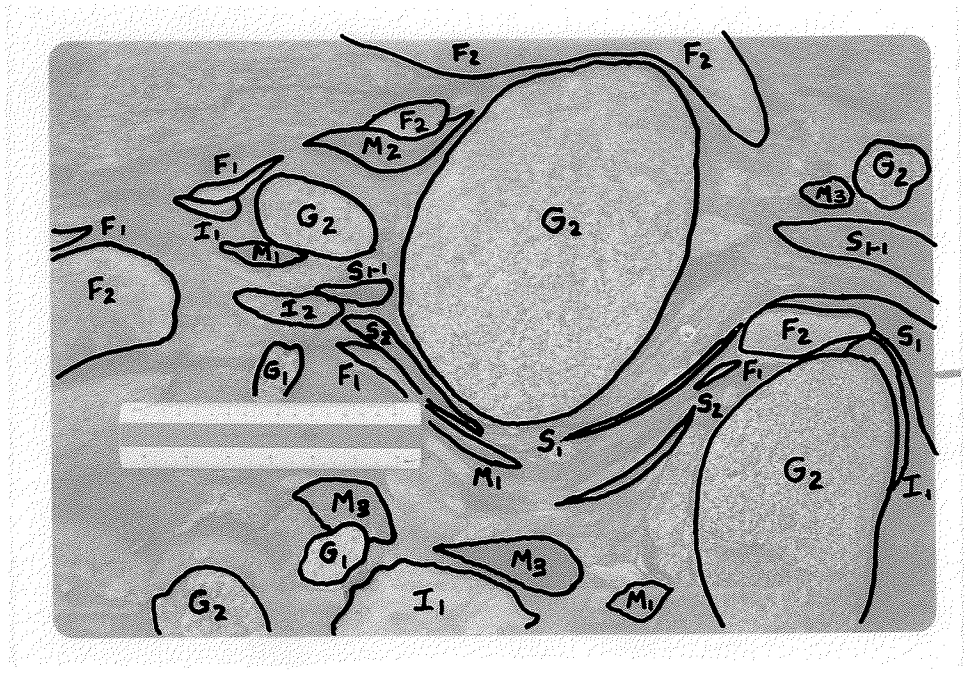

FIGURE 4 - EXAMPLES OF CLAST TYPES IN THE BOOSTER LAKE CONGLOMERATE (STATION 21G).

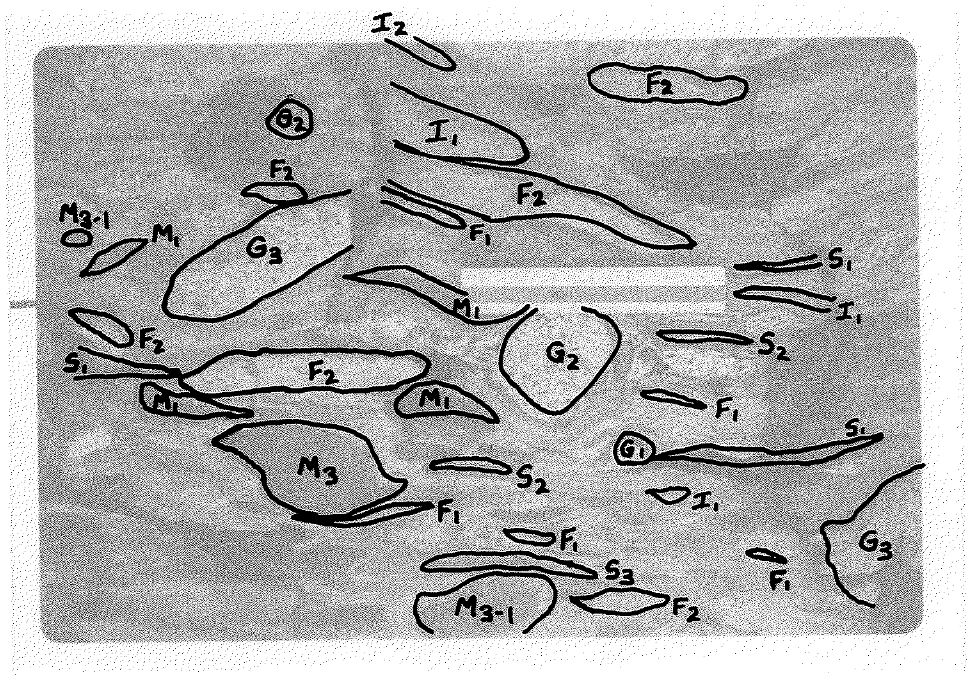

FIGURE 5 - EXAMPLES OF CLAST TYPES IN THE BOOSTER LAKE CONGLOMERATE (STATION 21D).

FIGURE 6 - AN ANDESITE PORPHYRY CLAST AND OTHER ASSOCIATED CLAST TYPES (LENS CAP DIAMETER 54 mm, STATION 21C).

FIGURE 7 - A MEDIUM GRAINED BLASTIC LEUCODIORITE CLAST AND OTHER ASSOCIATED CLAST TYPES (STATION 21G).

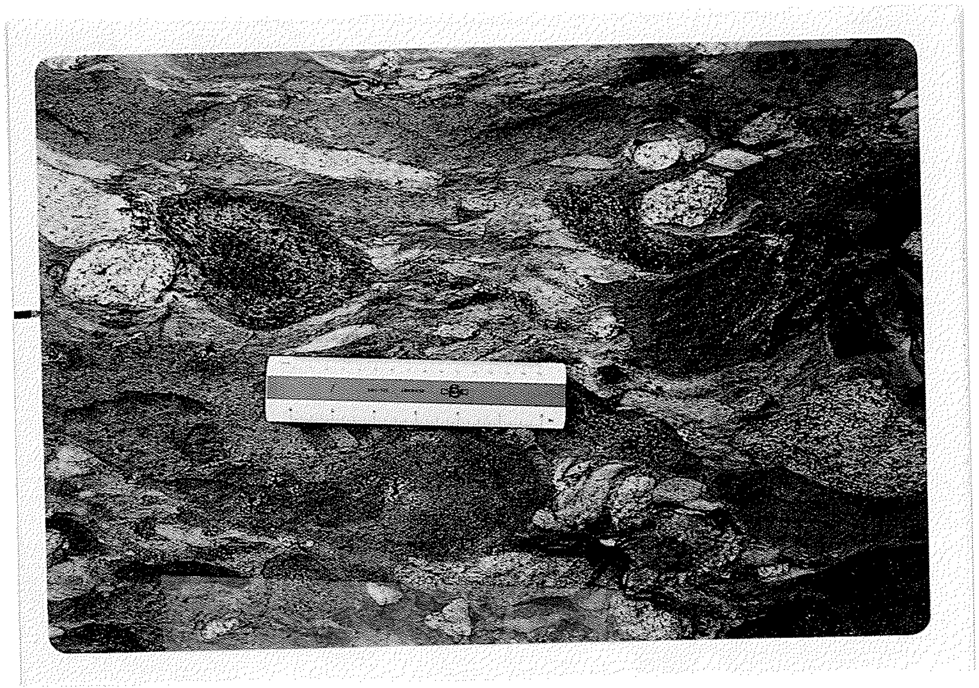

FIGURE 8 - ZONED MELADIORITE, MELADIORITE AND OTHER ASSOCIATED CLAST TYPES (STATION 21G).

FIGURE 9 - A MELAGABBRO CLAST (STATION 61).

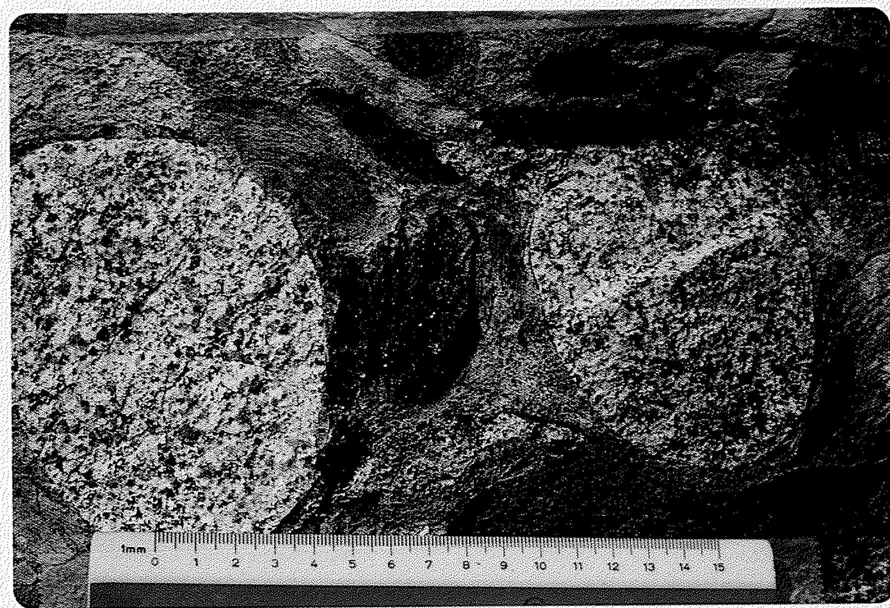

FIGURE 10 - AN IRON FORMATION CLAST BETWEEN TWO MEDIUM GRAINED TONALITE CLASTS (STATION 21F).

FIGURE 11 - A TOURMALINE SANDSTONE CLAST (STATION 21A).

Calc-silicate nodules and layers consisting of hornblende, diopside, plagioclase, biotite and quartz exist interlayered within the grey biotite-rich greywacke. These calc-silicate accumulations range in size up to several meters wide to several tens of meters long. They commonly show thin felsic reaction rims, compositional layering and probably represent original calcareous sandstone accumulations.

The biotite-rich greywacke generally contains less than 2 per cent scattered clasts. There also are scattered layers and lenses of pebbly greywacke, with up to 15 per cent clasts of well rounded to subrounded, pebble to granule sized clasts of volcanic sandstone, porphyritic felsic volcanic, tonalite and minor mafic schists. Complete gradations are observed between the greywacke and pebbly greywacke. The pebbly greywacke layers average 1 - 3 cm. in thickness (maximum 0.6 m), and occur as continuous layers, or as lenses at least 1 meter long.

The metagreywackes in thin section are highly recrystallized, exhibiting granoblastic to granoblastic-polygonal quartz-plagioclase-K-feldspar matrix with lepidoblastic biotite and minor nematoblastic hornblende. Lithic fragments are rare and are internally recrystallized. The lithic fragments are commonly volcanic sandstone and porphyritic felsic volcanic clasts, coarse sand to granule in size. Plagioclase clasts are subidioblastic to xenoblastic, poikiloblastic, compositionally zoned, fragmented and sericitized. Quartz clasts are rounded to subrounded, xenomorphic polygonal aggregates. Xenoblastic to subidioblastic epidote and sphene are common in biotite-rich

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beds. Detrital slate-grey to blue pleochroic, poikiloblastic tourmaline is found in the greywacke matrix. Medium grained, rolled, poikiloblastic, xenoblastic, inclusion-rich, pinitized cordierite is present. Garnet occurs in the greywacke as two types of crystals, viz: inclusion-free, post D_2, idioblastic, unaltered and nonrotated crystals; or as inclusion-rich cored crystals that are oblique to the external foliation with a moderately altered outer inclusion-free zone.

4) Shapes and Textures of the Clasts

a. General Description

Observed predepositional features include the following: (1) quartz veins that are not found outside of the clasts (in types F_2 and G_2 clasts); (2) curved fracture systems that are found only in melagabbro clasts; (3) sharp angular straight boundaries on a clast that also has subrounded edges; (4) rectangular to triangular tonalite clasts, the shape of which may be due to joint patterns; (5) felsic segregation pegmatites in mafic schist clasts that are not traceable outside the clast; (6) and fracture systems in the tonalite clasts. The fracture systems may have also resulted from the low overall ductility of the tonalite clasts relative to the rest of the rock, and the higher ductility contrasts of the differing clasts in the conglomerate. Thus the result is extensional fracturing of the lower ductile clasts on deformation (especially D_2).

Differing degrees of ductility of several clast types can be seen in Figures 4 and 5. Tonalite clasts are strongly nonductile, remaining subrounded while other clasts are deformed.

Tonalite clasts, under stress, deform by brittle extensional fracturing. In areas of strong deformation, tonalite clasts are slightly elongated, rotated, generally possessing quartz-pressure shadows, but lie with their intermediate axes at a small angle to the foliation. Mafic intrusive clasts are also relatively nonductile; except where they lie against tonalite clasts, where they are deformed. Large subangular porphyritic felsic volcanic clasts are moderately nonductile, being controlled (wrapped around, see Figure 4) by the above clast types, but warp and deflect the more ductile felsic and intermediate volcanic and mafic schist clasts. Intermediate volcanic clasts are poorly ductile, controlling the shapes of the volcanic sandstone, mafic schist and greywacke clasts. Mafic schist clasts are the most ductile of all clast types and subsequently occur as elongated, layer-like clasts.

In the inner arc of a fold closure, the very ductile mafic schist clasts are not highly stretched, but exhibit subrounded, tabular to elongate shapes. In the fold closure's outer arc, clasts are moderately deformed. In the fold limbs, and in areas of strong deformation, stretching of clasts has produced highly elongate layer-like clasts. Clasts have been folded into minor D_2 folds of Z and S shapes on the fold limbs. In one locality (Station 8), a volcanic sandstone clast expresses superimposed deformation by a closed dovetail pattern in outcrop (see Figure 54).

b. Gneissic Conglomerate

At Starr Lake (see Map 1), D_2 deformation has imposed inhomogeneous strain on the conglomerate and interbedded greywacke. This deformation is accompanied by upper almandine-amphibolite facies metamorphism and local partial anatexis. The result is the development of a gneissic structure in the conglomerate. The clasts appear as thin, ribbon-like layers that are highly stretched and traceable for several centimeters.

South along Davidson Creek (Station 93), that drains Davidson Lake into Starr Lake, varying degrees of gneissosity can be observed. Distinguishable clasts in a well foliated conglomerate are shown in Figure 12. Other layers at the same locality exhibit moderately to extensively stretched clasts (Figure 13). An extremely stretched conglomerate, with some almost indistinguishable clasts, and very highly stretched greywacke is illustrated in Figure 14. Figure 15 shows an advanced stage of gneissosity where clasts are indistinguishable. These variations in strain are found across strike (10 m), but lateral variation in the degree of stretching is also observed. A high degree of partial anatexis and migmatization is also noted in the same outcrop.

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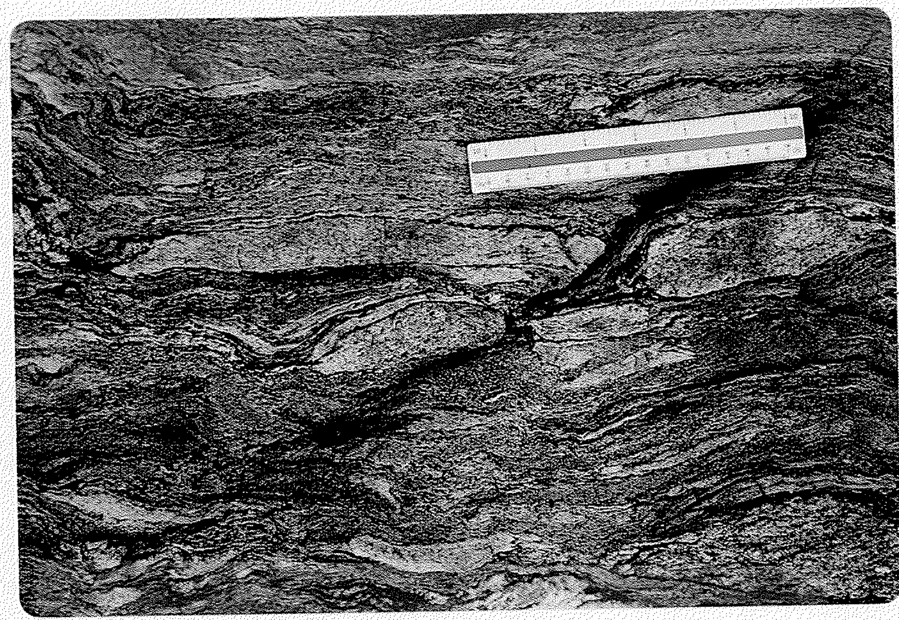

FIGURE 12 - A WELL FOLIATED CONGLOMERATE (STATION 93).

FIGURE 13 - MODERATELY STRETCHED CLASTS IN THE BOOSTER LAKE CONGLOMERATE (STATION 93).

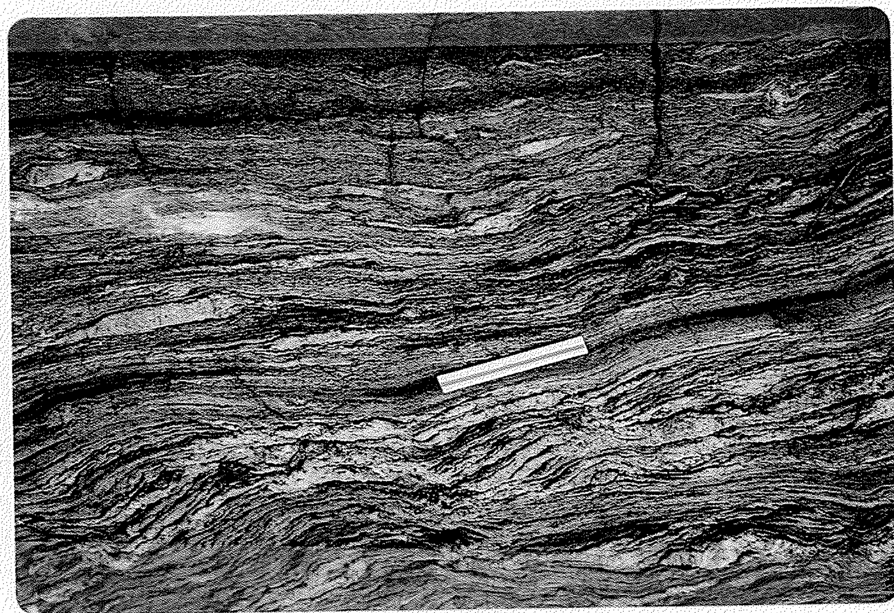

FIGURE 14 - HIGHLY STRETCHED CONGLOMERATE AND VERY HIGHLY STRETCHED LAYERS OF GREYWACKE AND PEBBLY GREYWACKE (STATION 93).

FIGURE 15 - A GNEISSIC CONGLOMERATE (STATION 93).

LATERAL AND VERTICAL VARIATIONS IN CLAST CONCENTRATIONS

1) Data Collection

To determine lateral and vertical variations in clast concentrations, macroscopic modal point counts of clast types were made on 48 outcrops, with station localities shown on Map 1, and the results tabulated in Appendix II. The problems involved in the determination of the relative amounts of differing clast types, that vary in size, shape, and ductility, have been discussed by Donaldson and Jackson (1965). Only a grid count will give clast type volume proportions. The megascopic modal point counts were taken using a fish net, as a grid system, with a spacing interval of 50 mm. At each intersection point, the clast type present was tallied. Any rare clast types that were seen but not tallied were also noted and listed as "trace" amount.

On an exposure, the grid system was positioned so that the traverse lines were set at 45 degree angles to the clast elongations. On the average, 500 modal point counts were made at each outcrop (requiring 1.4 - 1.8 square m of outcrop). Eight outcrops had 1000 modal point counts (requiring 1.8 - 2.3 square m of outcrop).

In order to analyse the data obtained, several methods of presentation were utilized. Histograms were abandoned as it was difficult to envisage variations from the large amount of data accumulated. Variations in clast concentrations can be perceived by the examination of Map 4 and the contoured maps of Figures 16 to 24. From these maps, not only are lateral and

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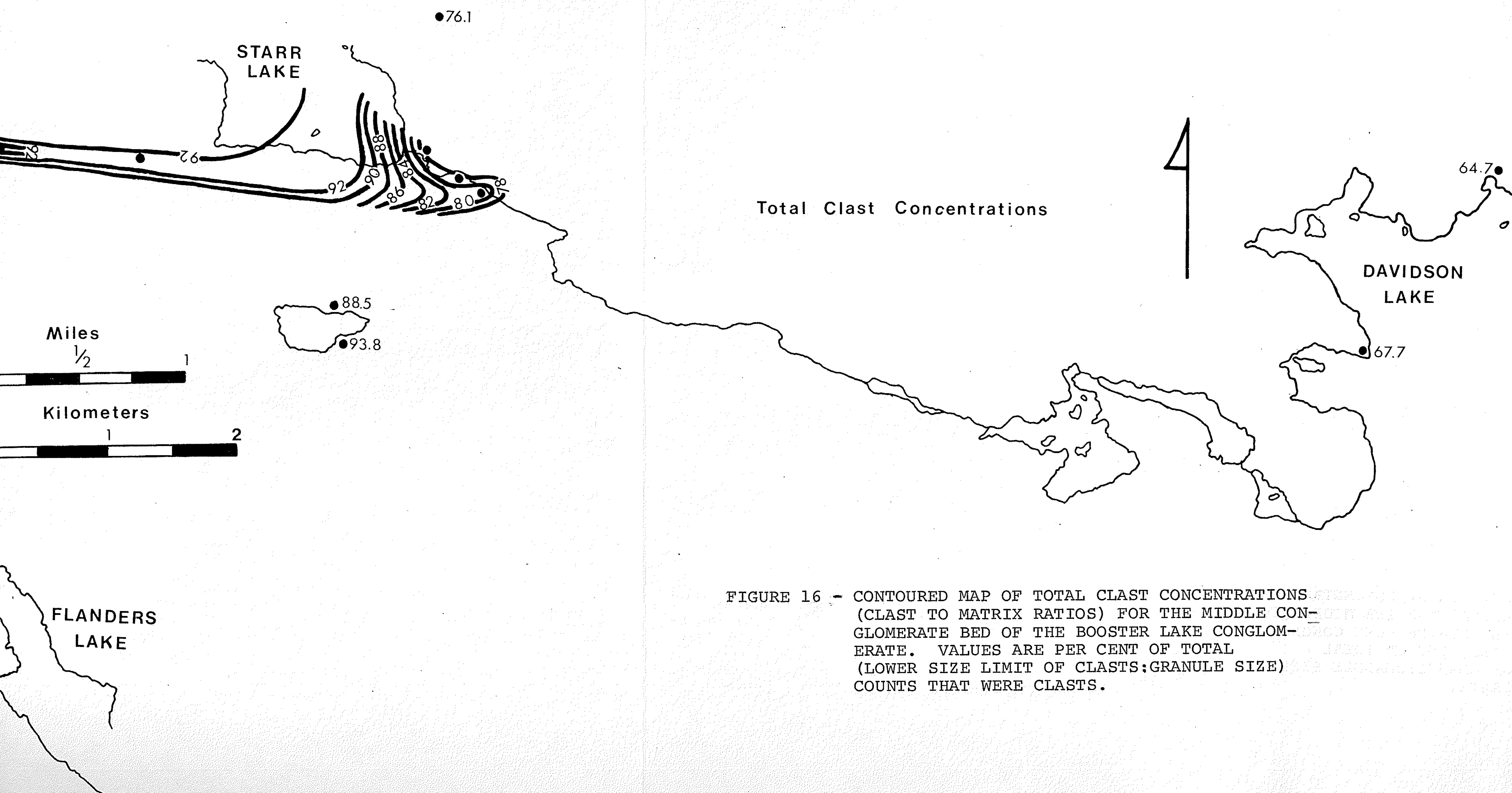

FIGURE 16 - CONTOURED MAP OF TOTAL CLAST CONCENTRATIONS (CLAST TO MATRIX RATIOS) FOR THE MIDDLE CONGLOMERATE BED OF THE BOOSTER LAKE CONGLOMERATE. VALUES ARE PER CENT OF TOTAL (LOWER SIZE LIMIT OF CLASTS; GRANULE SIZE) COUNTS THAT WERE CLASTS.

Total Clast Con

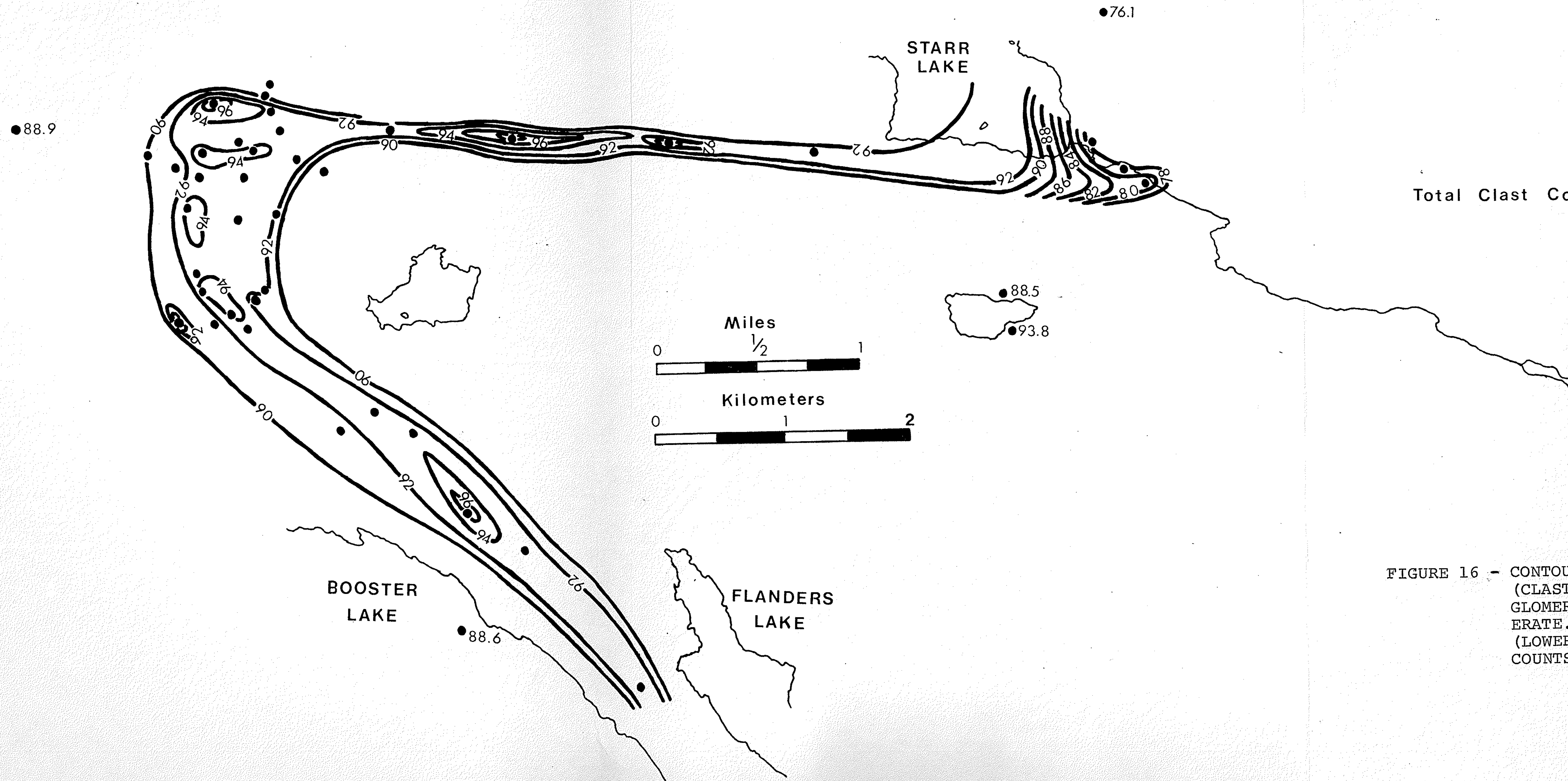

FIGURE 16 - CONTOUR
(CLAST
GLOMERA
ERATE.
(LOWER
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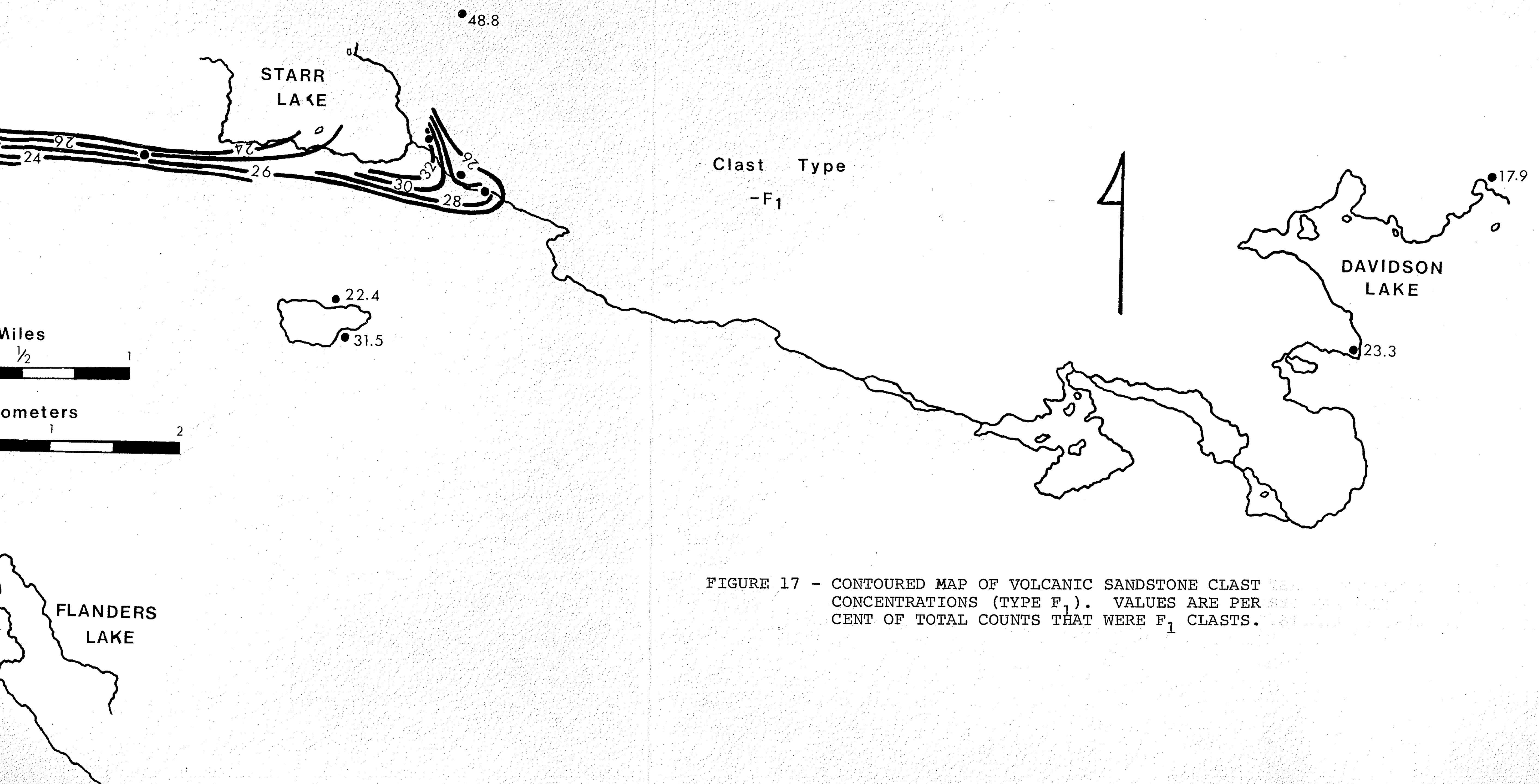
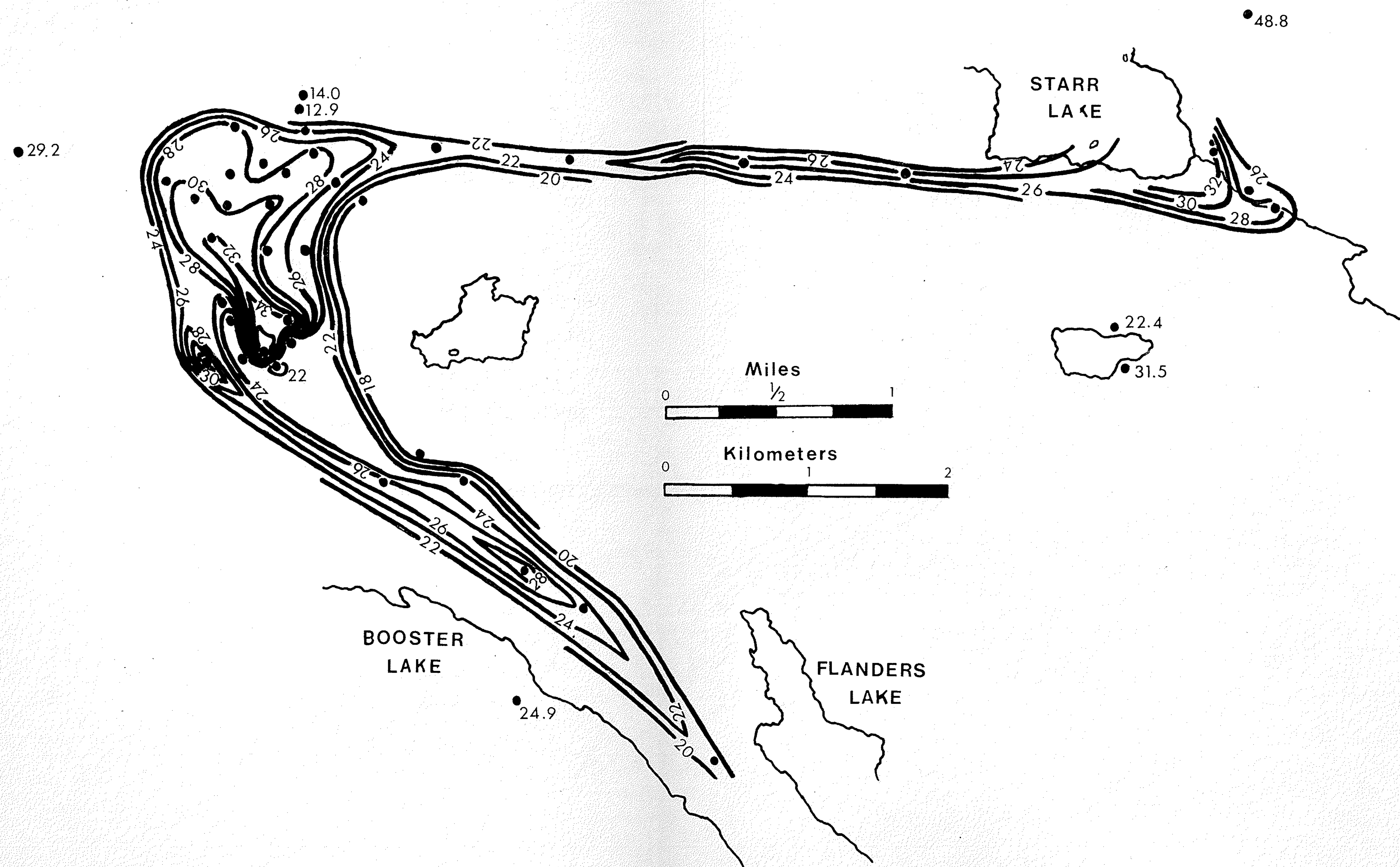


FIGURE 17 - CONTOURED MAP OF VOLCANIC SANDSTONE CLAST CONCENTRATIONS (TYPE F_1). VALUES ARE PER CENT OF TOTAL COUNTS THAT WERE F_1 CLASTS.



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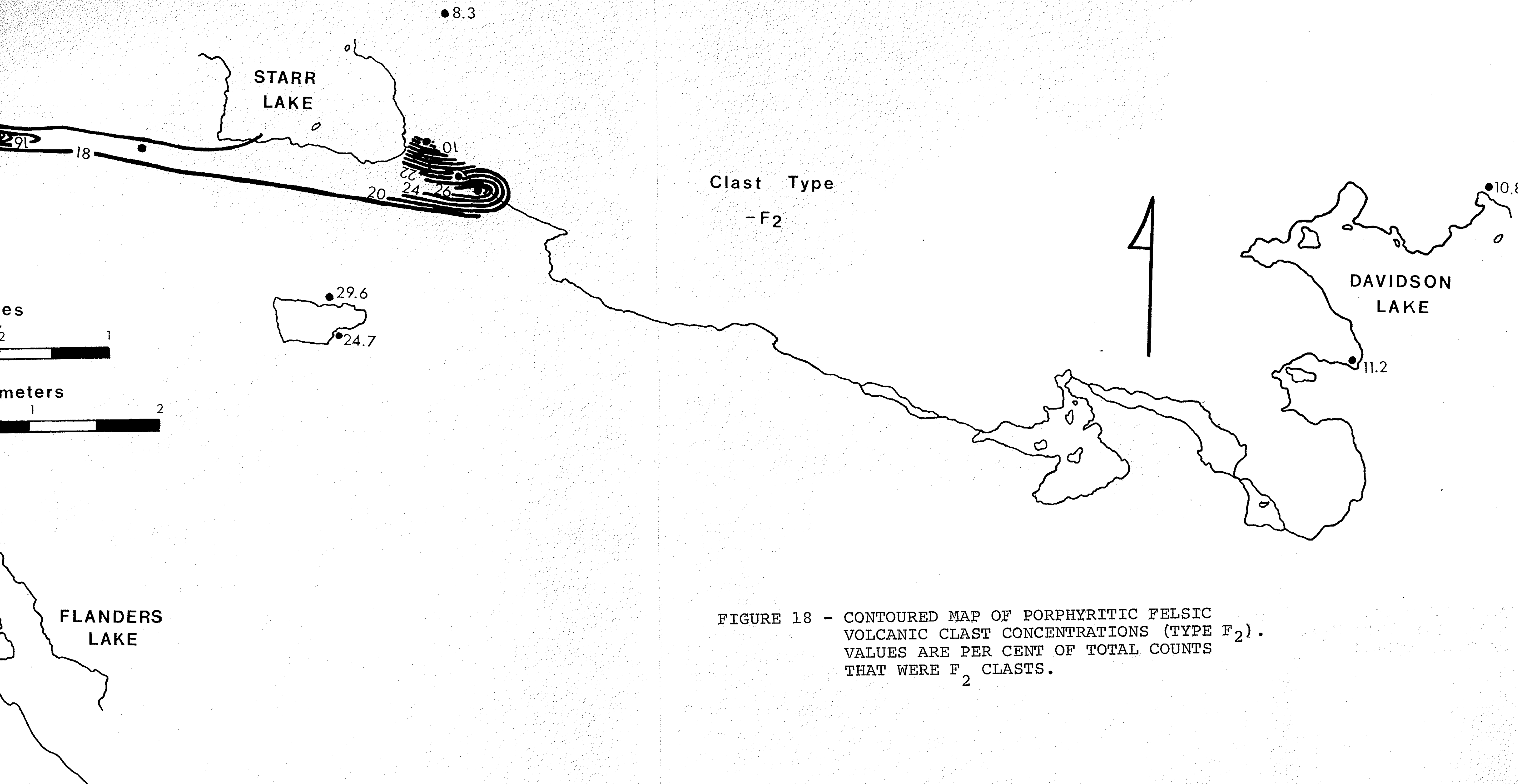
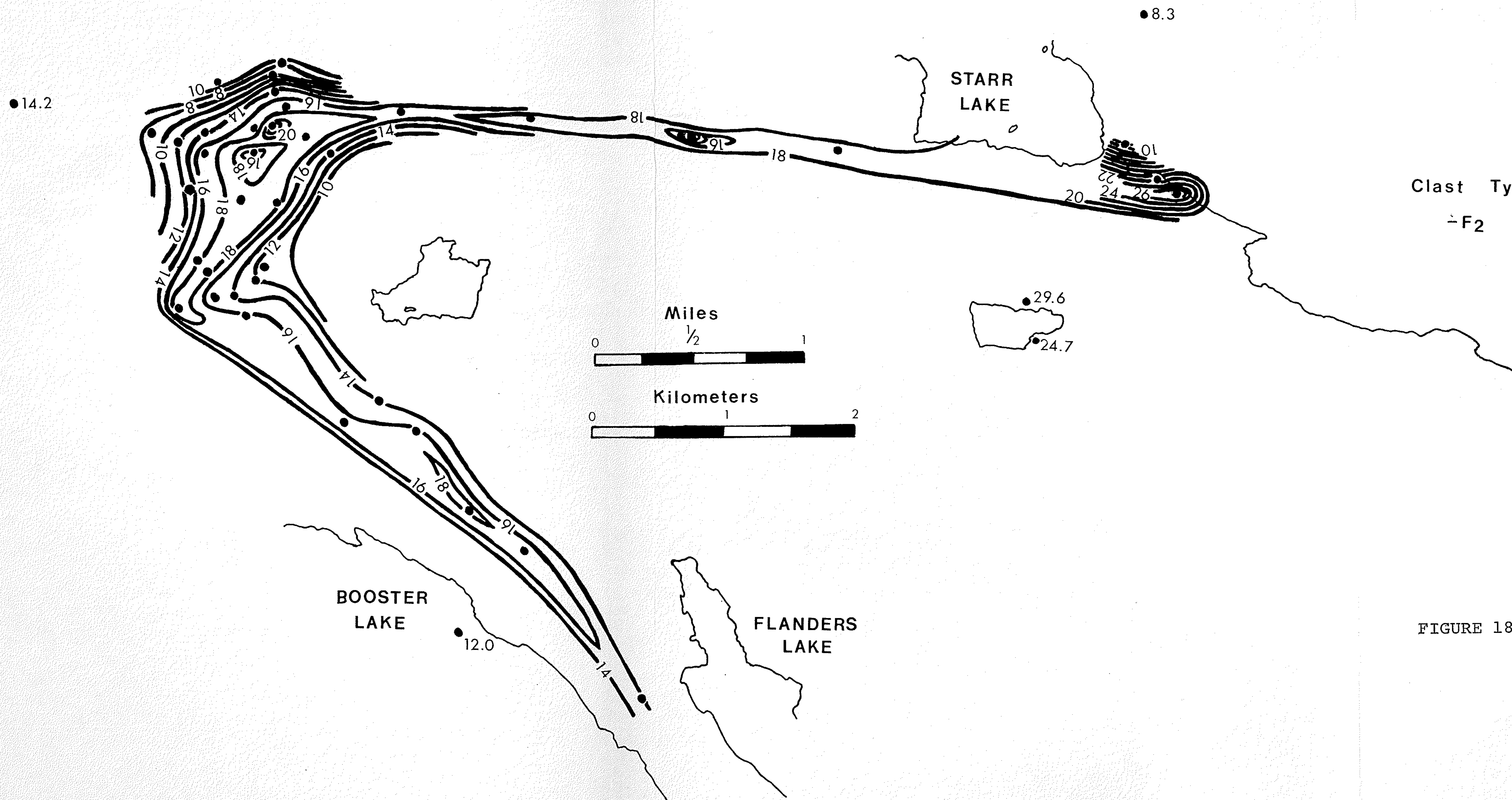


FIGURE 18 - CONTOURED MAP OF PORPHYRITIC FELSIC VOLCANIC CLAST CONCENTRATIONS (TYPE F_2). VALUES ARE PER CENT OF TOTAL COUNTS THAT WERE F_2 CLASTS.



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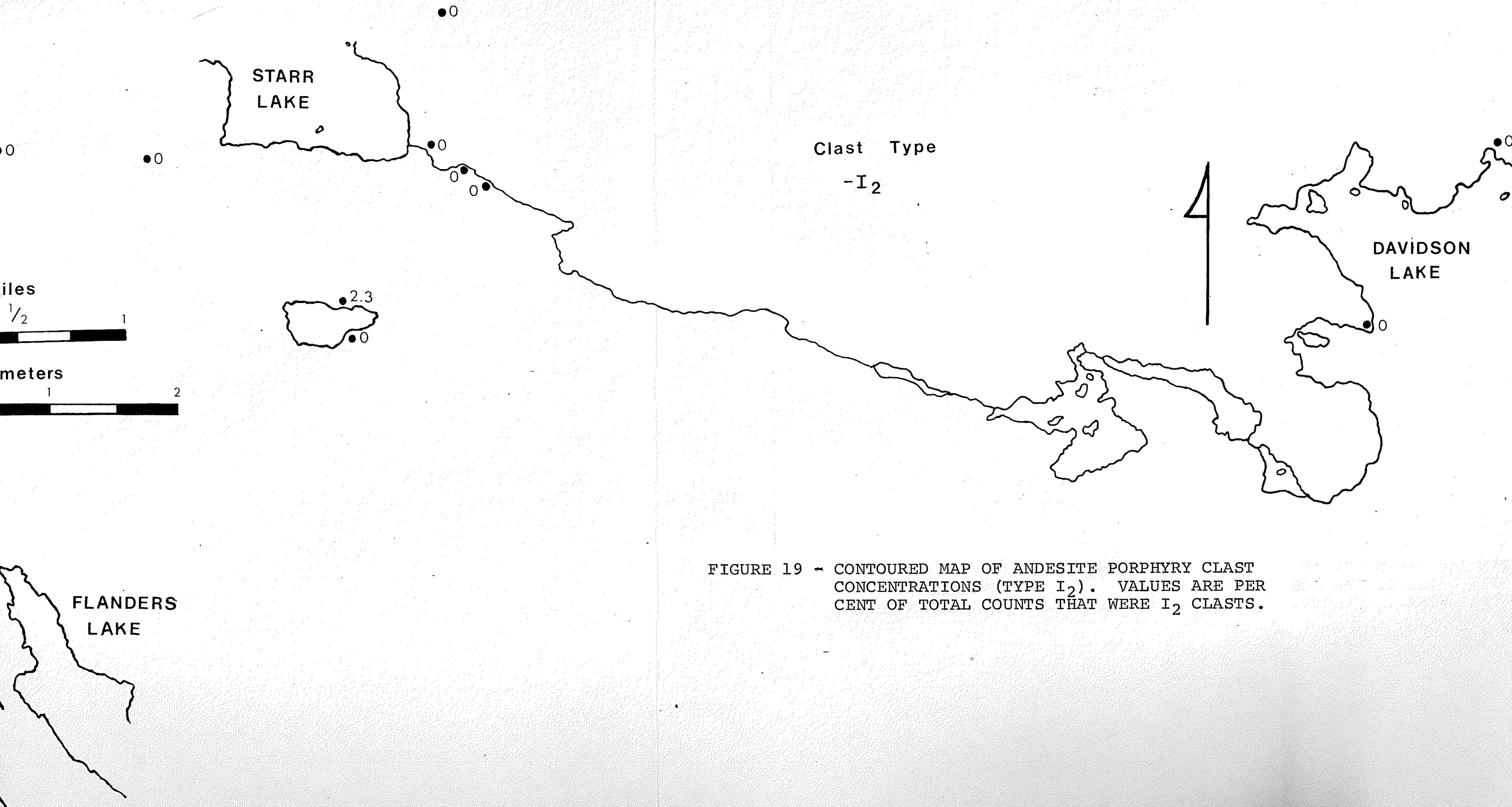

FIGURE 19 - CONTOURED MAP OF ANDESITE PORPHYRY CLAST CONCENTRATIONS (TYPE I_2). VALUES ARE PER CENT OF TOTAL COUNTS THAT WERE I_2 CLASTS.

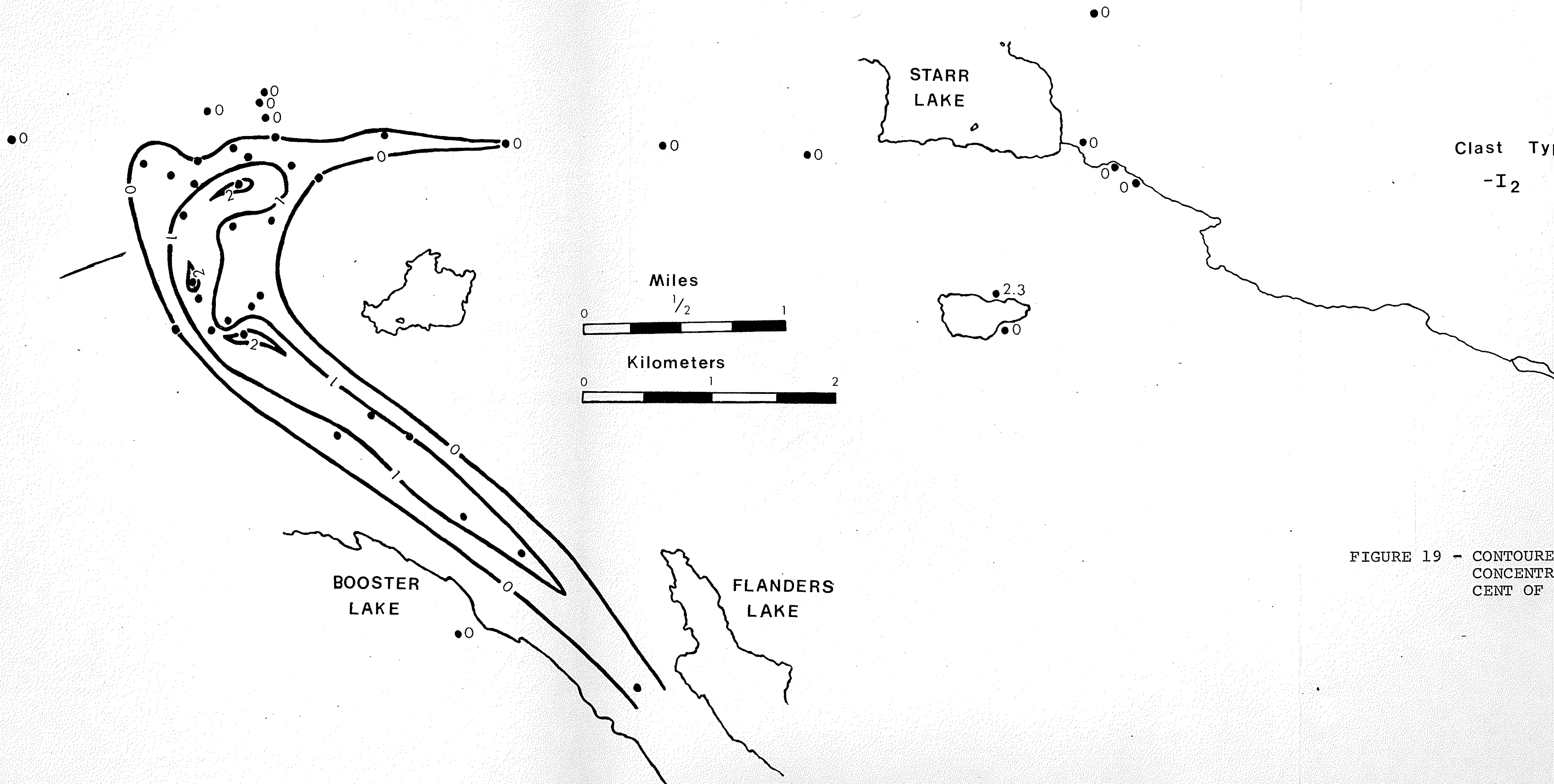

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FIGURE 19 - CONTOURE
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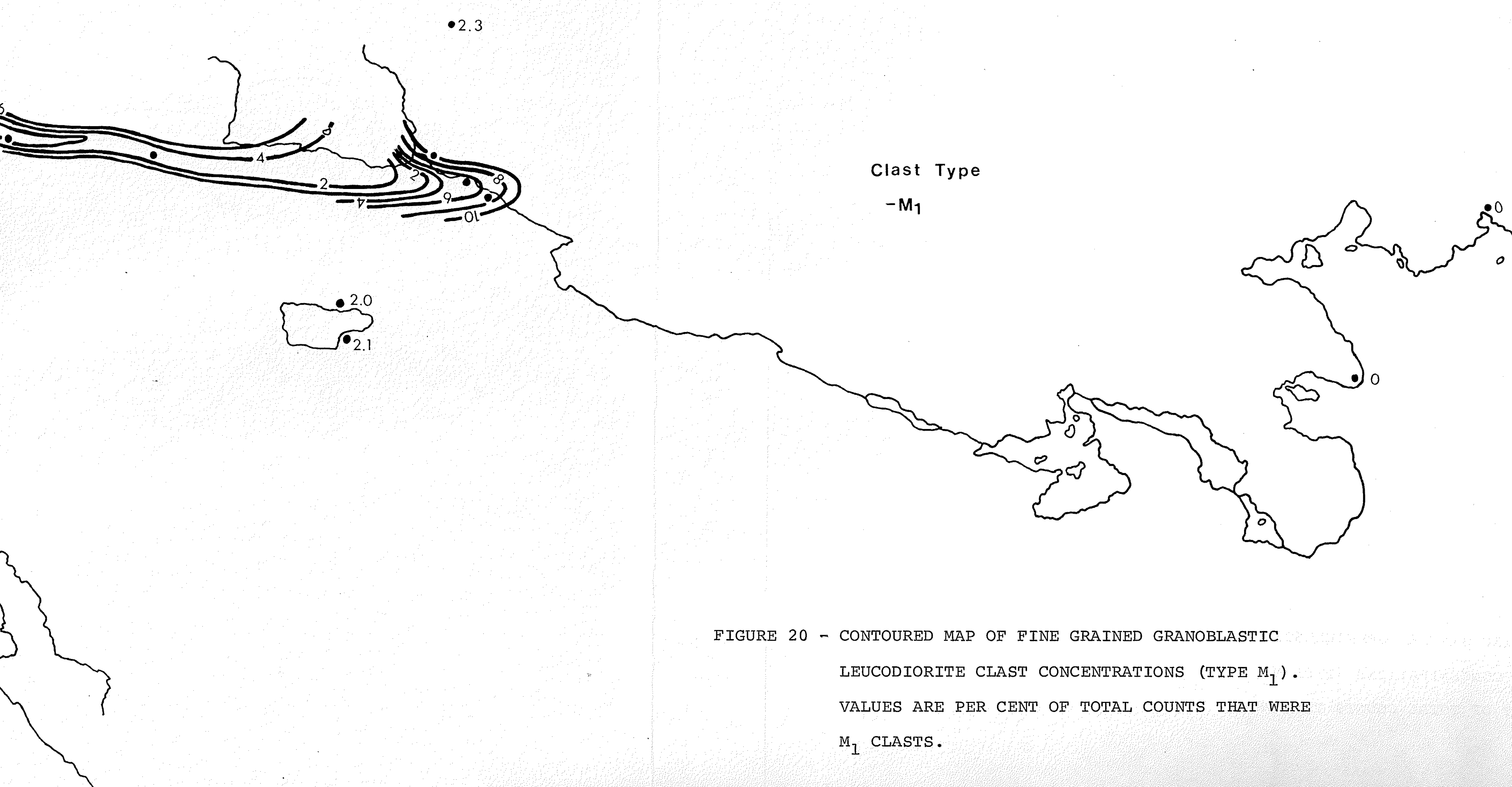

FIGURE 20 - CONTOURED MAP OF FINE GRAINED GRANOBLASTIC LEUCODIORITE CLAST CONCENTRATIONS (TYPE M_1). VALUES ARE PER CENT OF TOTAL COUNTS THAT WERE M_1 CLASTS.

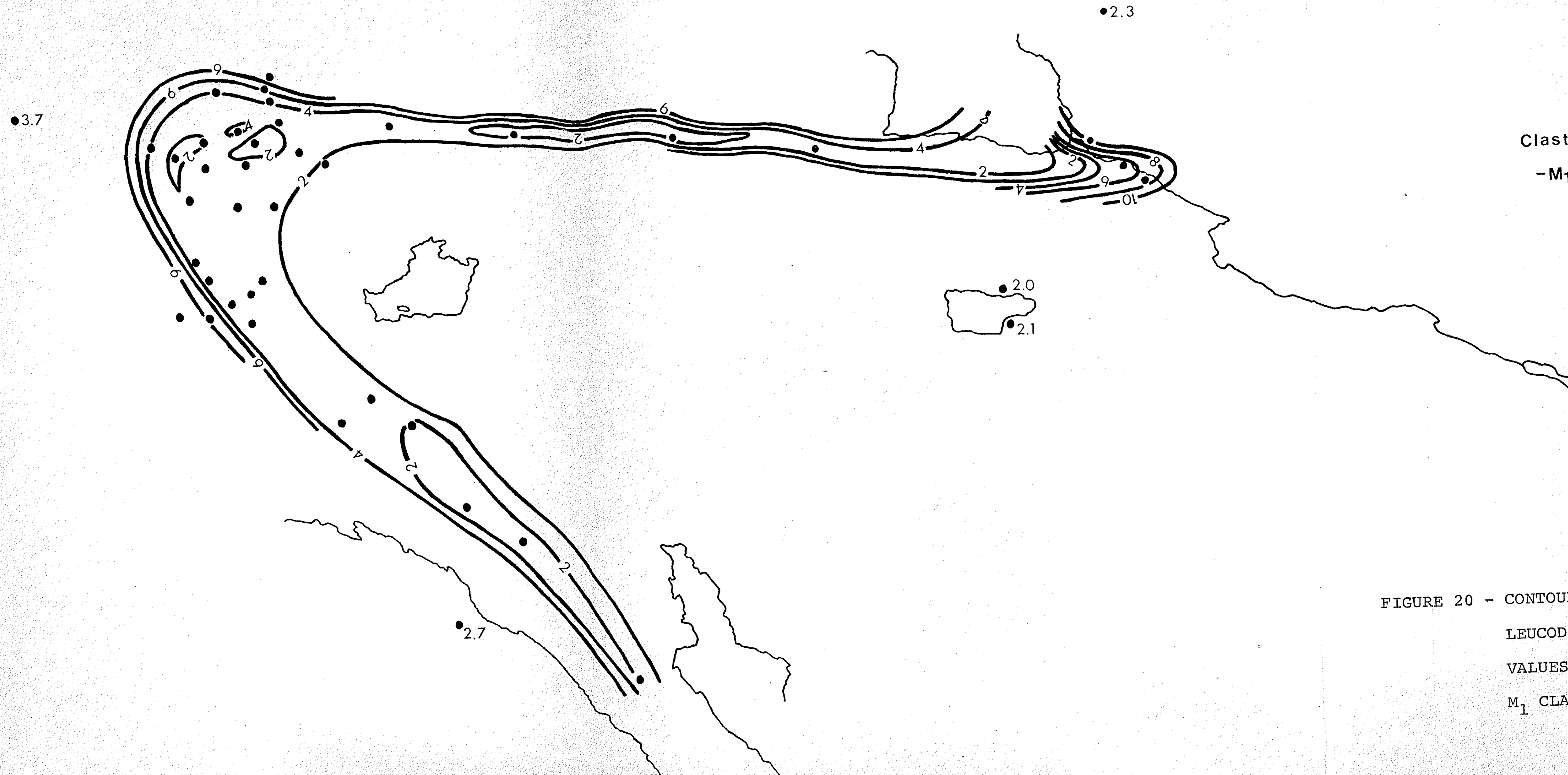

FIGURE 20 - CONTOU
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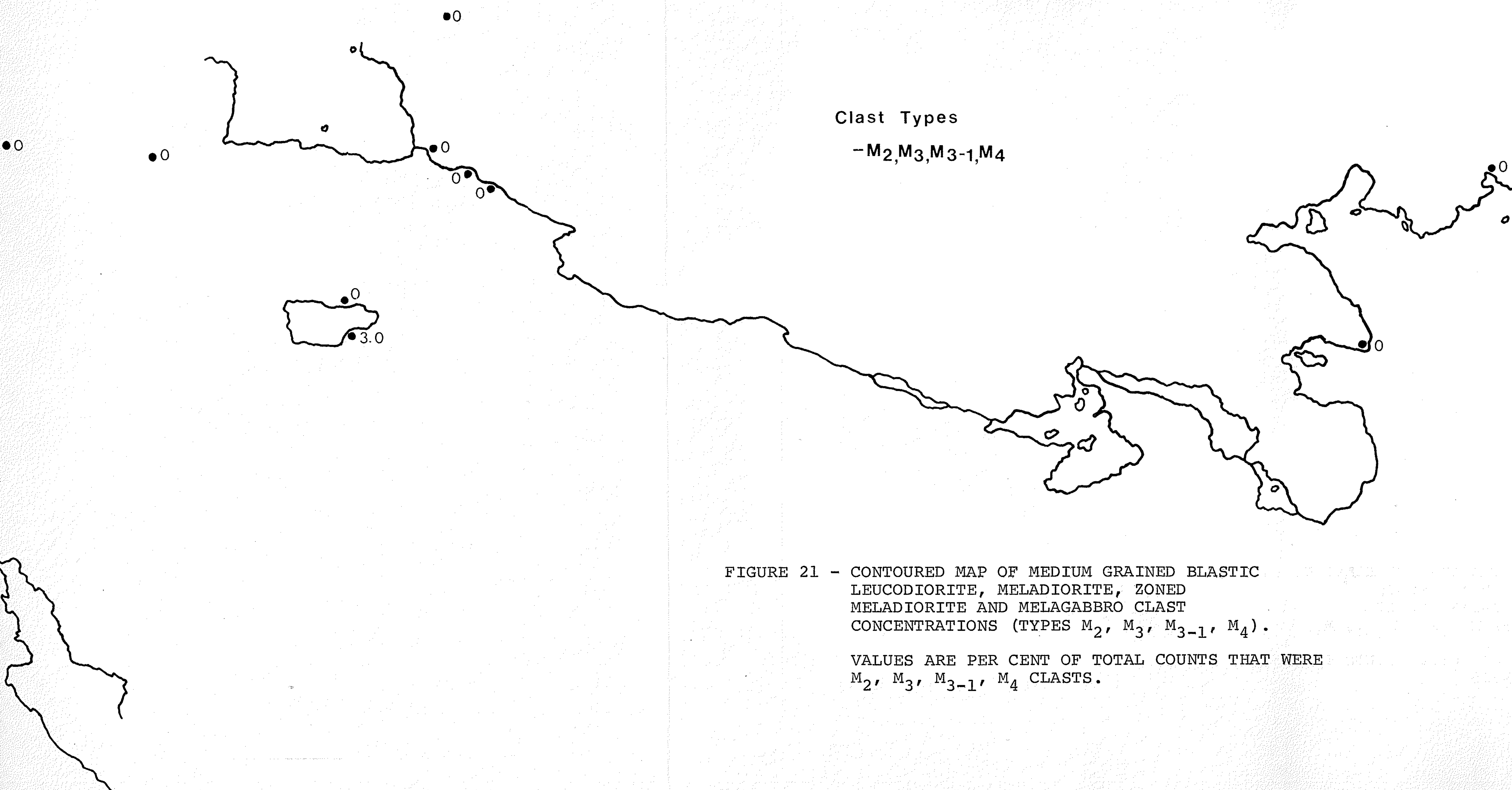
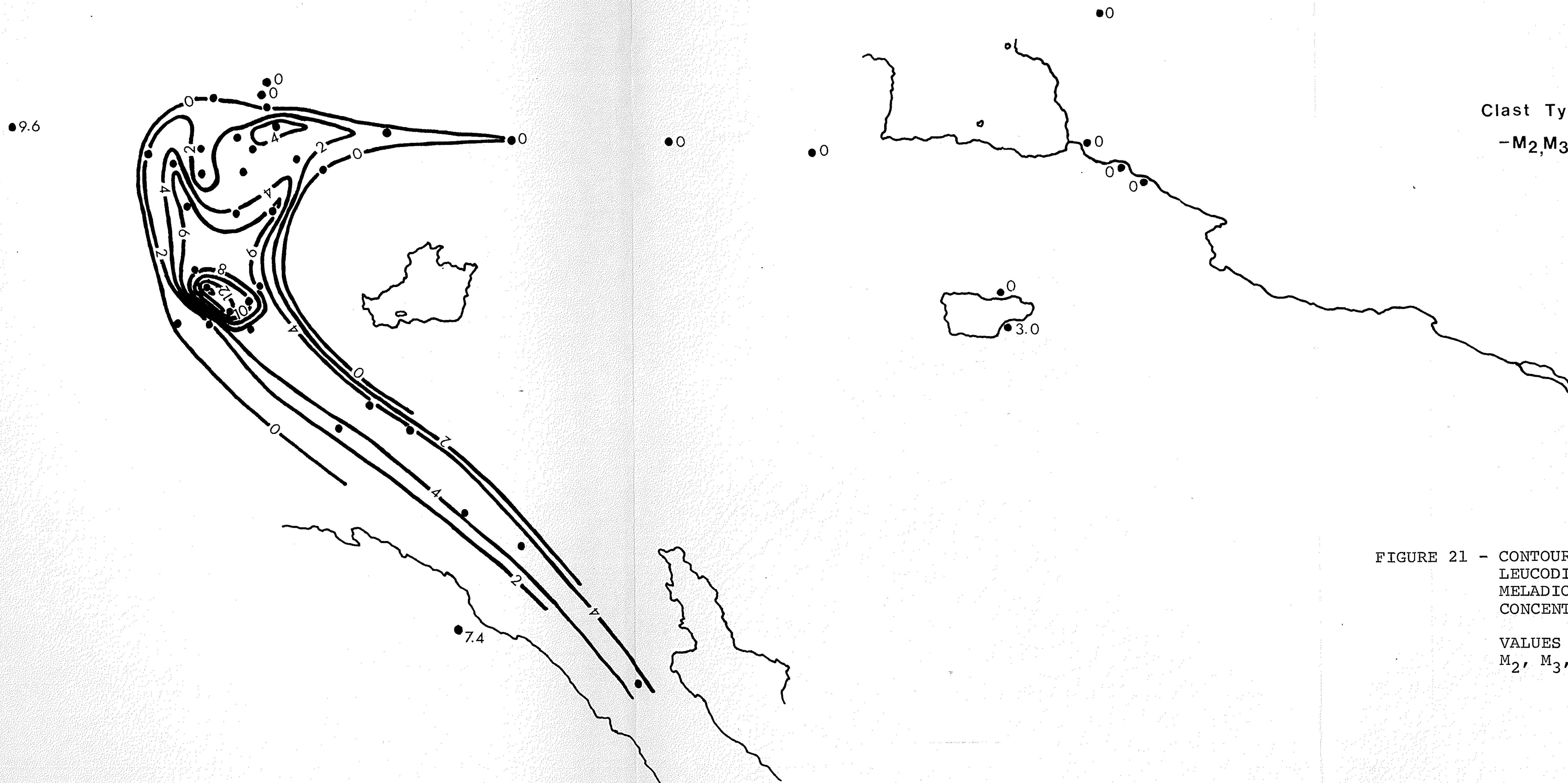


FIGURE 21 - CONTOURED MAP OF MEDIUM GRAINED BLASTIC LEUCODIORITE, MELADIORITE, ZONED MELADIORITE AND MELAGABBRO CLAST CONCENTRATIONS (TYPES M_2, M_3, M_{3-1}, M_4).

VALUES ARE PER CENT OF TOTAL COUNTS THAT WERE M_2, M_3, M_{3-1}, M_4 CLASTS.



Clast Typ

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FIGURE 21 - CONTOURE
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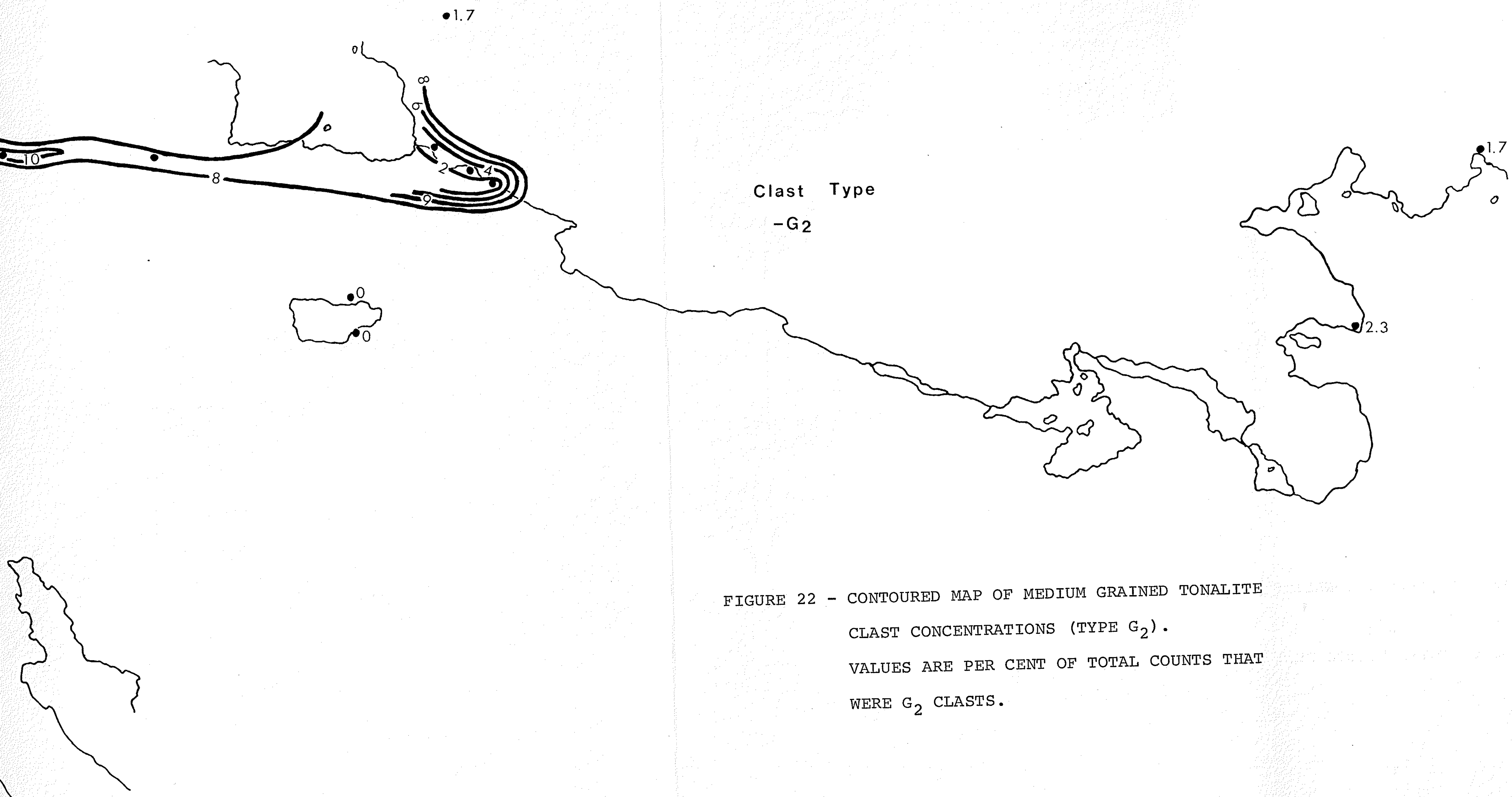
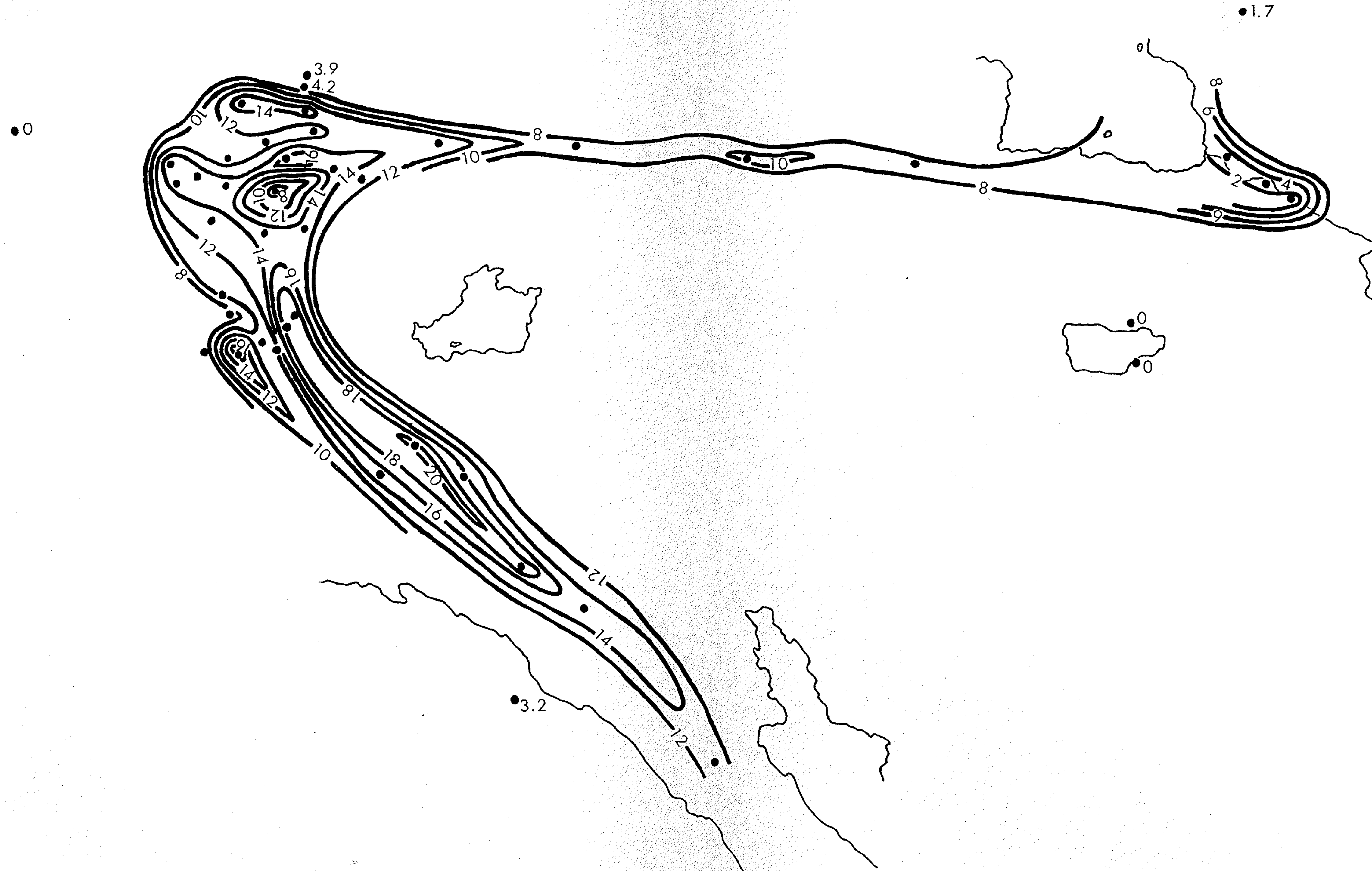


FIGURE 22 - CONTOURED MAP OF MEDIUM GRAINED TONALITE CLAST CONCENTRATIONS (TYPE G_2). VALUES ARE PER CENT OF TOTAL COUNTS THAT WERE G_2 CLASTS.



Clast Typ

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FIGURE 22 - CO
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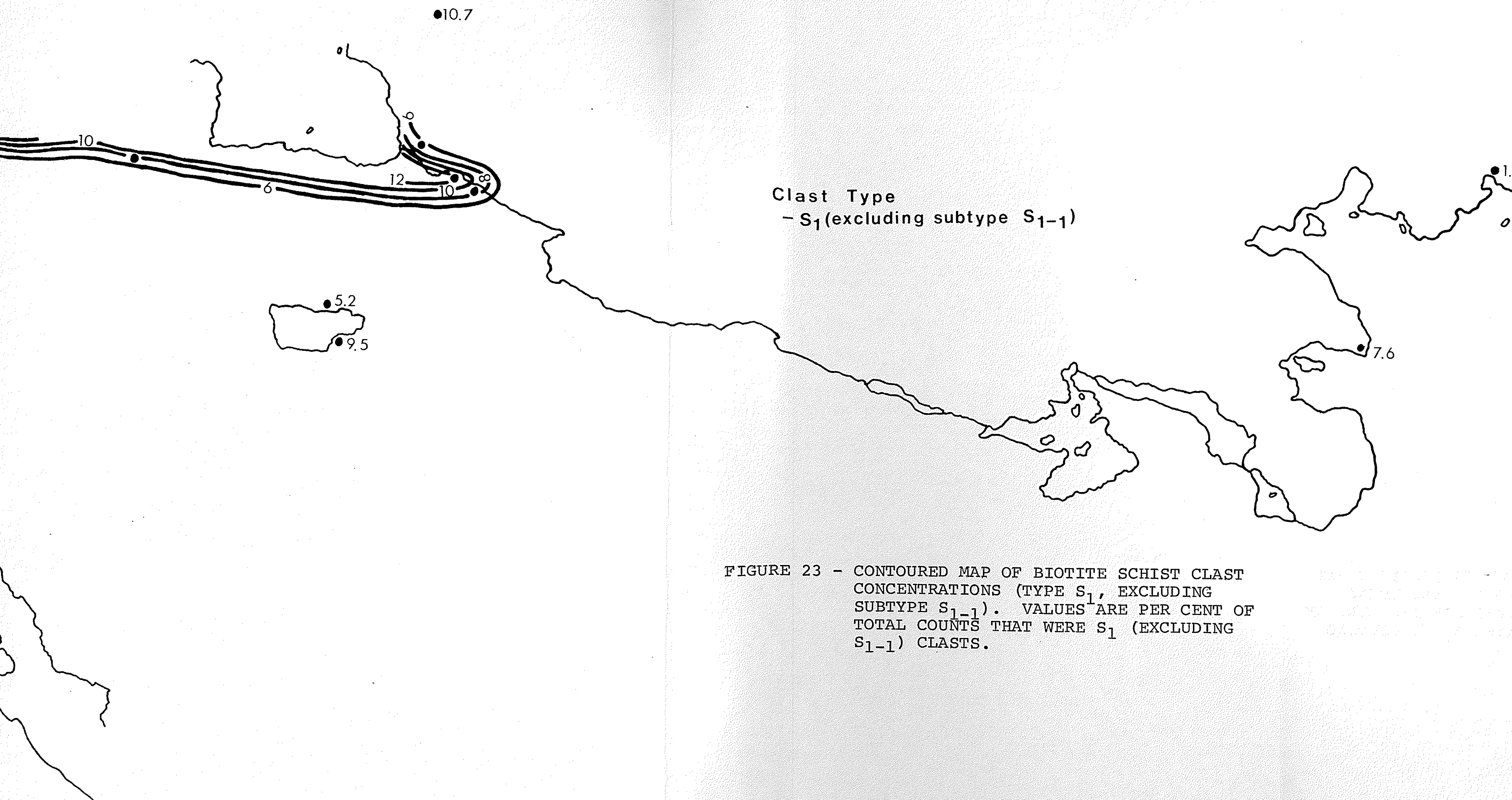
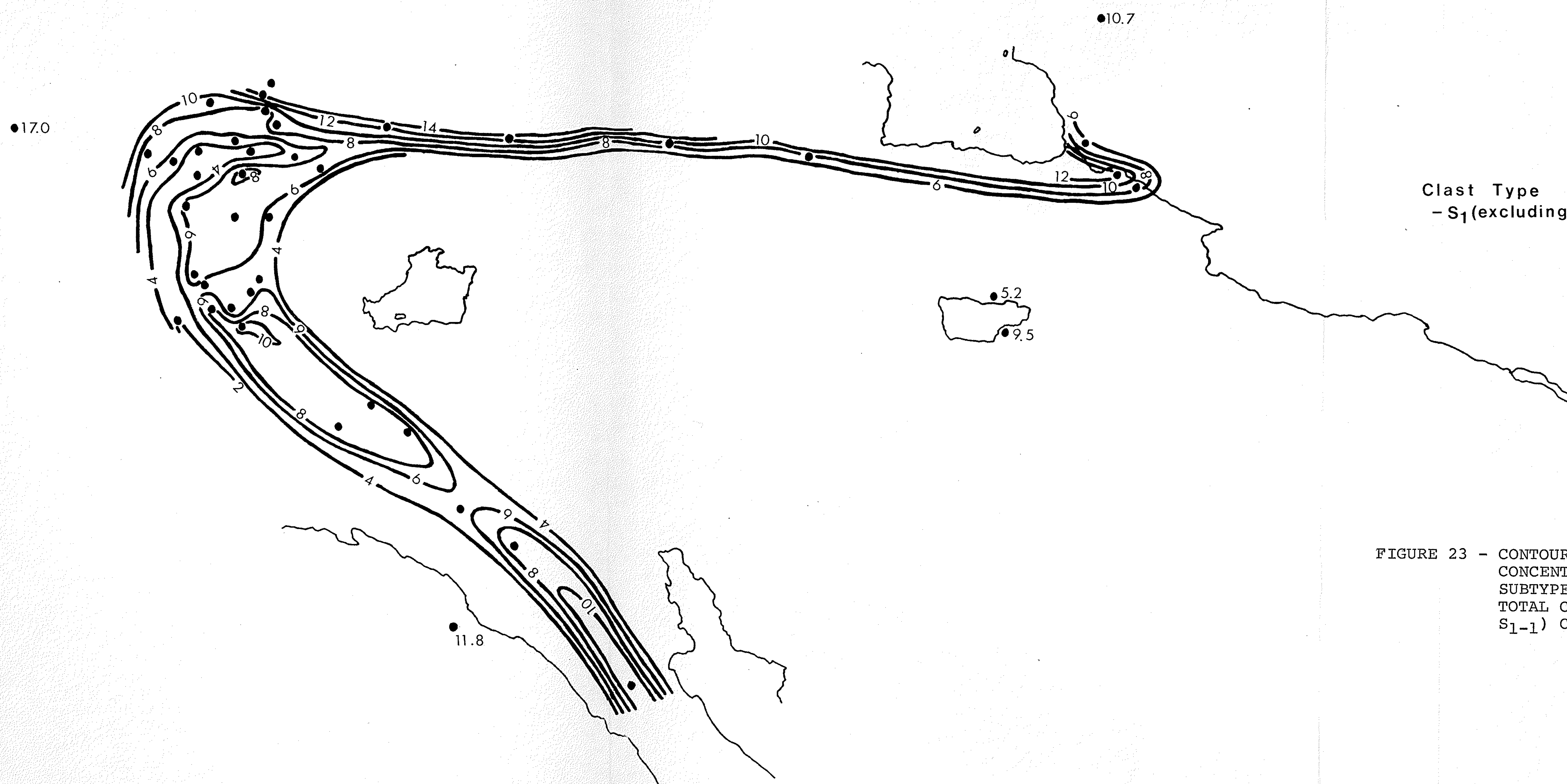


FIGURE 23 - CONTOURED MAP OF BIOTITE SCHIST CLAST CONCENTRATIONS (TYPE S_1, EXCLUDING SUBTYPE S_{1-1}). VALUES ARE PER CENT OF TOTAL COUNTS THAT WERE S_1 (EXCLUDING S_{1-1}) CLASTS.



Clast Type
– S_1(excluding

FIGURE 23 - CONTOUR
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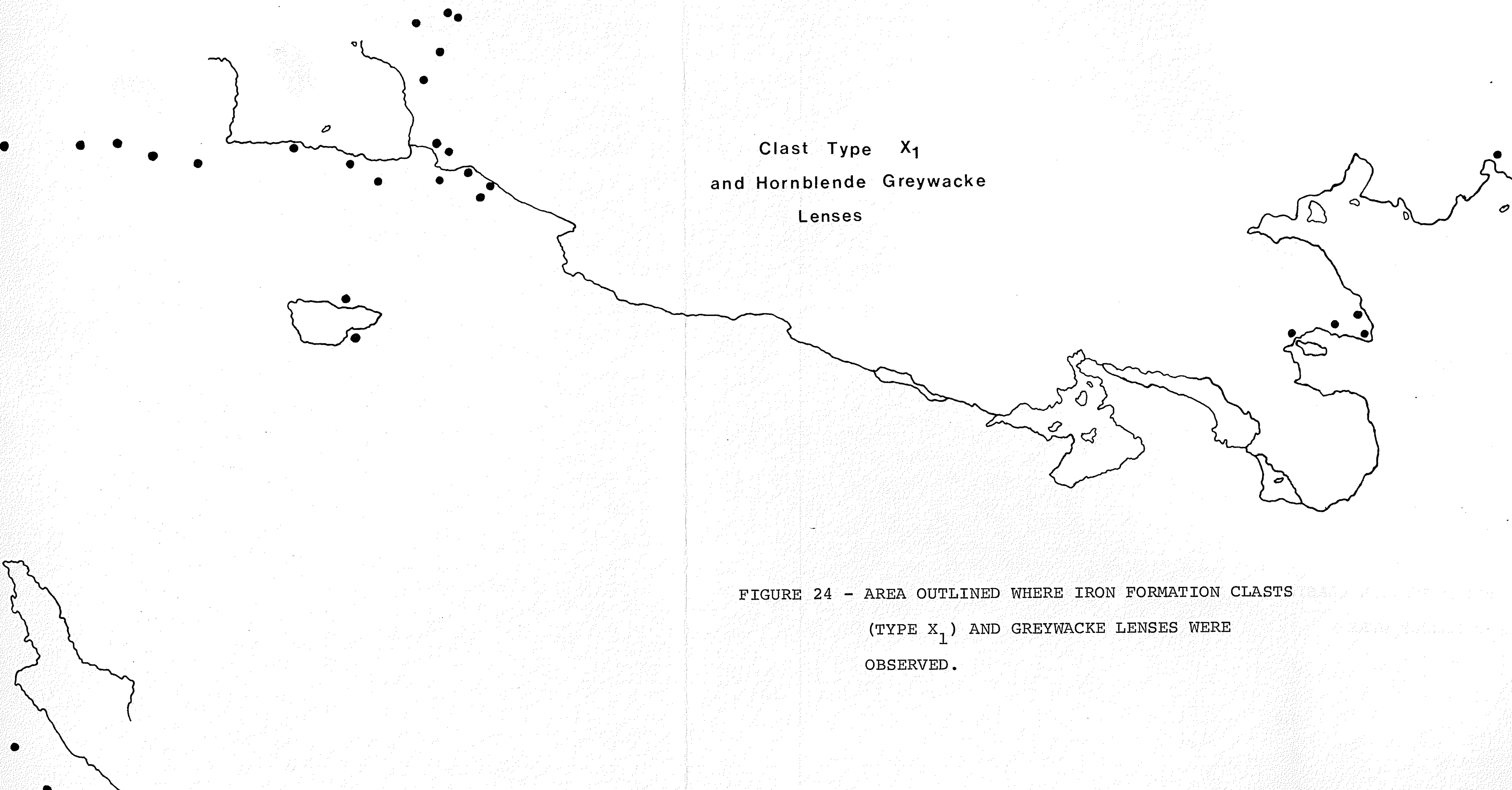
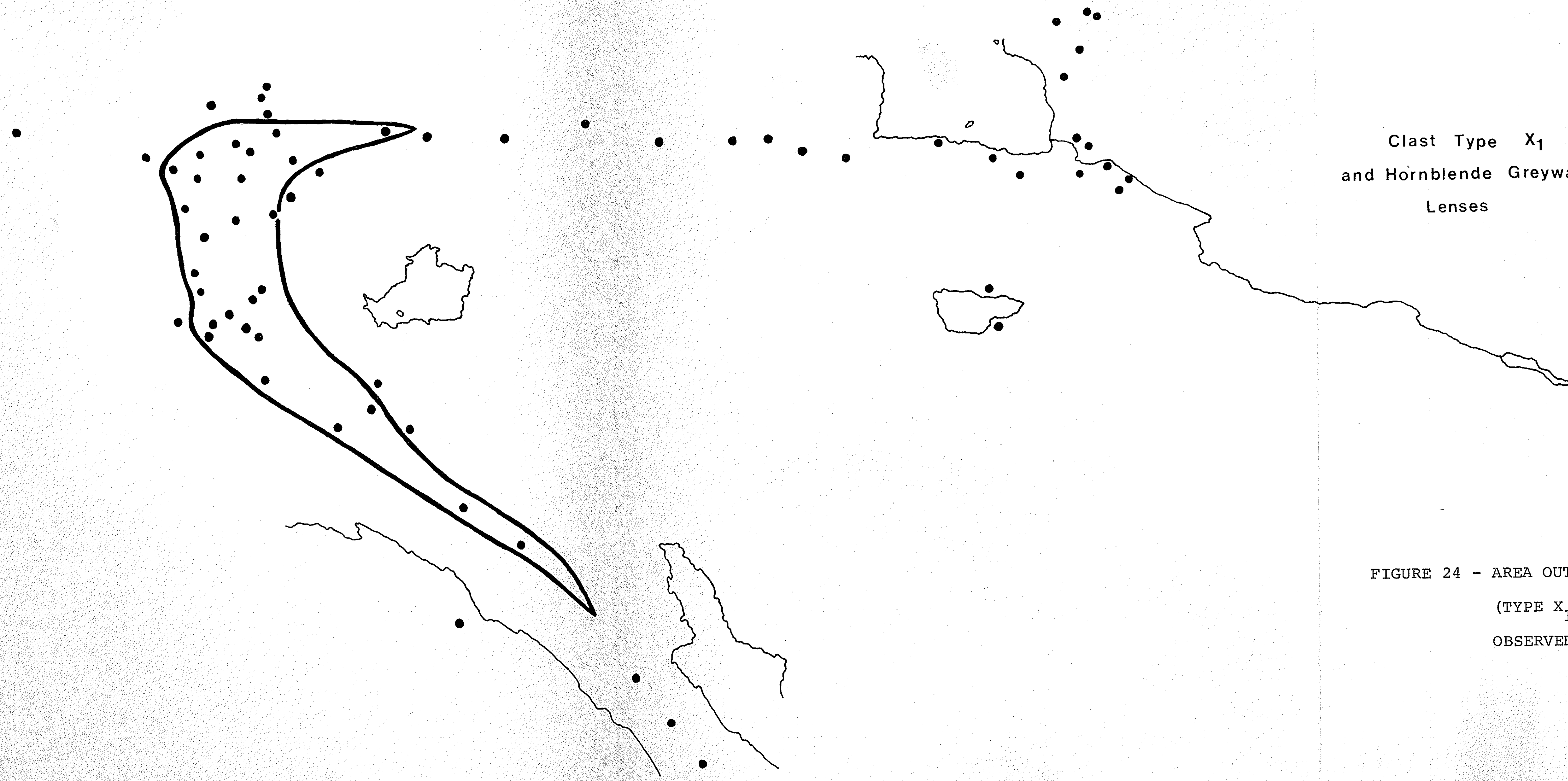


FIGURE 24 - AREA OUTLINED WHERE IRON FORMATION CLASTS (TYPE X_1) AND GREYWACKE LENSES WERE OBSERVED.



Clast Type X_1
and Hornblende Greywa
Lenses

FIGURE 24 - AREA OUT
(TYPE X_1
OBSERVED

vertical variations in clast concentrations apparent, but the existence of areas possessing differing variations in the stratigraphic section can be seen.

Because stratigraphic tops have been regionally established, clast concentration variations in a vertical extent from the base to the top of the section can be discussed. The lateral variation of clast concentrations, i.e. proximal to transitional facies, is taken to represent the downslope change in clast volume proportions.

2) Basic Lateral and Vertical Variations in Clast Concentrations

From Map 4, where the relative proportions of the major clast types have been plotted on a section, and from Figures 16 to 24, the following lateral and vertical variations of clast concentrations can be recognized.

Greywacke content (Map 4), as both clast and matrix, attains a maximum concentration around Starr Lake, ranging from a value of 10 per cent in the proximal facies to 40 per cent in the transitional facies. A decrease in content is seen in a vertical section on approaching the conglomerate through the pebbly greywacke and greywacke. Greywacke clasts are in larger quantities near the middle of the vertical section.

Medium grain tonalite clasts, type G_2, reach a slight maximum concentration in the upper parts of the section. A minimum content for this clast type is in the transitional facies to the northeast.

Mafic intrusive clasts, excluding type M_1, possess a maximum concentration in the higher parts of the section. They

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are concentrated in the proximal facies (area $\overline{\underline{II}}$ in Figure 2b) but there are none in the transitional facies. The fine grained granoblastic leucodiorite clasts, type M_1, exhibit a minimum concentration upwards in the section and remain approximately constant in amount in a lateral extent.

Volcanic sandstone clasts, type F_1, tend to reach a maximum concentration in the lower to middle portions of the section and remain constant to slightly increased in quantity in the transitional facies.

The maximum content of porphyritic felsic volcanic clasts is in the higher parts of the section and is slightly lower, to similar in concentrations, in the transitional facies.

The mafic schist clasts possess a strong minimum concentration in the upper portions of the section and remain essentially constant in quantity in the transitional facies.

Andesite porphyry clasts show a maximum content in the upper portions of the section and possess a strong minimum content in the transitional facies.

Both iron formation clasts and greywacke lenses (Figure 24) reach a maximum concentration in the upper parts of the section and are absent in the transitional facies.

Type G_1 clasts tend to possess a weak minimum concentration in the upper parts of the section and a strong minimum concentration towards the transitional facies. Proportions of type G_3 clasts are variable throughout the entire section.

Dacitic volcanic clasts show no recognizable trends.

The clast to matrix ratio can be interpreted to possess a maximum concentration in the higher stratigraphic sections and a minimum concentration in the transitional facies.

3) Specific Clast Concentration Variations in Defined Areas

Figures 16 to 24 illustrate that several clast types possess different lateral and vertical variations in the stratigraphic section. To facilitate the interpretation of these variations, the Booster Lake conglomerate was subdivided into seven areas as shown in Figure 2b.

Area I: This area exhibits a maximum concentration for the felsic volcanic group of clasts in the middle and lower portions of the conglomerate section. Specifically, these attain a maximum content at the base and decrease in amount to a minimum concentration near the top of the stratigraphic section. The andesite porphyry clast content has a maximum towards the middle and a minimum content near the top of the section (Area II is similar). The mafic intrusive clasts are most abundant in the upper stratigraphic section of Area I and remains in moderate content at this position along the fold limb. In contrast, type M_1 clasts display an elongate minimum concentration near the middle of the section. Area I shows a maximum concentration of type G_2 clasts towards the middle and top of the section, only to decrease in content at the very top. This variation of the type G_2 clasts differs markedly from Areas II, III and IV. Area I also differs for type S_1 clasts, in that there is a gradual increase in maximum concentration upwards in the section before a strong minimum content is found at the top of the section. This is in marked contrast to Areas II,

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III and IV. Iron formation clasts occur only in the middle and upper parts of the section (as in Area II). The total concentration of all clasts shows a maximum near the upper part of the section.

Area II: This area (Figure 2b) is situated in a fold closure where variations are more irregular than the trends found in areas on fold limbs. Local variable concentrations are superimposed upon major trends.

The volcanic sandstone clasts (Figures 2b and 17) exhibit maximum concentrations near the middle of the section, being in largest amounts to the south near Area I, with lower concentrations to the northeast. The porphyritic felsic volcanic clasts exhibit maximum concentrations towards the upper middle portion of the section and minimum concentration near the top. Also type F_2 clasts differ from type F_1 clasts in that the maximum concentration is shifted "downslope" to the northeast. Near Area I, type F_2 clasts are in low proportion with maximum content at the base of the section. Andesite porphyry clasts possess maximum concentrations near the southern limits of this area and near the middle of the fold closure. Also type I_2 clasts show a maximum concentration near the upper middle portion of the section, with lower contents near the top. The mafic intrusive clasts exhibit maximum concentration in the upper portions of the section, with a marked decrease in quantity near the top. These clasts (types M_2,M_3,M_{3-1} and M_4) have a similar distribution to type F_1 clasts, with greater concentrations near the southern extremities of the area with relative minimum concentrations to the northeast. Type M_1

clasts possess minimal concentrations towards the top of the section, with minor local variations. Type G_2 clasts exhibit minor variations throughout the vertical section, though a slight maximum concentration can be discerned in the middle and upper parts of the section. Mafic schist clasts possess minimum concentrations in the lower middle portion of the section, and maximum concentrations near the upper middle section and another stronger minimum at the very top of the section. The total clasts exhibit moderate maximums of concentration towards the middle upper portion of the section, with minor local variations, and minimal concentrations at the top.

Areas III and IV: These two areas are similar in regard to the relative variation in clast concentrations. Area IV has more greywacke and less type G_2 clast concentrations than Area III.

The volcanic sandstone clasts exhibit the trend of maximum concentrations near the middle or top of the section. In Area IV, type F_1 clasts have concentrations similar to those of Areas I, II and III. Andesite porphyry, mafic intrusive and iron formation clasts were not found in Area IV. Leucodiorite clasts (type M_1) have maximum concentration in the upper portion of the section. Their total concentration is greater than that of Areas I, II and III. Type G_2 clasts have maximum concentrations in the middle of the section in Area III, while minimum contents occur in the same position in Area IV. Much lower concentrations of type G_2 clasts were found in Area IV, as compared to Areas I, II and III. Mafic schist clasts possess minimum concentrations towards the top of the section in Area III, while the reverse occurs in Area IV. Area IV possesses greater or equal concentration of mafic schist clasts as compared to Areas I, II and III. Concentration of clasts show a maximum value towards the middle or top of the section for Areas III and IV, respectively. The concentration of clasts in Area IV is lower than in Area III.

Area V: This area is situated in the same structural position as Area III (north limb of an overturned similar fold) and possesses clast concentrations similar to Areas II and III. If the conglomerate is unfolded, the two areas (III and V) would occupy different positions along the original lateral extent of a submarine fan. It is distinct from Areas II and III in the relatively higher concentration of hornblende porphyritic felsic volcanic clasts and low to neglible tonalite clast content. The lower greywacke, higher porphyritic felsic volcanic, higher mafic schist clasts and higher clast to matrix ratios makes this area distinct from Area IV.

Area V is similar to Areas II and III in relation to type F_1, M_1, M_3 and S_1 clast concentrations.

Area VI: This area is interpreted to be part of a "more distal" facies of sedimentation of Area V on the basis of a lower ratio of clast to matrix, and smaller sizes of clasts. It is structurally related to Area IV in occupying the equivalent D_2 fold closure. It is characterized by the absence of the following clast types; I_2, M_1, M_2, M_3 and M_4. This area is similar to Areas IV and V in type F_1 concentration. Type G_2

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clast concentrations are similar to that found in Area IV, but are in greater concentrations than that found in Area V. It also differs from Areas IV and V in the lower type F_2, type S_1 and total clast concentrations.

Area VII: This area comprises part of the lower conglomerate bed (see: Figure 3 and Geometry of the Sedimentary Units and Generalized Section) and has a different assemblage of clasts as compared to the middle conglomerate bed.

Area VII is distinct from the other areas in the greater concentration of type S_1, M_2, M_3 and M_4 clasts and the lower content of type G_2 clasts. This area is also distinct with the absence of andesite porphyry clasts and lower clast to matrix ratios.

a. Three Component Clast Concentration Variations

Another approach used to visualize variations between clast types was to plot concentrations on a triangular diagram.

Figure 25 illustrates the variations between the clast types G_2, F_1 and F_2. Squares on this figure are for consideration of vertical variations of clast concentrations in the stratigraphic section at stations which may be located on Map 1. From Figure 25, it is seen that the relative vertical variation between G_2 and F_1 clasts is effectively constant, though F_1 is in higher concentrations at the top of the section. F_2 clasts possess a maximum concentration in the middle portion of the section that produces a hairpin loop in the trend lines. Laterally, the proportion of G_2 clasts diminishes from the proximal facies to the transitional facies. Type F_2 clasts occur in constant

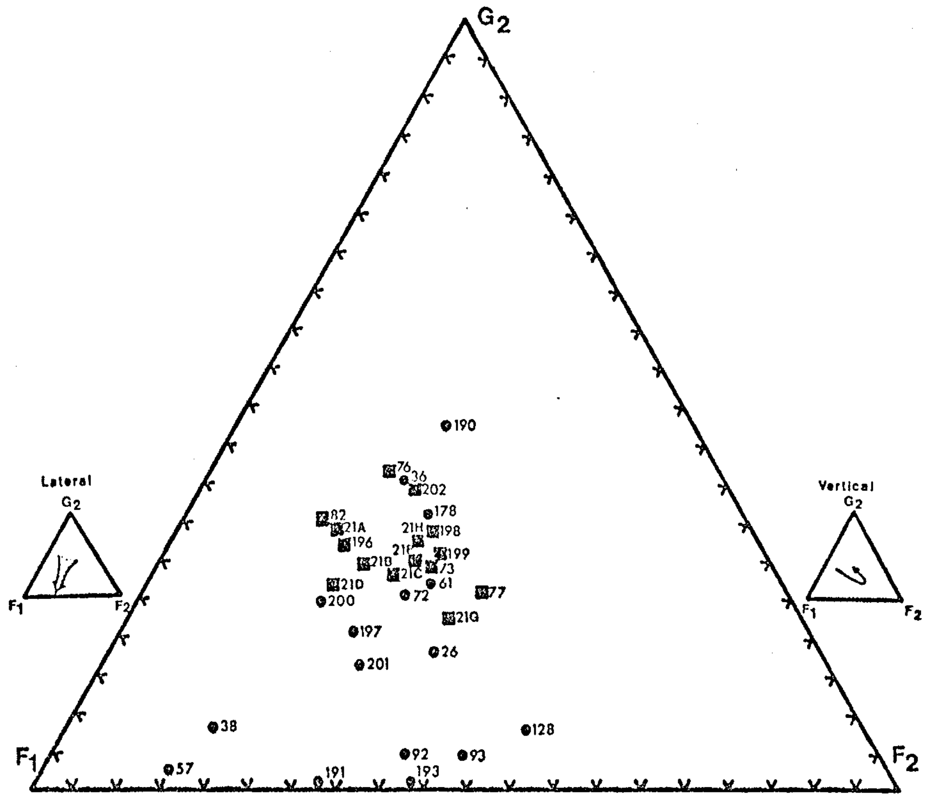

FIGURE 25 - TRIANGULAR DIAGRAM TO ILLUSTRATE LATERAL AND VERTICAL VARIATIONS BETWEEN VOLCANIC SANDSTONE (F_1), PORPHYRITIC FELSIC VOLCANIC (F_2) AND TONALITE (G_2) CLASTS. SQUARED STATIONS ARE USED FOR INTERPRETATION OF VERTICAL VARIATIONS AND ALL STATIONS WERE CONSIDERED FOR LATERAL VARIATIONS.

amounts, relative to the other clast types, into the transitional facies. Type F_1 clasts exhibit a strong relative maximum concentration "transitionally".

Figure 26 illustrates the variations between clast types G_2, F_1 and mafic intrusive clasts. Mafic intrusive clasts possess a maximum concentration in the middle portion of the section, with minimum concentrations relative to the other two clasts, at the base and top of the section. The vertical variation between G_2 and F_1 clasts is constant, though there is a much larger increase of F_1 clasts relative to G_2 clasts to the top of the section as compared with that found in Figure 25. Laterally, type G_2 clasts do not show as much of a decrease in concentration as in Figure 25, while volcanic sandstone clasts show perhaps a relative maximum concentration into the transitional facies. Mafic intrusive clasts possess a relative minimum concentration relative to the other clast types in the transitional facies.

4) Significance of the Clast Concentration Variations

Variation in clast concentrations and clast to matrix ratios permitted the distinction of proximal and transitional facies of environment.

The lateral and vertical variations can be related to the successive unroofing, exposure and weathering of calc-alkaline subvolcanic gabbroic to tonalitic intrusive rocks. Pyroclastic (polymictic breccias) and epiclastic sedimentation were consanguineous with uplift of this volcanic pile.

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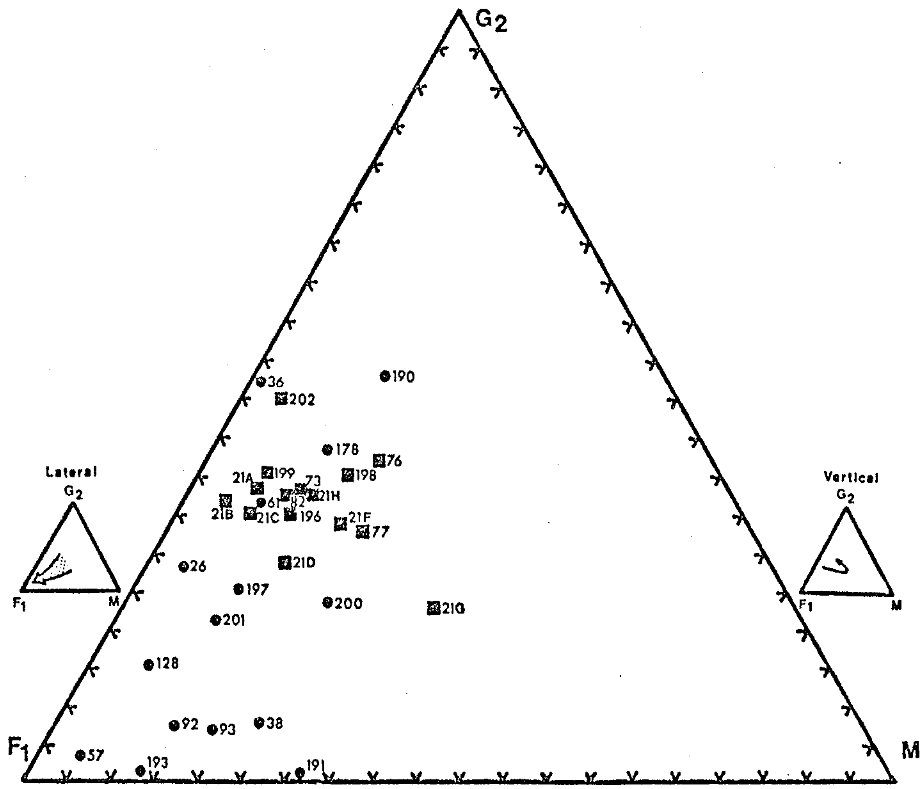

FIGURE 26 - TRIANGULAR DIAGRAM TO ILLUSTRATE LATERAL AND VERTICAL VARIATIONS BETWEEN VOLCANIC SANDSTONE (F_1), MAFIC INTRUSIVE CLASTS (M_1, M_2, M_3, M_4) AND TONALITE (G_2) CLASTS. SQUARED STATIONS ARE USED FOR INTERPRETATION OF VERTICAL VARIATIONS AND ALL STATIONS WERE CONSIDERED FOR LATERAL VARIATIONS.

The volcanic sandstone clasts (type F_1) are interpreted to indicate two cycles of erosion and deposition. Early weathering of rhyolitic volcanic flows produced quartz and feldspar-rich volcanogenic sandstone. This rock type was formed near the top and outer margins of the volcanic pile, and on further uplift was first to shed clasts into the sedimentary basin, thus being in greater concentration near the basal portions of the proximal facies. Later tectonic activity exposed more volcanic sandstone so that this clast type increases in concentration higher in the section of the transitional facies (see Figure 27). Perhaps earlier type F_1 clasts were suspended by clast to clast dispersion because of the clasts' lighter relative specific gravity, and thus moved further downslope to be deposited last when the flow subsided.

Clast type F_2 is concentrated at the base of the section of the proximal facies. Therefore, the source rock was unroofed and eroded during the early stages of orogeny. Because tonalite clasts are concentrated in the upper portions of the proximal facies, erosion of this source rock occurred later in the orogeny than for type F_2. Tonalite clasts possess a minimum concentration in the transitional facies with relative higher content in the basal parts of the section as shown in Figure 27. The mafic intrusive clasts hypothetically had an intrusive source near the base of the volcanic pile that supplied clasts later into the sequence. Figure 27 shows a maximum concentration for the mafic intrusive clasts near the top of the sequence in the proximal facies and in the transitional facies relative maximum concentrations are found in the lower part of the section and in lesser amounts than in the proximal facies. Andesite porphyry

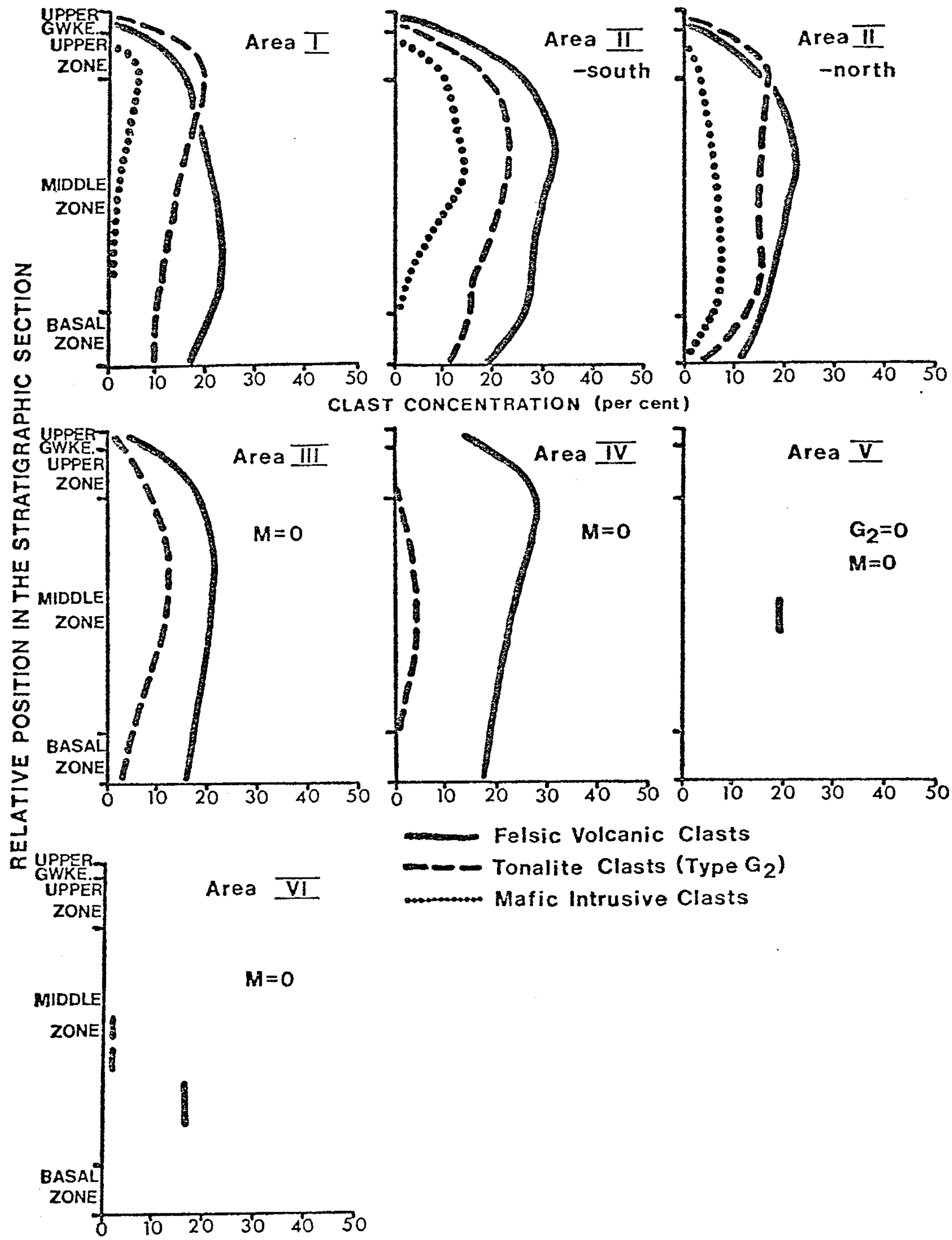

FIGURE 27 - DIAGRAMS ILLUSTRATING VERTICAL VARIATIONS IN FELSIC VOLCANIC, MAFIC INTRUSIVE AND TONALITE CLAST CONCENTRATIONS FROM THE MIDDLE CONGLOMERATE BED ALONG THE LATERAL EXTENT OF THE BOOSTER LAKE CONGLOMERATE (SEE FIGURE 2b FOR AREA LOCALITIES).

clasts would have source bodies located near the middle or upper parts of the volcanic-subvolcanic complex. Thus type $\overline{\underline{I}}_2$ clasts would be supplied early to the basal parts of the proximal facies.

A maximum in the clast to matrix ratios occurs in the higher parts of the section in the proximal facies, thus this indicates better sorting late in the history of the subaqueous sedimentary gravity flow. This ratio diminishes laterally from the proximal to transitional facies, which indicates that the flow had decreased in strength and this is interpreted as indicating the downslope direction.

Other clast types (I_1, S_1, S_2, X_1 and X_2) do not exhibit any lateral or vertical variations that can be related to the exposure and supply of clastic material from a source into the basin. These latter apparent unrelated lateral and vertical variations may be related to: multiple independent uplifts of source areas that varied in time and exposure of source material; longshore drift; or remobilization of deposited sediments by submarine gravity flows that resulted in poor sorting and mixing of clast types.

SEDIMENTOLOGICAL ASPECTS OF THE BOOSTER LAKE CONGLOMERATE AND GREYWACKE

1) Geometry of the Sedimentary Units and Generalized Section

The conglomerate and greywacke have been affected by three phases of superimposed deformation. This style of folding affected the hypothetical original clastic wedge of conglomerate and thus precludes exact delineation of the original shape and size.

As a result of the complex folding, the thickest bed of the Booster Lake conglomerate (the middle conglomerate bed) is approximately 90 m (300 ft) thick on the limbs of the fold and up to 700 m (2300 ft) at the fold closures. The original thickness is between these limits, and a working estimate of 600 m was taken on the basis that thickening at the closure may have been 10 - 20%. Total thickness of the entire clastic sequence is approximated at 2459 m. A generalized section of the Booster Lake succession is shown in Figure 3. The sediments lie unconformably on an erosional surface developed over the felsic volcanic and polymictic breccia units (Figure 1.).

At the base of the section is approximately 152 m of massive, moderately laminated biotite-rich greywacke with sparse clasts. The upper contact of this lower greywacke bed is not exposed. The overlying lower conglomeratic bed is approximately 122 m thick being composed of moderately sorted, well rounded, massive, pebble to cobble conglomerate. This conglomerate (Area VII) is characterized by low concentrations of G_2, S_1 and high concentrations of F_2 and mafic intrusive clasts.

Above this coarse clastic unit is a 365 m thick middle greywacke unit with interbedded pebbly greywacke layers. The lower contact is not exposed. This bed differs from the lower greywacke bed by the presence of well sorted, lenticular to layer-like pebbly greywacke. The number of interbedded pebbly greywacke layers, the number of clasts, the amount of tonalite clasts and the maximum size of clasts increase gradually into the overlying conglomerate.

The planar basal contact of the middle conglomerate bed is gradational with the underlying pebbly greywacke, and is illustrated in Figures 28 to 30. This major bed is approximately 600 m thick and the contacts are well exposed. This bed has been tentatively divided into three zones. The basal zone is poorly sorted, subangular to subrounded, boulder to coarse pebble conglomerate. The basal portions of this zone are typified by poor inverse graded bedding, poor sorting, high contents of clast types G_2 and S_1, low contents of F_1, F_2 and M.

The basal zone of the middle conglomeratic bed passes gradationally into a middle zone where the clasts are relatively better rounded, moderately sorted and of cobble to pebble size. In this zone, mafic intrusive, porphyritic felsic volcanic, volcanic sandstone, intermediate volcanic and iron formation clasts are dominant. The middle zone is also typified by minor large and small-scale bedding, greywacke lenses and diffuse hornblende-rich greywacke matrices.

A narrow upper zone of pebble to cobble-sized clasts that are well rounded, moderately to poorly sorted and nonbedded occurs at the top of the middle conglomerate bed.

The upper boundary of the middle conglomerate bed is sharp

FIGURE 28 - GREYWACKE AND PEBBLY GREYWACKE FROM THE MIDDLE GREYWACKE BED. NOTE THE DISCORDANCE OF THE LITHOLOGIES' CONTACTS (STATION 66A).

FIGURE 29 - PEBBLY GREYWACKE AT THE TOP OF THE MIDDLE GREYWACKE BED (STATION 66B).

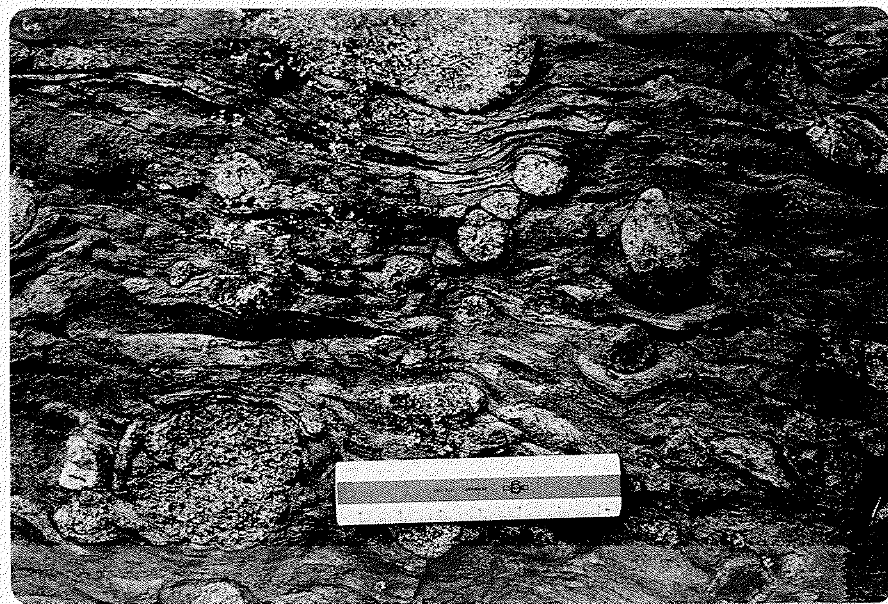

FIGURE 30 - POORLY SORTED,PEBBLE TO COBBLE CONGLOMERATE FROM THE BASAL ZONE OF THE MIDDLE CONGLOMERATE BED (STATION 66B).

FIGURE 31 - CONCORDANT CONTACT BETWEEN THE UPPER ZONE OF THE MIDDLE CONGLOMERATE BED AND THE UPPER GREYWACKE BED (STRATIGRAPHIC TOP TO THE LEFT). A NON-LAMINATED QUARTZ-RICH GREYWACKE LIES ON TOP OF THE CONGLOMERATE (30m SOUTH OF STATION 26).

as shown in Figure 31, with an overlying massive quartz-rich greywacke. Higher up in the section, minor pebbly greywacke is interbedded with biotite-rich greywacke as shown in Figure 32. This interbedding is of a minor scale as compared to that found below the middle conglomerate bed. The middle conglomerate is concordant with the underlying greywacke bedding, but a slight discordance is found with the overlying greywacke.

The overlying upper greywacke bed is massive, nongraded and poorly cross-stratified. It contains minor pebbly greywacke layers, conglomeratic lenses and hornblende-rich greywacke layers. The conglomerate lenses are poorly graded as shown in Figure 33. This upper unit is approximately 1070 m thick; because a synformal axis passes through this unit, the above value is a minimal estimated thickness.

Another minor conglomerate bed is located in the synformal axis between Starr and Davidson Lakes (Figure 3 and Map 2). Although it was not investigated in detail, this rock appeared to be a well rounded, well sorted, pebble conglomerate with a relatively low content of tonalite clasts.

2) Sedimentary Textures and Structures

Clasts range in size from granule (2 - 4 mm), pebble (4 - 64 mm), cobble (64 - 264 mm) to boulder (>264 mm) in size, but the cobble to coarse pebble-sized clasts are the most common. Clast shapes range from subangular to subrounded.

Sorting in general is poorly developed, but occasionally appears as layers and patches of relatively better sorted clasts, as shown in Figure 34.

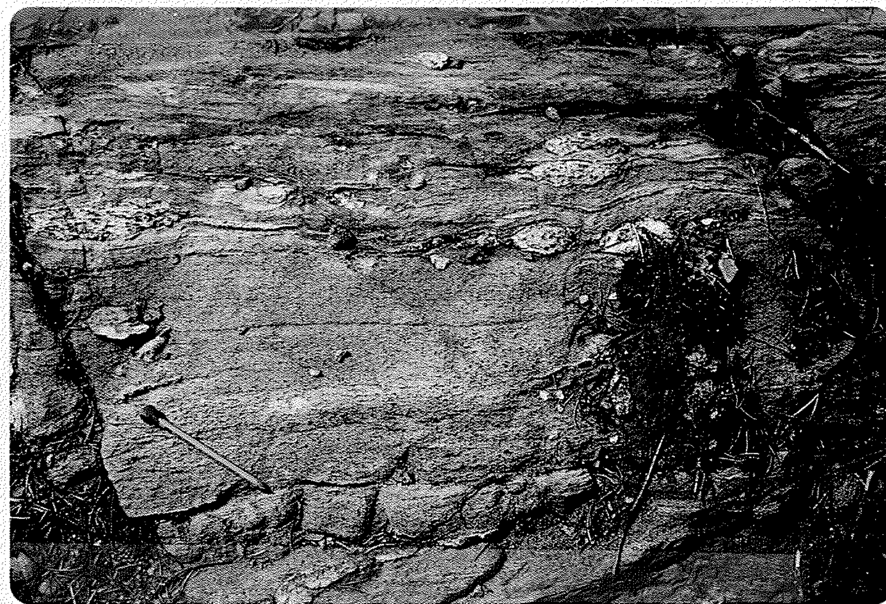

FIGURE 32 - THE UPPER GREYWACKE BED WITH MINOR PEBBLY GREYWACKE LAYERS. STRATIGRAPHIC TOP IS TO THE TOP OF THE PICTURE. NOTE THE CONCORDANCE OF THE LOWER CONTACT OF THE PEBBLY GREYWACKE LAYER OVER THE GREYWACKE AND THE UPPER DISCORDANT CONTACT AT THE TOP OF THE PICTURE (30m SOUTH OF STATION 26).

FIGURE 33 - POORLY GRADED CONGLOMERATIC LENS IN THE UPPER GREYWACKE BED. STRATIGRAPHIC TOP TO THE LEFT (STATION 27).

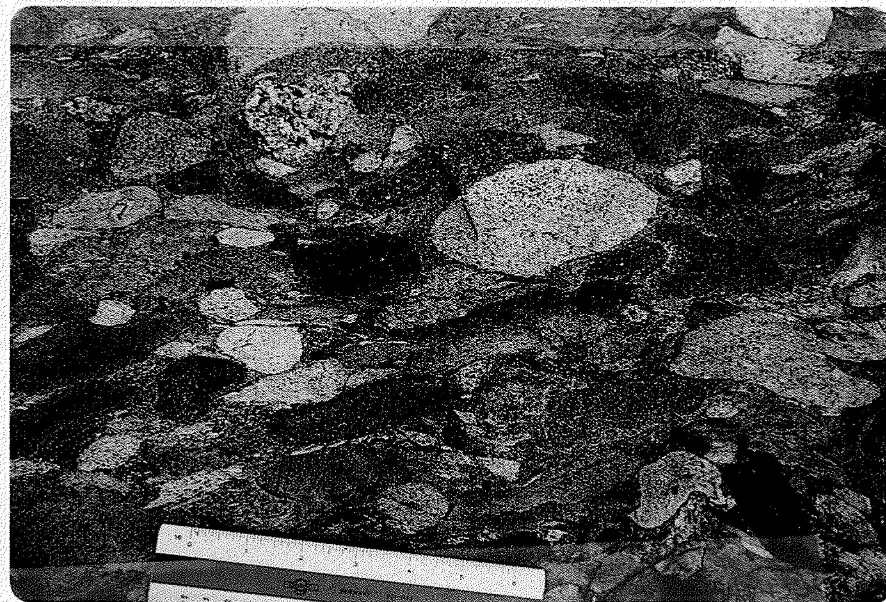

FIGURE 34 - RELATIVELY BETTER SORTING AND ROUNDING IN THE MIDDLE ZONE OF THE MIDDLE CONGLOMERATE BED AS COMPARED TO OTHER ZONES IN THE SAME BED. (STATION 21C).

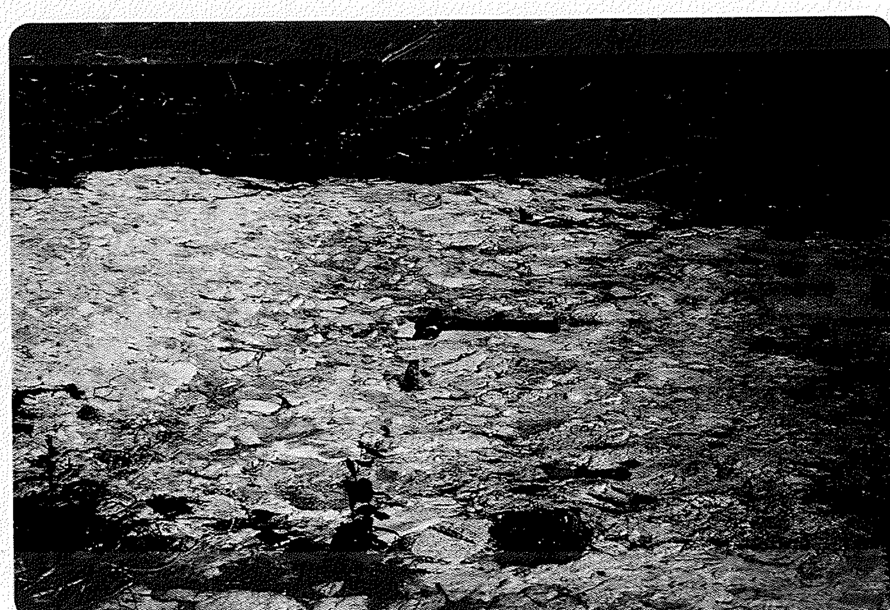

FIGURE 35 - LARGE-SCALE BEDDING IN THE CONGLOMERATE. PEBBLE TO COBBLE-SIZED, LOW MATRIX BED ON THE LEFT; COBBLE TO BOULDER-SIZED, RELATIVELY HIGHER MATRIX CONTENT BED IN THE CENTER (HAMMER); AND PEBBLE TO COBBLE-SIZED, LOW MATRIX, GREYWACKE LENS-RICH BED ON THE RIGHT (STATION 69).

The conglomerate is essentially massive, as portrayed in Figures 4 and 5. A few examples of very large-scale bedding were recognized by differing clast sizes, clast types and concentrations, and the relative degree of sorting. These large-scale beds are in the order of 2 to 5 meters wide as shown in Figure 35. Minor small-scale bedding was also observed by the presence of well sorted, well rounded granule to pebble-sized clasts in a massive cobble conglomerate. This is shown in Figure 36 and occurs on a scale of 10 to 50 centimeters.

Graded bedding in the conglomerate on outcrop scale is not readily detectable. A very thin minor zone of inverse grading is found at the base. On examination of the average maximum clast size throughout the entire middle conglomerate bed, an apparent gradual normal graded bedded to massive sequence is detected.

In the proximal facies, the conglomerate can be described as massive and disorganized. Approaching the transitional facies, an inverse to normal graded bedded or massive sequence typifies the internal organization of the conglomerate (see Figure 2a). In the transitional facies, structures in the conglomerate and greywacke correspond to the normal graded stratified model of Walker (1975, 1976), as shown in Figure 37. The normal graded stratified model is evidenced by the presence of distinct normal graded bedding in the conglomerate, poor oblique stratification, alternating greywacke and pebbly greywacke layers that possess good laminations and crossbeds. The inverse to normal graded, normal graded stratified and

FIGURE 36 - SMALL-SCALE BEDDING PARALLEL TO D_1 (COMPOSITIONAL LAYERING) AND OBLIQUE TO THE CLAST ELONGATION (D_2). BEDDING EVIDENCED BY DIFFERING CLAST TYPES, SIZES, CONCENTRATIONS AND DEGREE OF SORTING (STATION 69).

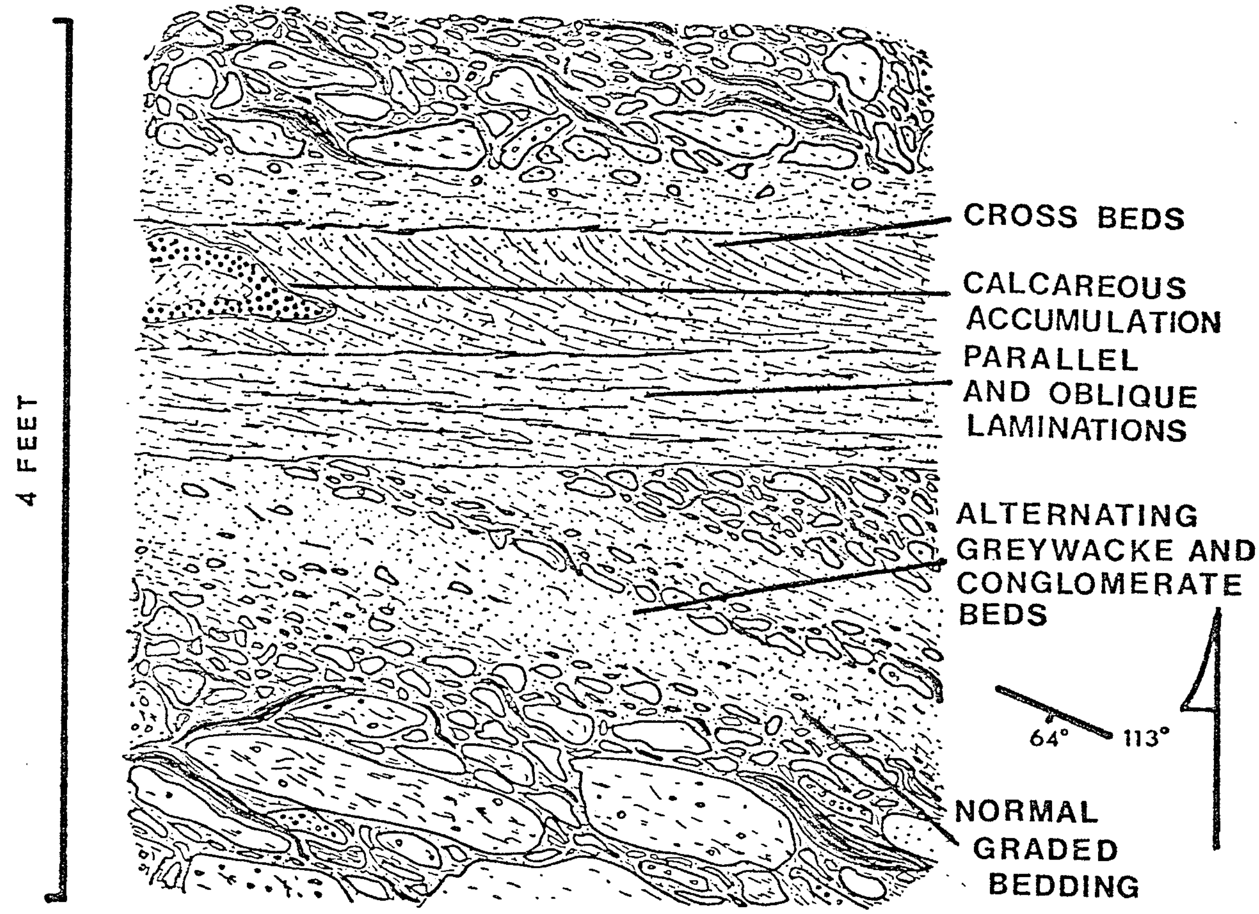

FIGURE 37 - A DRAWING FROM AN EXPOSURE IN THE TRANSITIONAL FACIES OF THE BOOSTER LAKE CONGLOMERATE AND GREYWACKE ILLUSTRATING THE TEXTURAL FEATURES AND INTERNAL ORGANIZATION THAT CHARACTERIZE THE NORMAL GRADED STRATIFIED MODEL OF WALKER (1975, 1976) (STATION 193).

massive disorganized nature of the conglomerate can be compared to the examples of the internal organizations of models proposed by Walker (1975, 1976) for resedimented conglomerate.

Cross-stratification was interpreted from low angle cross-laminations in the greywacke. The laminations may be the result of metamorphic segregation and or of tectonic origin. Overprinting of original laminations by a tectonic foliation should also be considered. No internal examples of cross-stratification were found in the conglomerate.

Associated within the middle conglomerate bed, in the middle zone, are massive discontinuous grey biotite-rich greywacke lenses that possess poor laminations, no visible grading and sharp contacts. The lenses are aligned normal or oblique to the adjacent clast elongations and presumably represent an original compositional layering. Also present are discontinuous, diffuse lenses of hornblende-rich greywacke. These hornblende-rich greywackes occur as very diffuse patches with undefineable boundaries and enclosing only volcanic sandstone clasts (as illustrated in Figure 38); also at the base of grey biotite-rich greywacke lenses with sharp flat upper contacts with the biotite greywacke.

Rare hornblende-rich greywacke accumulations with relatively flat tops, curved bottom contacts and possessing lensoid to layered shapes were noted. The base of these lenses, as shown in Figure 39, are highly irregular, with clasts elongated parallel to D_2 foliation and cross-cutting the basal contacts. The basal contacts of these lenses show downward extensions or "fingering" of the hornblende-rich greywacke between the

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FIGURE 38 - DIFFUSE DISCONTINUOUS HORNBLENDE-RICH GREYWACKE MATRIX AND VOLCANIC SANDSTONE CLASTS (STATION 21C). THESE MAFIC PATCHES, AS CONTAINING ONLY ONE LITHOLOGICAL CLAST TYPE, MAY POSSIBLY REPRESENT MATERIAL OF A PREVIOUS CLASTIC UNIT.

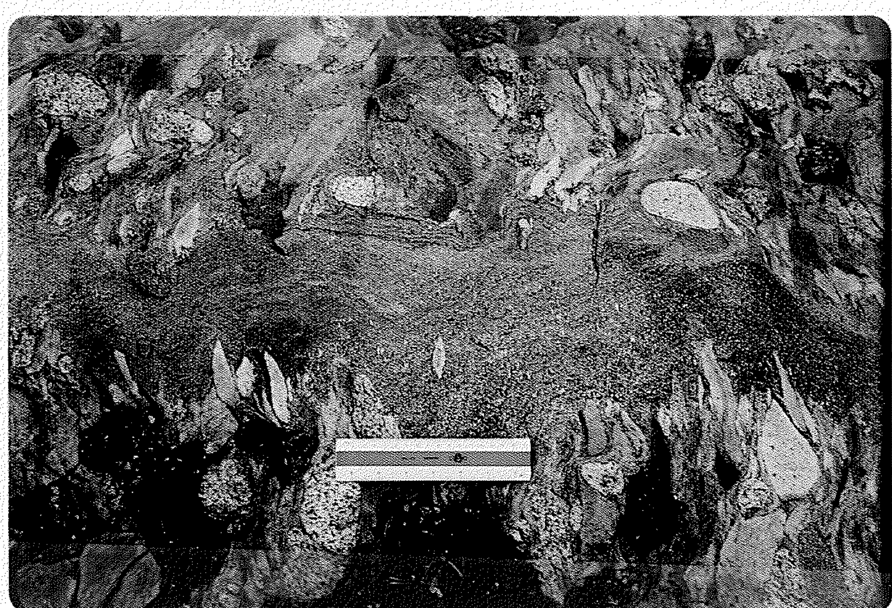

FIGURE 39 - A HORNBLENDE-RICH GREYWACKE LENS IN THE MIDDLE ZONE OF THE MIDDLE CONGLOMERATE BED. BASE OF THE LENS IS SHOWN BY THE RULER (STATION 21D). STRATIGRAPHIC TOP TO THE TOP OF THE PICTURE.

clasts (as shown in Figure 39) indicating some sort of selective winnowing or removal of the biotite-rich greywacke, presumably by erosion. The grey biotite-rich greywacke is present as the matrix for the conglomerate overlying the lens. The lower and central portions of these hornblende-greywacke lenses contain volcanic sandstone clasts which are graded upwards and outwards to the outside lateral contacts. This is taken to suggest that a faster moving traction current was in existence on the outer and basal portions of the lenses. Currents slowed during the filling of the central parts of the channel and allowed deposition and grading of larger clasts.

The upper central portions of these lenses are massive with minor, widely distributed clasts. The upper zone has well developed laminations that are parallel to the top surface. The overlying conglomerate has not appreciably eroded the upper part of these lenses, but the deposition of the clasts has produced "load-like" structures as evidenced by the warping of the laminations, as shown in Figure 39. The average dimension of these lenses is 20 - 50 cm thick by 50 - 150 cm wide.

3) Classification of the Conglomerate and Greywacke

According to Pettijohn's (1975) classification scheme for conglomerates, the coarse epiclastic rocks from Booster Lake can be described as clast supported, volcanogenic, cobble to coarse pebble, extraformational, polymictic orthoconglomerates. The greywacke, though now highly recrystallized to biotite schist, could perhaps have been originally volcanogenic feldspathic greywacke.

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PROVENANCE, DEPOSITIONAL ENVIRONMENT AND MECHANISM

1) Provenance of the Conglomerate Clasts

To indicate a general direction towards a suitable source area, the distribution of clast to matrix ratios was examined. Using this factor, a proximal facies (88 - 95 per cent volume proportion of the conglomerate as clasts) and a transitional facies (clast concentration 44 - 68 per cent) was recognized as shown in Figure 2a. The distribution of these lithofacies can be correlated with the distribution of clast types, clast sizes and sedimentary textures and structures.

Another means employed to delineate a provenance was the examination of the distribution of maximum clast sizes. In order to attempt this, the measurement in several outcrops of ellipsoidal strain axial ratios of several clast types were measured. Then the axial ratios of the ten largest clasts were determined (see: Structure chapter for discussion). Figure 40 shows a decrease in the average maximum Y (ellipsoidal strain axes: $X<Y<Z$) axes to the northeast, for the clasts of type G_2. In the Booster Lake area, it was readily apparent that there is an eastward increase in the degree of stretching of the clasts and corresponding increases in metamorphic grade and recrystallization. Figure 41 shows elongation of Y relative to axes X, i.e. low X to Y ratios, on the fold limbs. Comparison of the two fold closures illustrates a neglible increase in the stretching of the Y axes relative to the X axes to the northeast. As there is a marked decrease in elongation of the Y axes to the northeast (Figure 40), and a poor to non-

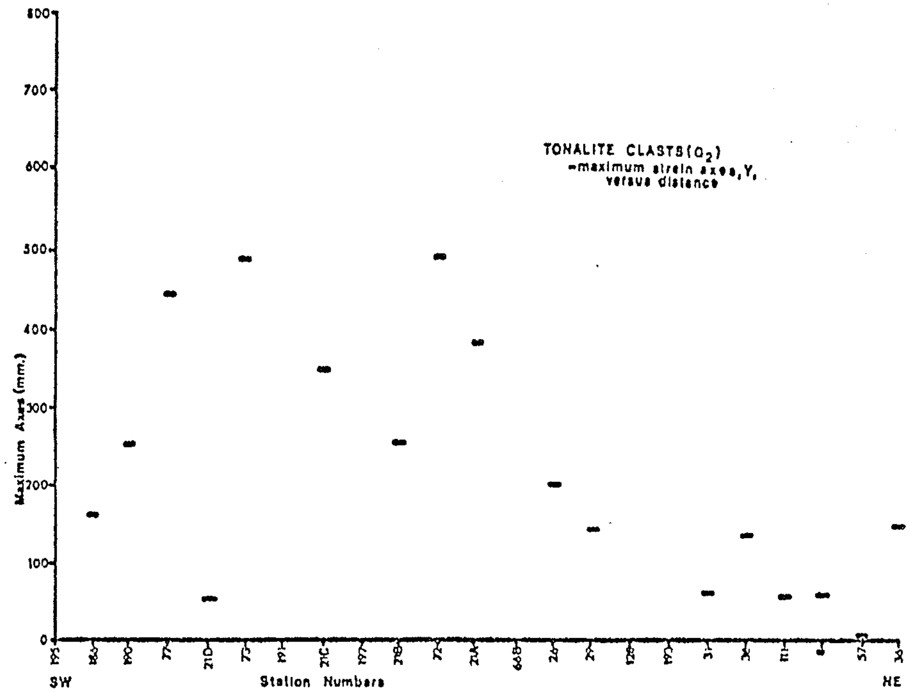

FIGURE 40 - TONALITE CLASTS (G_2); THE MAXIMUM Y AXES (ELLIPSOIDAL STRAIN AXES X<Y<Z) VERSUS RELATIVE DISTANCE FROM THE PROPOSED PROVENANCE (INCREASING DISTANCE AWAY FROM THE SOURCE TO THE RIGHT ALONG THE X-AXIS).

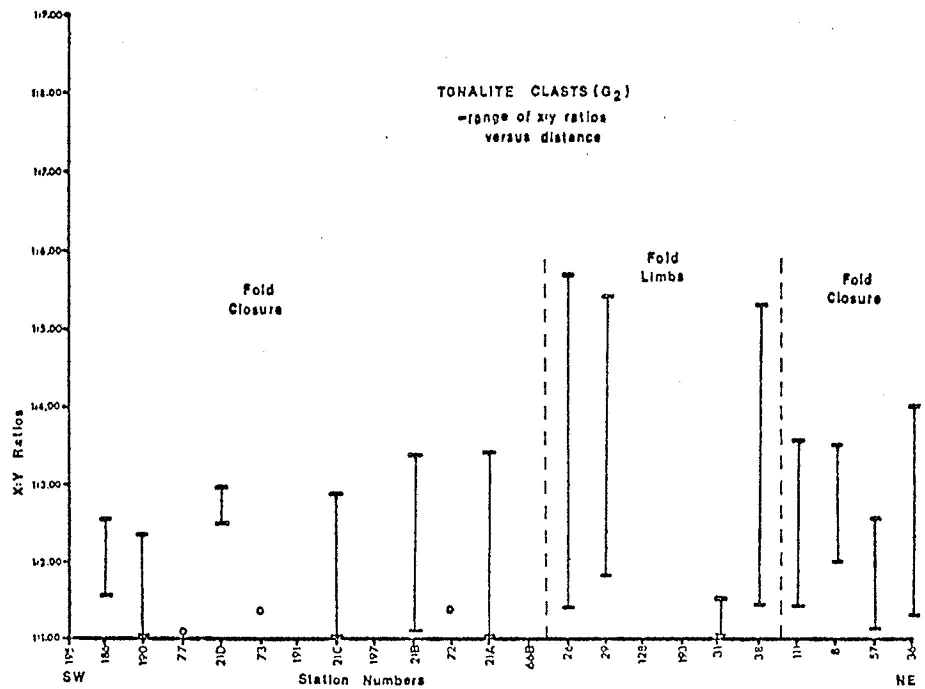

FIGURE 41 - TONALITE CLASTS (G_2): RANGE OF X:Y ($X<Y<Z$) RATIOS VERSUS RELATIVE DISTANCE FROM THE PROPOSED PROVENANCE (INCREASING DISTANCE AWAY FROM THE SOURCE TO THE RIGHT ALONG THE X-AXIS).

existent increase in the stretching of the Y axes relative to X axes to the northeast, it must be concluded that the maximum size of the tonalite clasts decreases to the northeast.

Clasts of type F_2 also show a decrease in the maximum Y axes to the northeast, as illustrated in Figure 42. Maximum X to Y ratios in the fold closures of the proximal and transitional facies are roughly equivalent as shown in Figure 43. Figure 44 illustrates almost a constant value of maximum Y axes transitionally for type F_1 clasts. Figure 45 displays a constant to poor increase of the range of X to Y ratios in the transitional facies.

Figures 46 to 48 show the decrease in maximum Y axes to the northeast for clast types G_2, F_2 and F_1.

Therefore, in spite of increased deformation to the east, there is evidence of a decrease in maximum clast size from proximal to transitional facies (northeast from Booster Lake to Starr Lake).

Detailed petrographic studies were made on possible source rocks in the Bird River greenstone belt, particularly in the areas southwest of Booster Lake.

Initially a"cratonic" borderland was assumed to be the source for the tonalite clasts. Such a "craton" may have been made up of the granitoid plutons on three sides of the greenstone belt, as shown in Figure 1. However, the Maskwa Lake pluton consists of several compositional phases ranging from monzonite to quartz diorite (but not tonalite, McRitchie, 1971). Modal analyses for the Maskwa Lake pluton is shown in Table 5b. Table 5b also shows the modal analyses of the Marijane Lake pluton, outcropping around Davidson Lake, to

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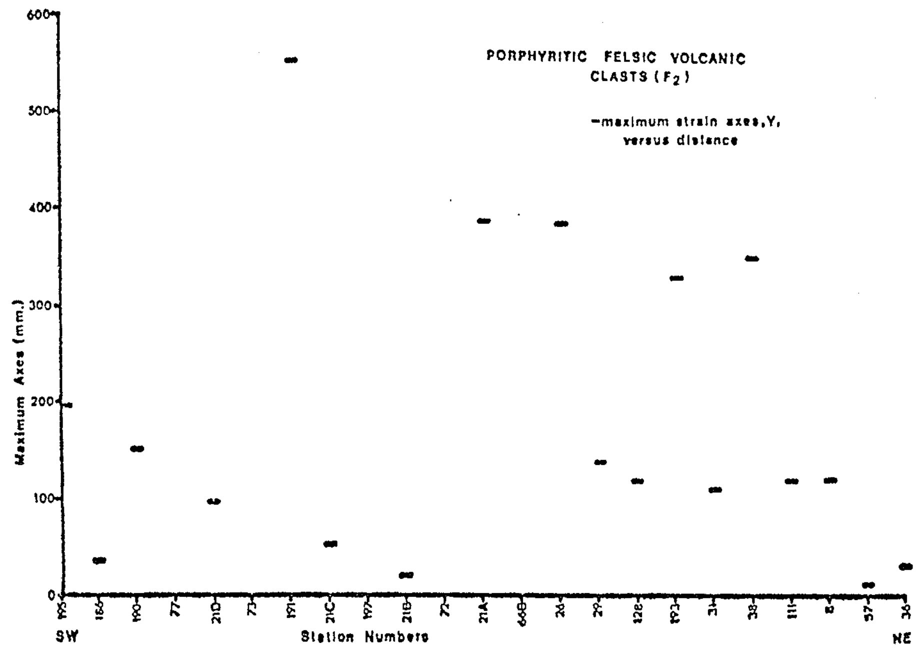

FIGURE 42 - PORPHYRITIC FELSIC VOLCANIC CLASTS (F_2); THE MAXIMUM Y AXES VERSUS RELATIVE DISTANCE.

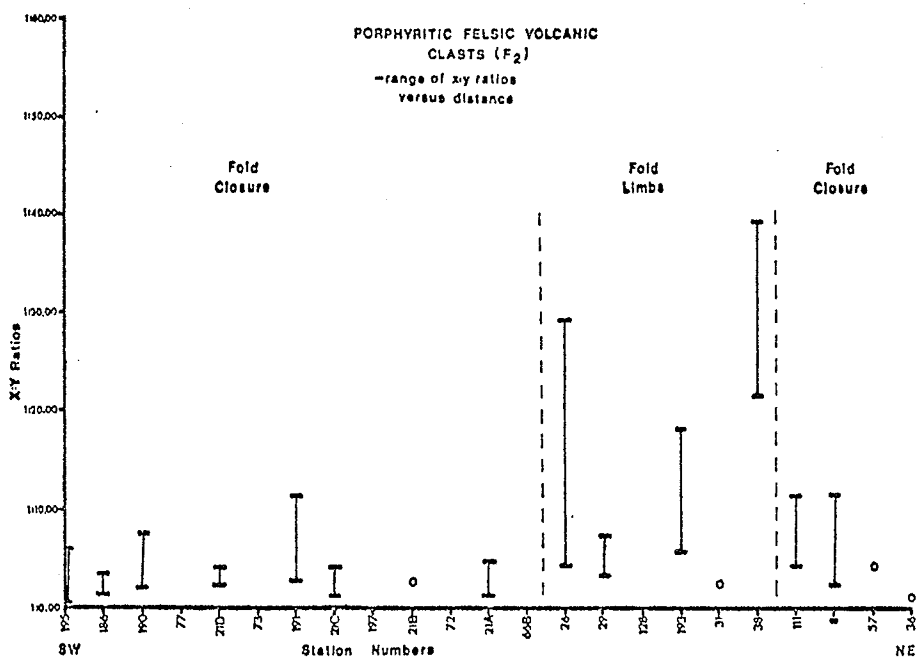

FIGURE 43 - PORPHYRITIC FELSIC VOLCANIC CLASTS (F_2);
RANGE OF X:Y RATIOS VERSUS RELATIVE DISTANCE.

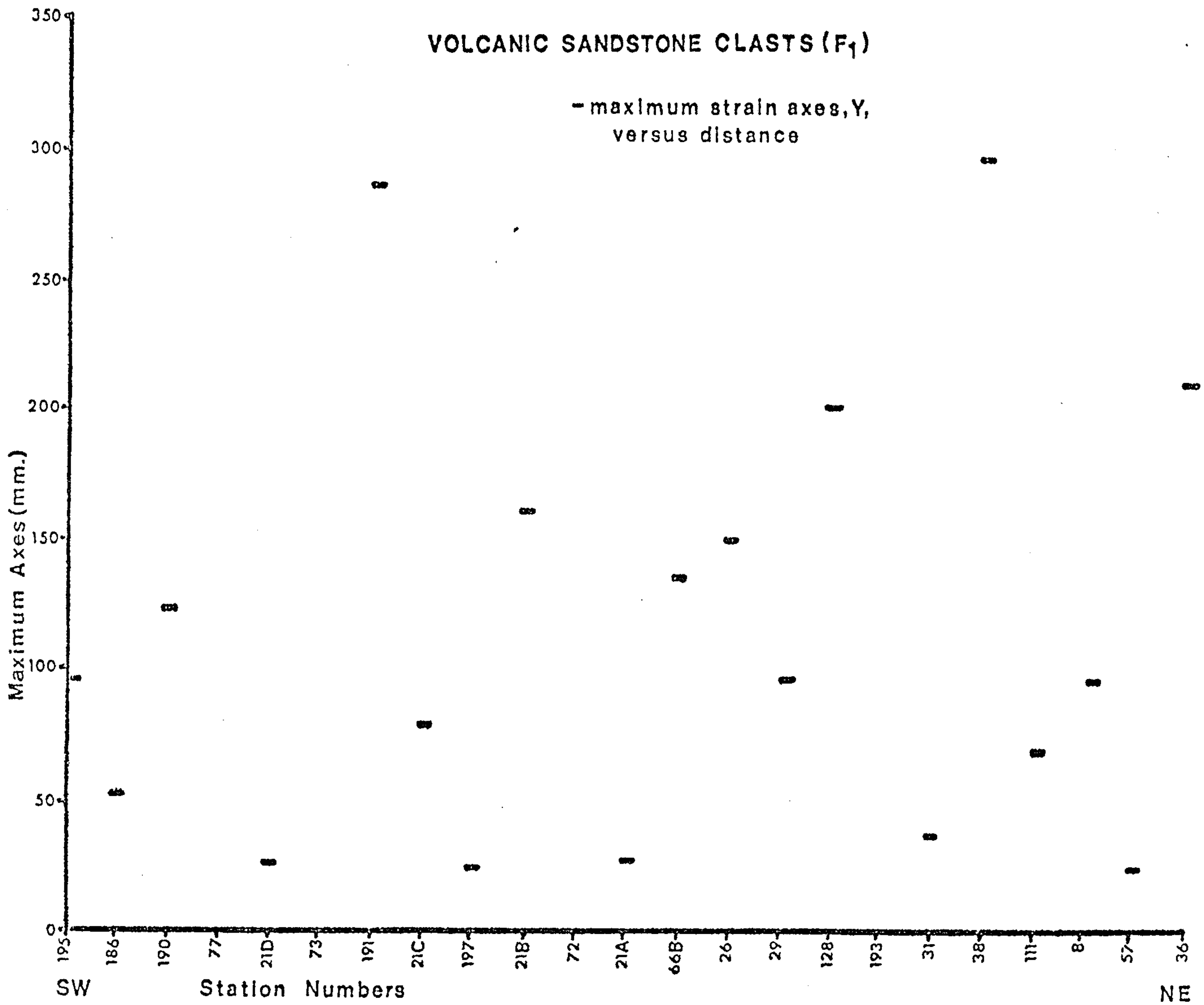

FIGURE 44 - VOLCANIC SANDSTONE CLASTS (F_1); THE MAXIMUM Y AXES VERSUS RELATIVE DISTANCE.

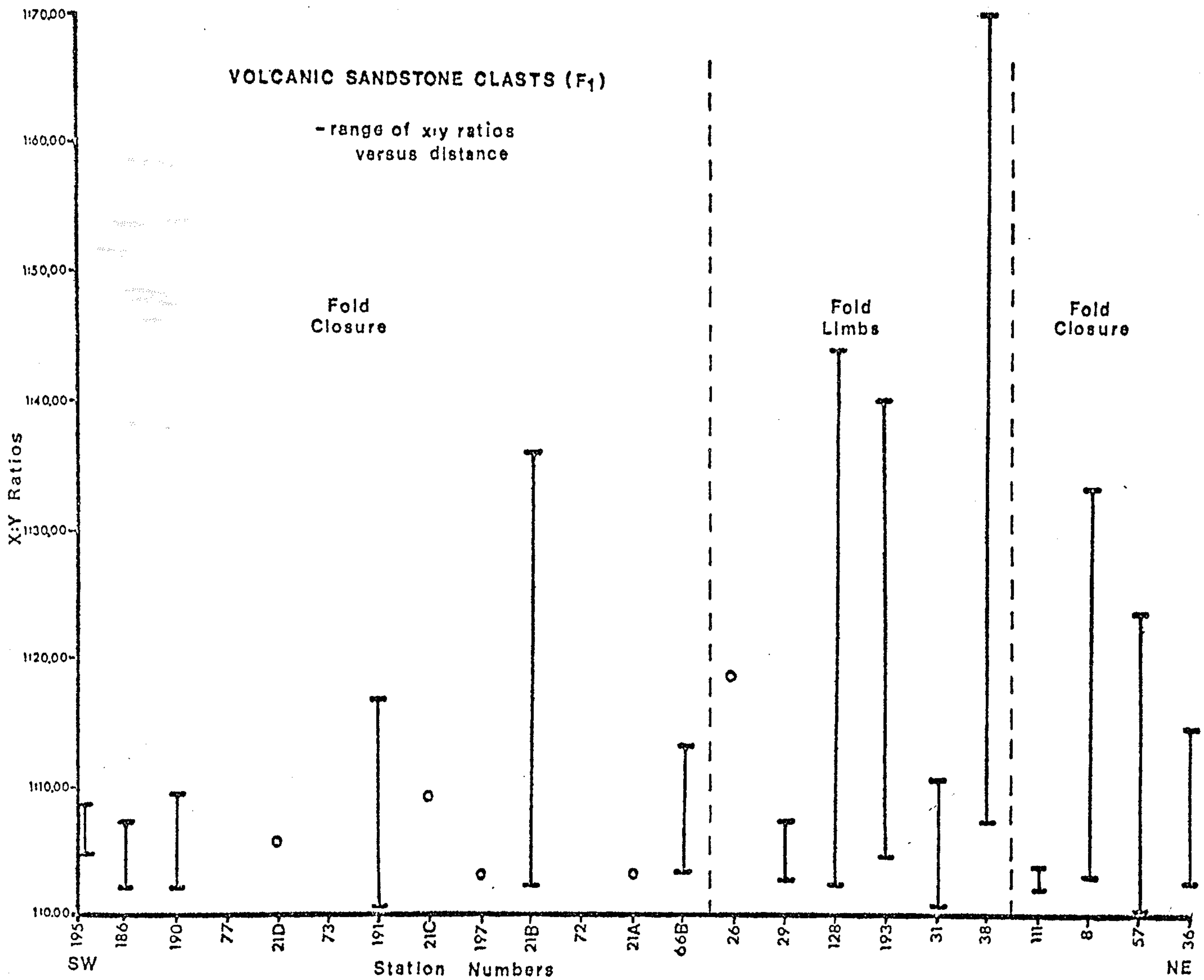

FIGURE 45 - VOLCANIC SANDSTONE CLASTS (F_1); RANGE OF X:Y RATIOS VERSUS RELATIVE DISTANCE.

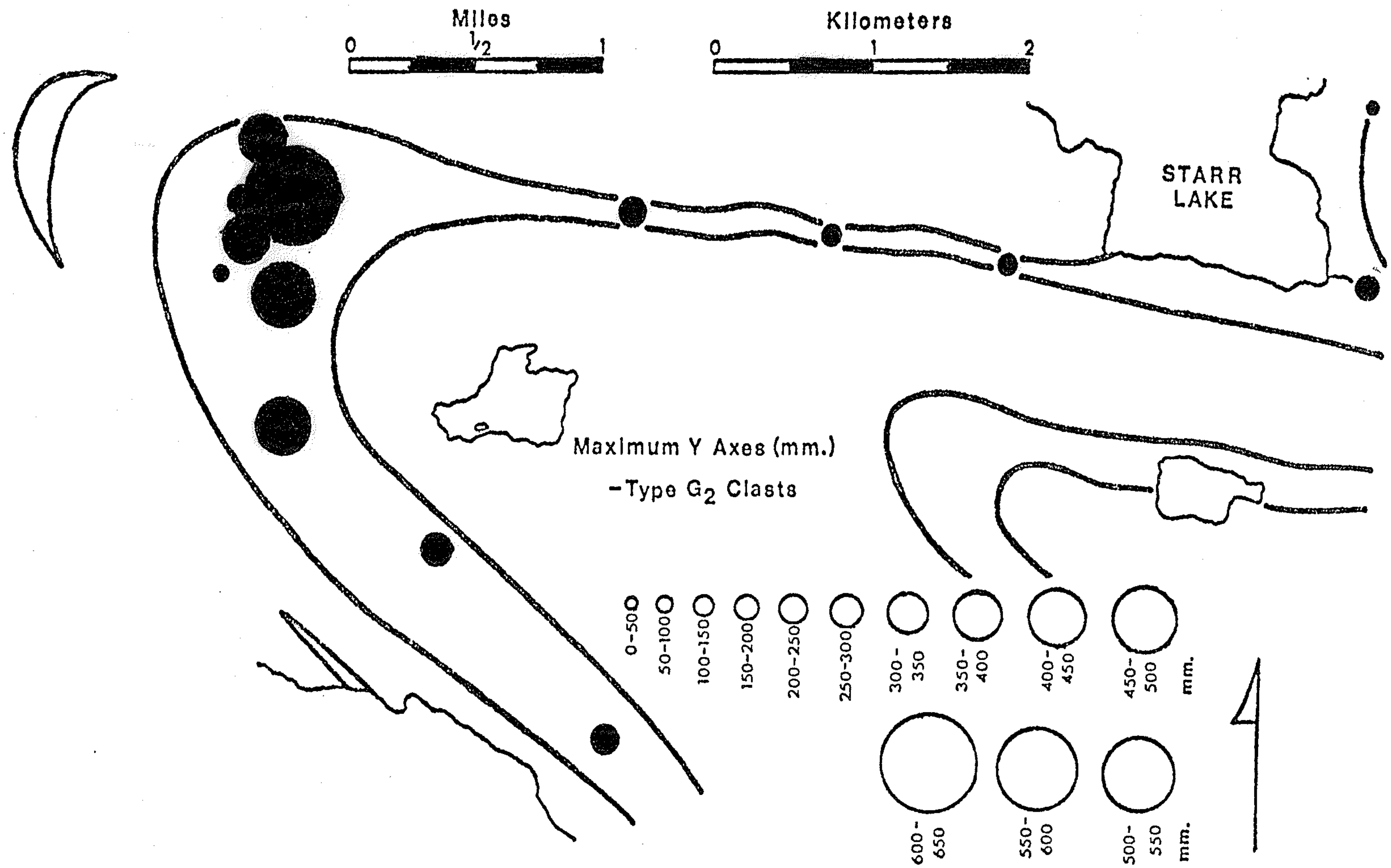

FIGURE 46 - AREAL DISTRIBUTION OF MAXIMUM Y AXES FOR TONALITE CLASTS (TYPE G_2).

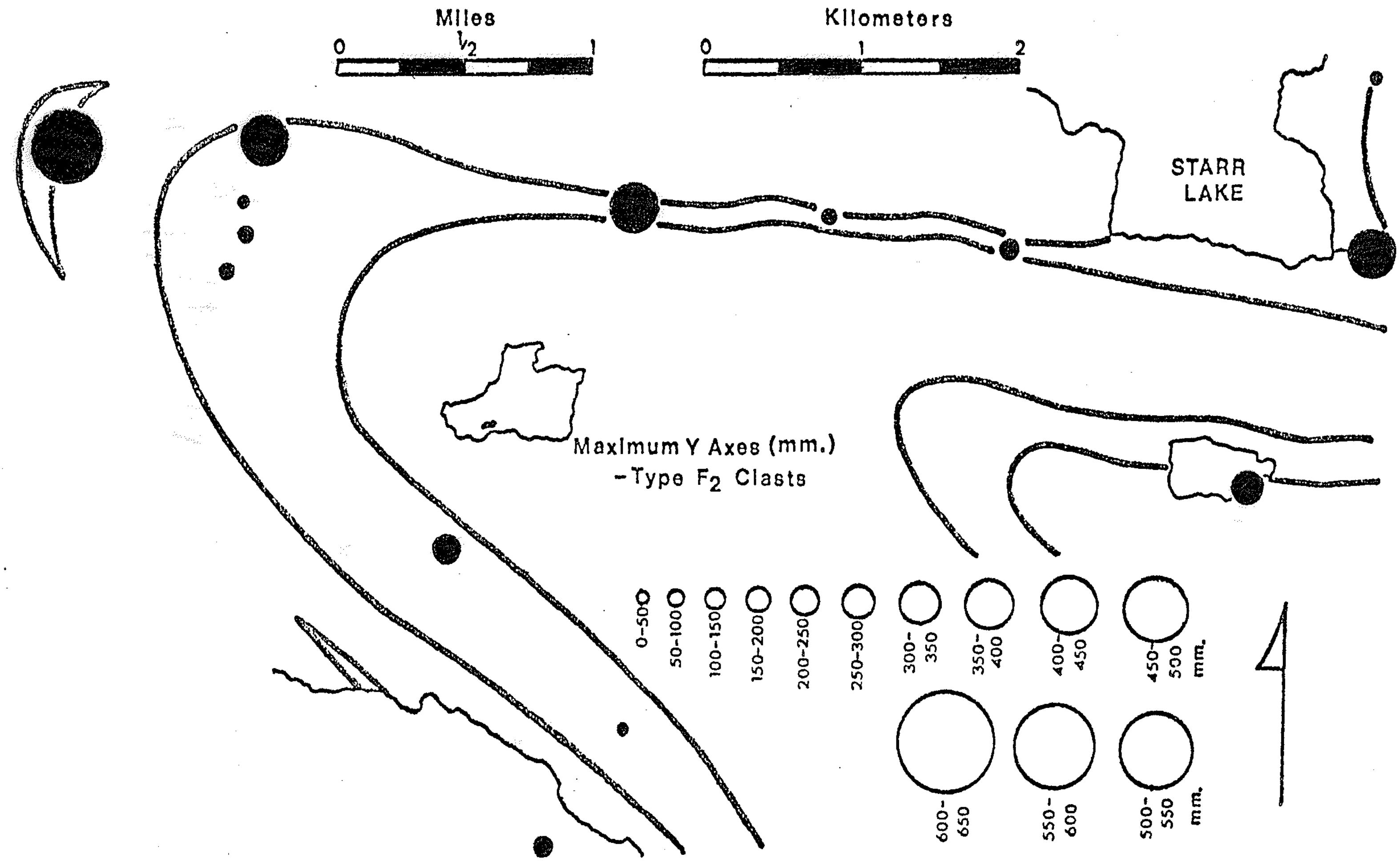

FIGURE 47 - AREAL DISTRIBUTION OF MAXIMUM Y AXES FOR PORPHYRITIC FELSIC VOLCANIC CLASTS (TYPE F_2).

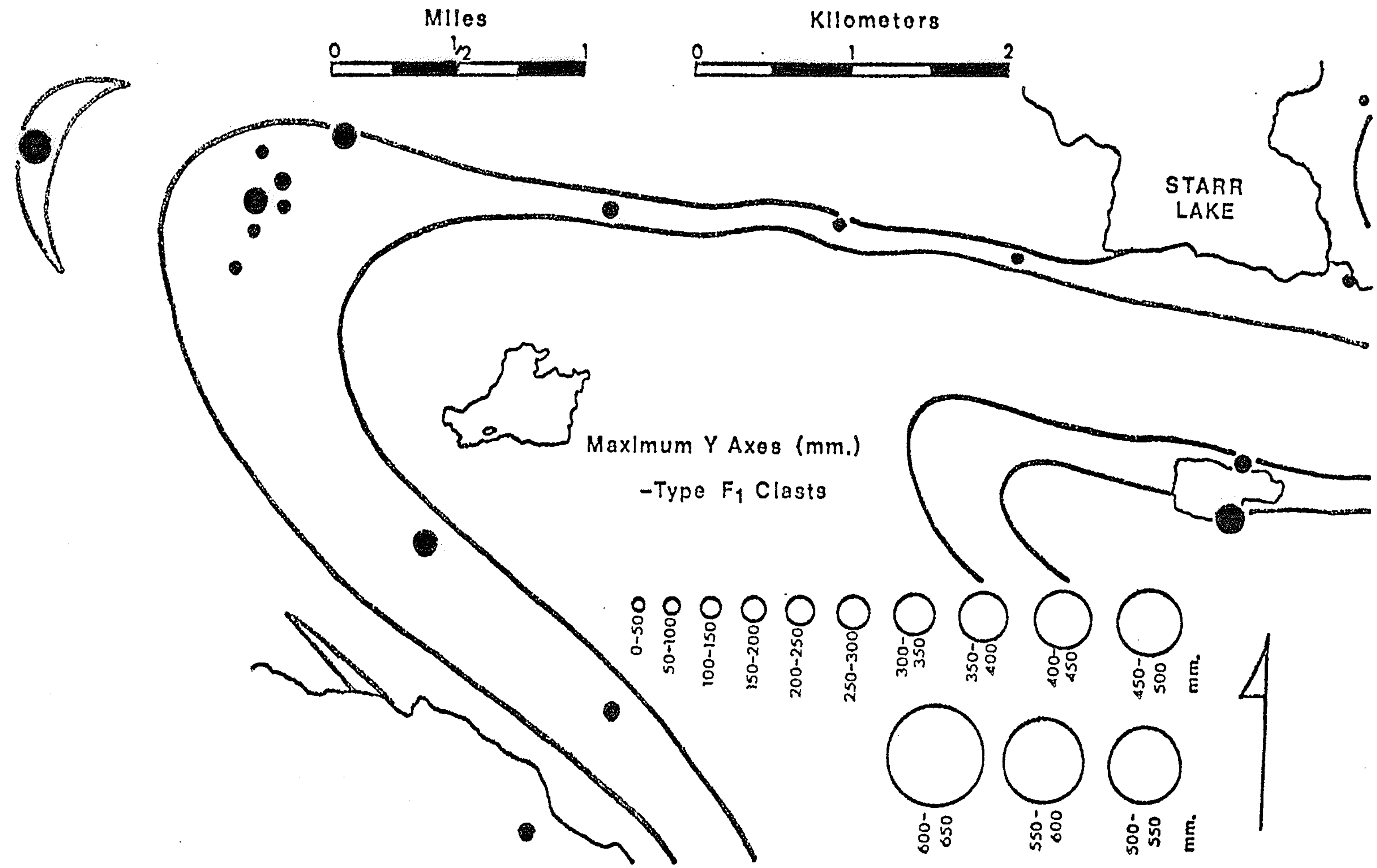

FIGURE 48 - AREAL DISTRIBUTION OF MAXIMUM Y AXES FOR VOLCANIC SANDSTONE CLASTS (TYPE F_1).

be monzonite in composition. There are no monzonite clasts in the conglomerate. Modal analyses in Tables 5a and 5b depict mineralogical similarities between tonalite clasts and tonalitic intrusions from the Bernic Lake volcanic-subvolcanic complex. Figure 49 illustrates the above discussion of a suitable provenance for the felsic intrusive clasts.

The medium to coarse grained mafic intrusive clasts presumably could have had their origin in several medium to coarse grained mafic rock occurrences, found in the Bird River greenstone belt and surrounding areas. In the meladioritic rocks from the Bernic Lake subvolcanic intrusives, there is a slate-grey to blue pleochroic, xenoblastic, poikiloblastic tourmaline. Mafic rocks of this nature have not been reported from the surrounding area. In meladioritic clasts, xenoblastic tourmaline of the same habit has been found as shown in Figure 50 (source) and Figure 51 (clast). Similar relict diabasic textures, very similar modal analyses (as given in Table 4 and shown in Figure 52) and equivalent ranges in the anorthite component of the plagioclases, petrographically support the subvolcanic complex of Bernic Lake as a possible source.

Modal analyses given in Table 3 illustrates how the volcanic sandstone clasts differ from the felsic volcanic rocks of the belt. In outcrop, this clast type appears quite similar texturally to the volcanic sandstone clasts in the polymictic breccia of the Bernic Lake area (Figure 1), which have as their source the underlying volcanic pile of the Bernic Lake volcanic-subvolcanic complex.

Modal analyses of porphyritic felsic volcanic clasts, shown in Table 3, are similar to the porphyritic volcanic rocks

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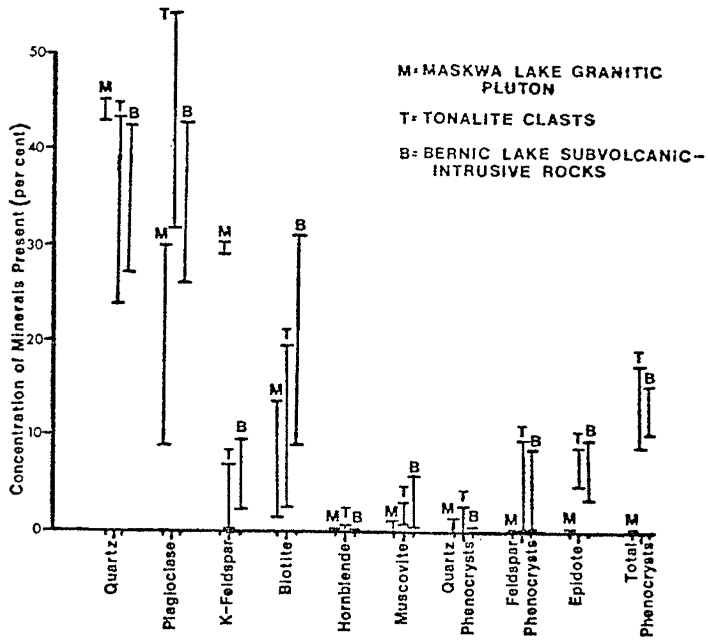

FIGURE 49 - COMPARISON OF THE RANGES OF MICROSCOPIC MODAL POINT COUNTS OF MINERAL CONCENTRATIONS OF FELSIC INTRUSIVE ROCKS OF THE BIRD RIVER GREENSTONE BELT. RANGE OF MINERAL CONCENTRATIONS OF THE MASKWA LAKE GRANITIC PLUTON IS ON THE LEFT, TONALITE CLAST RANGE IS IN THE CENTER AND FOR THE FELSIC INTRUSIVE ROCKS OF THE BERNIC LAKE VOLCANIC-SUBVOLCANIC COMPLEX IS GIVEN ON THE RIGHT.

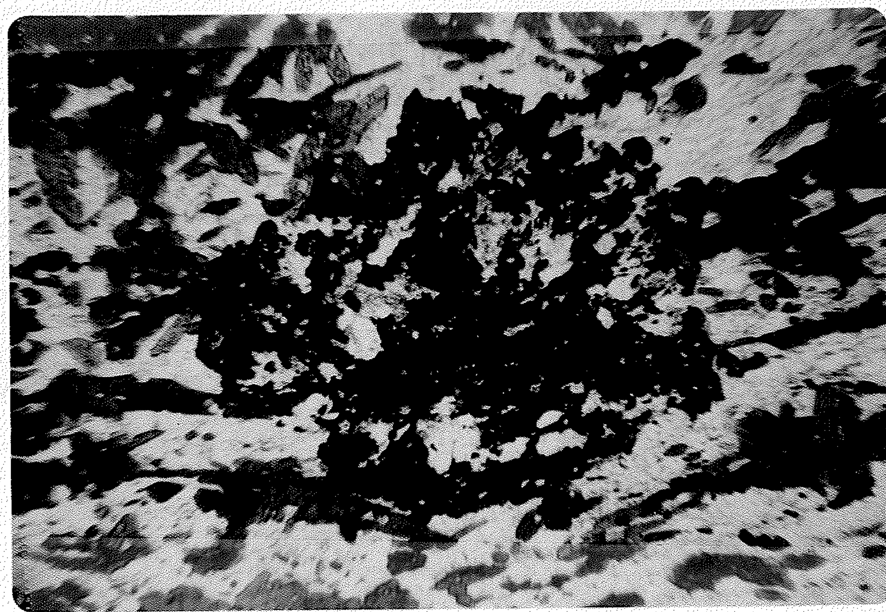

FIGURE 50 - A MICROPHOTOGRAPH OF A SLATE-GREY TO BLUE PLEOCHROIC, POIKILOBLASTIC TOURMALINE CRYSTAL IN THE MELADIORITE OF THE BERNIC LAKE VOLCANIC-SUBVOLCANIC COMPLEX (SLIDE 75-114, 3 3.5x, STATION 114).

FIGURE 51 - SLATE-GREY TO DEEP BLUE PLEOCHROIC, POIKILOBLASTIC TOURMALINE IN A MELADIORITE CLAST OF THE BOOSTER LAKE CONGLOMERATE (SLIDE 75-21A, 10x, STATION 21A).

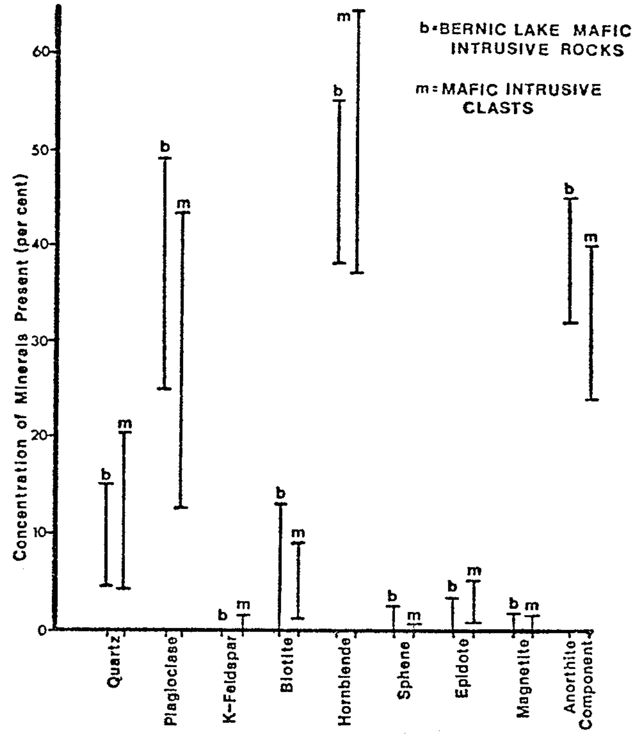

FIGURE 52 - COMPARISON OF THE RANGES OF MICROSCOPIC MODAL POINT COUNTS OF MINERAL CONCENTRATIONS OF MAFIC INTRUSIVE ROCKS OF THE BERNIC LAKE VOLCANIC-SUBVOLCANIC COMPLEX ON THE LEFT AND OF MAFIC INTRUSIVE CLASTS OF THE BOOSTER LAKE CONGLOMERATE ON THE RIGHT.

at Bernic Lake. But the original variability in composition and phenocryst concentrations makes correlation with a source difficult. Figure 53 illustrates some similarity in the mineral compositions diagrammatically. Other quartz feldspar porphyry volcanic, or shallow intrusive, rocks are not known elsewhere in the belt, though very fine grained quartz porphyries exist.

Mafic schist clasts presumably represent recrystallized mafic extrusive or volcanogenic sediments. These rock types are common in the Bird River greenstone belt, but there are no distinctive properties to pinpoint a source area.

Greywacke clasts presumably originated from the tearing up of the underlying lithified greywacke or conglomerate matrix. The greywacke appears volcanogenic, with embayed quartz and zoned subidiomorphic plagioclase fragments. Detrital slate-grey to deep blue pleochroic, poikiloblastic tourmaline and garnet were found in the greywacke.

Several iron formation units occur throughout the Bird River greenstone belt. One layer of this rock type lies below but close to the unconformity at the base of the conglomerate-greywacke sequence.

The source of the green tourmaline sandstone clast (Appendix I, type X_2) from the belt is not known.

The major supplier of clasts thus appears to be the Bernic Lake volcanic-subvolcanic complex on the north side of Bernic Lake (Figure 1). Other rock units in the metamorphosed volcanic-sedimentary Bird River greenstone belt may have contributed detritus, but not the surrounding granitoid plutons or gneissic rocks.

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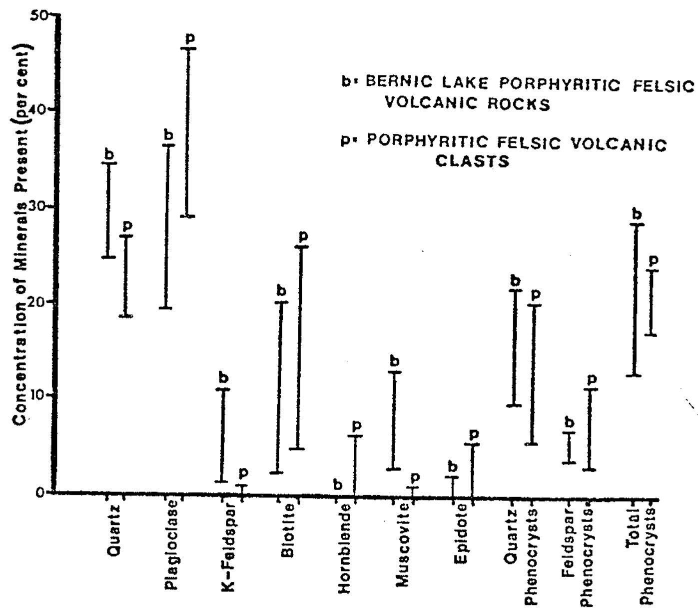

FIGURE 53 - COMPARISON OF THE RANGES OF MICROSCOPIC MODAL POINT COUNTS OF MINERAL CONCENTRATIONS OF PORPHYRITIC FELSIC VOLCANIC ROCKS OF THE BERNIC LAKE VOLCANIC-SUBVOLCANIC COMPLEX ON THE LEFT AND OF PORPHYRITIC FELSIC VOLCANIC CLASTS OF THE BOOSTER LAKE CONGLOMERATE ON THE RIGHT.

2) Environment of Deposition

The history of the Bird River greenstone belt may be deduced from the above data. Starting with a "cratonic" basement, there was volcanism and the structural development of a trough. Volcanic extrusives and volcanogenic sediments were deposited, showing the trend of a gradually emerging volcanic pile in a tectonically active basin. Polymictic breccias mark the emergence of the volcanic pile, in containing fragmental material from the volcanic pile and clasts of genetically related andesitic flows. Further tectonic activity and uplift, which exposed the sub-volcanic intrusives to erosion, produced the conglomerate and greywacke which have been described here.

The environment of deposition of the conglomerate and greywacke may be interpreted from the sedimentary textures and structures, internal organizations and clast concentration variations. Some of the field criteria used for distinguishing ancient depositional environments for conglomerate are tabulated in Appendix III.

Stauffer (1974) and Mukherjee (1971) studied the Missi Group cobble conglomerate and pebbly arkose in the Flin Flon area. They proposed that the underlying Amisk Group (andesitic lava flows, rhyolites and basalts) and related felsic intrusives are the sources, and that a submarine fan is the depositional environment.

Campbell (1971) studied the Edmunds Lake Formation in the Rice Lake Group of southeastern Manitoba and proposed subaqueous movement with initial deposition, mass movement and redeposition. Campbell identified two volcanic piles as provenances as well as a pre-volcanic cratonic basement and the Ross River Pluton.

Work on the Ogishke Tonalite Pebble Conglomerate of the Knife Lake Group in northeastern Minnesota by McLimans (1972) and Ojakangas (1972) proposed a submarine fan type deposition of a 'turbidite'-type environment flanking felsic-intermediate volcanic centers and coeval plutonic sources.

Walker and Pettijohn (1971) suggested a depositional environment of a submarine fan of a turbidite facies association for the Abram conglomerate near Sioux Lookout, Ontario.

A deep marine environment was discounted due to the lack of the following features in the conglomerate which characterize this environment: open framework; good bedding; minor cross beds; moderate to good sorting; good parallel laminations; relatively thin deposits; and a common association of shale.

A beach environment was not considered applicable due to the absence of the following features in the Booster Lake conglomerate and greywacke: very well rounded clasts; prismatic thin beds; and the lack of abundant cross bedded interbedded sandstone.

A lacustrine environment was excluded on the absence of these features: very good sorting; good bedding, both cross and graded; high amount of matrix; and good horizontal laminations.

A fluvial environment was eliminated with the conglomerate not possessing these features: moderate to good sorting; good bedding; irregular highly scoured pattern; moderate matrix content; and good stratified interbedded sandstones.

A tilloid was discounted due to the absence of the following features in the conglomerate: wide range in clast sizes up to very large, anomalous boulders; irregular disrupted framework; relatively higher and more variable matrix content; dropped clasts; striated clasts; associated sediments above the tilloid being arenaceous and followed by argillites; a thickening away from the source; and finely laminated argillites.

The geotectonic environment of an aulacogen was discounted due to the lack of the required tectonic environment and the lack of interbedded alkalic basalts and evaporites, interbedded with the late clastic sedimentation.

A classical turbidite environment was eliminated on the absence of: good regular and rhythmic bedding; graded bedding; good sorting; moderate to high matrix; good lamination; and interbedded sands and shales.

A fluxoturbidite environment was not deemed possible with the lack of the following features that characterize this controversial, poorly defined type of movement gradational between slumping and turbidity currents: very coarse size of clasts; a thickening of beds downslope; moderate-scale cross beds; repeated, irregular thick beds; features indicative of slumping; bases scoured; absence of fine material; and minor discontinuous argillaceous beds.

Subaerial alluvial fans were discounted with the following features absent in the conglomerate: large anomalous angular to subangular clasts; regular repeated beds of different size, texture and composition; lack of cross beds; extensive channelling, even in a lateral section; beds rapidly thicken to the apex; maximum clast size decreases abruptly from the source; and the coarse clastic deposit lies near the source.

Most of the above listed sedimentary features may together be taken to be indicative of a certain type of depositional environment. The absence of some of these features should not eliminate that type of environment for the Booster Lake conglomerate and greywacke. Evaluation and consideration of the relative importance of certain sedimentary textures and structures should be done before proposing a certain type of depositional environment, as has been done in this thesis.

To transport coarse, poorly sorted clastic sediment associated with fine-grained massive sediment, that is not identically repeated in the section and relatively constant in thickness laterally, requires a nonepisodic turbulent current. These two diverse rock types; oblique stratification, normal graded beds and cross beds found transitionally; and internal structureless features proximally are taken to be indicative of a high-energy turbulent current filling a geosynclinal basin.

Several authors have recently proposed the idea of re-sedimented conglomerate (Davies and Walker, 1974; Middleton and Hampton, 1973; Nelson and Kulm, 1973; Rocheleau and Lajoie, 1974; Turner and Walker, 1973; Walker, 1975, 1976; Walker and Mutti, 1973). In this theory, detritus accumulates on a shelf adjacent to a rugged tectonic upland where emerging fluvial systems have dropped their load. Multiple point sources and the coalescence of fan-shaped accumulations have produced apron-like deposits in a littoral to neritic zone. Shallow marine tractional currents, longshore currents and wave erosion supply additional clasts and resulted in further rounding and sorting of the clasts. Rapid influxes of sediment, oversteepening of the slope and seismic or tectonic activity may reactivate the sediments as submarine sedimentary gravity flows into a deeper transitional marine environment. These deposits are not normal turbidite deposits but have been referred to as coarse clastics associated with flysch deposits (Bouma and Brouwer, 1964; Aalto and Dott, 1970; Walker, 1976).

The three models of resedimented conglomerate proposed by Walker (1975, 1976) have been tentatively interpreted in the Booster Lake conglomerate. The massive disorganized model can be applied to most of the conglomerate. On consideration of a large-scale normal grading to massive textures present above a minor poor inverse graded zone, the inverse to normal graded model is found further downslope in the feeder channels of a submarine fan. Also found in the downslope areas in adjacent outcrops, or in the same outcrops, are conglomerates of massive, disorganized character. In the transitional facies, examples of the normal graded stratified model can be found. Perhaps the conglomerate and greywacke units could be traced into a hypothetical "normal" turbidite sequence further out into the sedimentary basin.

The Booster Lake conglomerate may be compared to the cobble to coarse pebble resedimented conglomerate of Davies and Walker (1974), although the Booster Lake conglomerate differs in the greater thickness of the beds and of a less repetitive nature. This could be explained by dominant nonepisodic sedimentary events.

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Resedimented conglomerates are typically massive with minor large and small-scale bedding. Heteorogeneity of clast types, vertically and laterally, are also characteristic. The associated greywacke is fine grained, feldspathic, massive to poorly laminated with minor cross-stratifications.

Using Walker and Mutti's (1973) turbidite facies association, the conglomerate is similar to facies A_1. This facies is typified by a disorganized conglomerate with a low proportion of matrix, boulder to cobble-sized clasts, irregular massive beds and lack of stratification. Facies A_2 (organized conglomerate) typifies the transitional facies with higher matrix content, distinct sedimentary structures and fabrics, good stratification and good normal grading. These authors have termed these two facies the "proximal exotic" facies. According to these workers, the deposits occur high in the proximal facies of coalesced aprons of submarine fans.

The discontinuous greywacke layers and lenses are believed to be indicative of marine environments by Hendry (1972), who described similar structural features of these lensoid accumulations in the conglomerates of Lower Ordovician in Québec.

The finely bedded greywacke with rare channels, rare cross-stratifications, minor clast-rich layers and calc-silicate nodules may be interpreted as indicative of a marine sedimentary environment. The lack of sedimentary structures may be due to intense recrystallization or rapid deposition. Features characteristic of a fluvial environment were not observed in the greywacke, i.e. large and small-scale troughs, cross-stratifications, and basal scoured surfaces.

3) Transportational and Depositional Mechanisms

Sedimentary structures may not solely be indicative, or unique, of any type of transportational or depositional mechanism. Similarities of structures found in the conglomerate and greywacke with those created by experimental studies and found in Paleozoic to Recent materials, suggest some type of subaqueous sedimentary gravity flow. A classification scheme proposed by Middleton and Hampton (1973) depends solely on the dominant sediment-support mechanism. Two of these types of mechanisms that may apply here are:

1. Grain flow - sediments supported by grain to grain interaction.
   - thick, massive, ungraded beds; sharp contacts; poor parallel laminations; large clasts; minor inverse grading.
2. Debris flow -sediments supported by a matrix consisting of a very viscous mixture of fluid and sediment; high density; low matrix.
   - highly concentrated laminar flow with minor turbulence.
   - massive, ungraded beds; irregular tops; no sorting; planar lower contact and large clasts.

These features of a debris flow are found in the proximal facies of the conglomerate. Deposition from debris flows is from suspension and this is seen by the poorly eroded tops of the greywacke lenses and the concordance of the overlying conglomerate on the underlying greywacke. The massive disorganized character of the conglomerate indicates rapid deposition on steep slopes in a proximal facies by a subaqueous sedimentary gravity flow.

The erosive greywacke lenses, discordant overlying greywacke layers and the relative "nonerosive" conglomerate layers may be related to differing means of transportation and deposition. The graded nature, with massive textures and parallel laminations near the top of the greywacke lenses may indicate a slowing down of the current over the lower slopes, rapid deposition and possibly a change from a "laminar" flow to bed load traction.

Further downslope, grain flow processes are found in which grain to grain interaction produces basal inverse grading, massive to normal graded upper beds and a relatively better degree of sorting. These relatively moderately sorted beds may be found interbedded with massive unsorted beds. This is believed due to the fine distinction of sediment support mechanisms and the ability for the current to change in mechanism in time and space.

For the transitional facies, a normal graded stratified model is appropriate. It can be explained by deposition from suspension dominant in the lower portion, while bed load movement is more important towards the top of the flow.

The associated massive greywacke indicates a "laminar" grain flow type of transport. This massive character may also be due to suppression of traction by rapid burial or the result of intensive recrystallization and tectonic overprint. The minor laminations and cross-stratifications found in the greywacke may represent minor tractional deposition.

STRUCTURAL GEOLOGY

1) Folding

The conglomerate and greywacke have been folded to produce a close to tight, inclined, gently to moderately plunging similar fold. It is overturned to the north and has steeply inclined axial planes. The spatial distribution of the rock units allow the fold to be classified as a Class 2 - 3 fold (according to Ramsay, 1967). Using stratigraphic top indicators, structural foliations and lineations, a D_1 synformal axis is found to occupy the upper greywacke bed as shown in Map 3.

The conglomerate and greywacke have been subjected to at least three phases of deformation. The first deformation, D_1, was flexural in character as evidenced by clast elongation parallel to the lithological boundaries. D_2, the strongest tectonic event, was passive in nature as evidenced by the layers not influencing the folding. D_2 elongated the clasts oblique to the compositional layering indicating shear folding. D_2 was also inhomogeneous in strain as seen by differing degrees of elongation of the clasts (gneissic conglomerate immediately adjacent to slightly elongate conglomerate). D_3 was weak, flexural in nature and had little effect on the conglomerate.

D_1 was initially a gently inclined fold that had a surface axial planar trace of 345° to 030°. This event was refolded by D_2 that possessed a surface axial planar trace of 080° to 110° and resulted in a Type 1 pattern of superimposed folding (according to Ramsay, 1967). Due to the inhomogeneous character of D_2, the fold pattern appears somewhat similar to a Type 3

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pattern. D_2 deformation is also revealed by the boudinage of leucopegmatites, kink banding, pressure shadows and extensional fracturing.

Map 3 is a structural map for the Booster Lake area and Figure 54 illustrates the complex refolding patterns that occur in the Starr Lake fold closure.

2) Strain

The shape of the clasts may not be used as true quantitative indicators of strain, although the relative ratios of clasts' ellipsoidal strain axes (X<Y<Z) may reveal the type of strain incurred. On measuring clast ratios one must consider: the original clast shape; ductility contrasts; clast to matrix ratios; and interference with other clasts.

Using the style of folding, foliations, lineations and textures, Lamb (1974) proposed that either of the following mechanisms of strain occurred in the Booster Lake conglomerate: heteorogeneous pure shear; homogeneous flattening superimposed on a flexural fold; flexural folding followed by heteorogeneous or homogeneous pure shear and heteorogeneous simple shear; and heteorogeneous or homogeneous pure shear followed by heteorogeneous simple shear.

In this study, measurements of at least two ellipsoidal strain axes were made on 105 clasts to determine relative X:Y ratios. Though a few outcrops did allow the measurement of all three strain axes. As the outcrop surface is irregular and cuts randomly through the ellipsoidal clasts, the down plunge method was used. To employ this method, approximation

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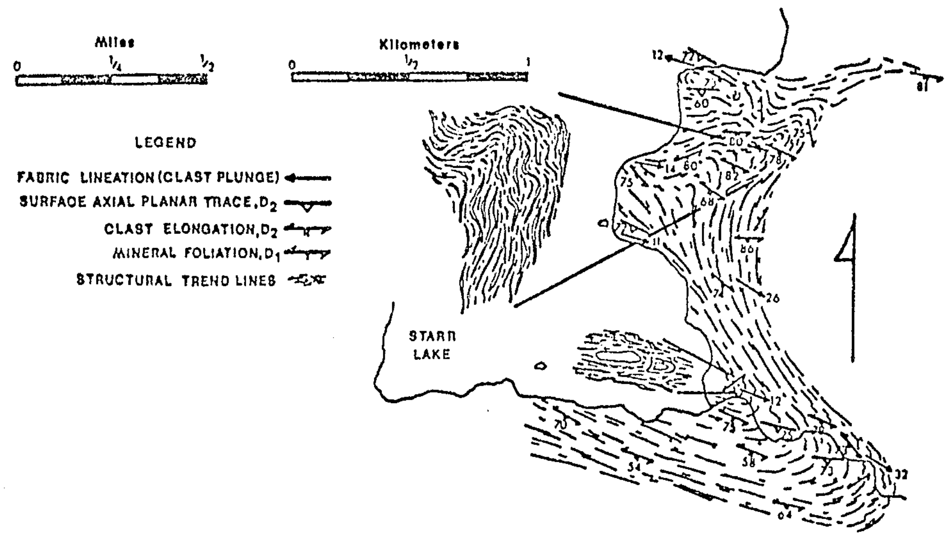

FIGURE 54 - COMPLEX REFOLDING PATTERNS IN THE STARR LAKE FOLD CLOSURE. DRAWINGS FROM PHOTOGRAPHS OF REFOLDING PATTERNS AS EXHIBITED BY THE STRETCHED CLASTS IN THE CONGLOMERATE.

of the middle of the clast, the plunge of the clast, as well as the foliation must be determined. Looking down plunge, the minimum (X) and intermediate (Y) axes can be measured through the middle of the clast between the maximum extremities of the clast in that dimension on the outcrop. To measure the maximum axis (Z), an outcrop with exposure parallel to the length of the clast is required.

It is evident from Figure 55 that the clasts in the fold closures are generally oblate ellipsoids (S tectonites; pancake shaped) and are the result of uniaxial flattening. In the fold limbs, as shown in Figure 56, prolate ellipsoids are found (L tectonites; cigar shaped) thus indicating uniaxial stretching or extension. Oblate ellipsoids are also found in the fold limbs. The indefinite variable pattern of ellipsoidal shapes within the fold and the differing degrees of elongation, indicates that the D_2 deformation was inhomogeneous.

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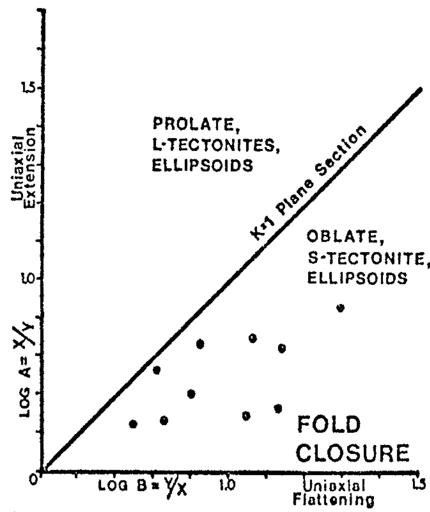

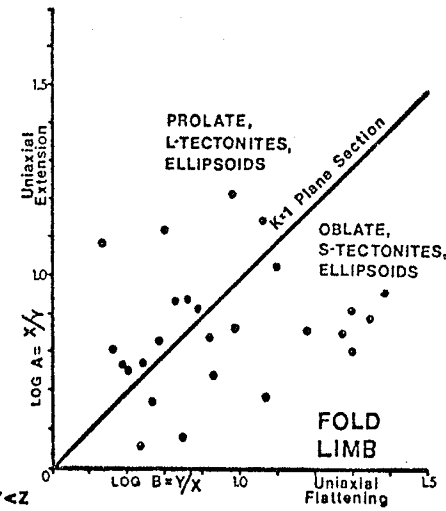

FIGURE 55 - STRAIN ELLIPSOIDS IN THE FOLD CLOSURES OF THE BOOSTER LAKE CONGLOMERATE.

FIGURE 56 - STRAIN ELLIPSOIDS IN THE FOLD LIMBS OF THE BOOSTER LAKE CONGLOMERATE.

CONCLUSIONS

1. The Booster Lake conglomerate is a clast supported, volcanogenic, cobble to coarse pebble, extraformational, polymictic orthoconglomerate. The associated greywacke may have been a volcanogenic feldspathic greywacke interbedded with pebbly greywacke.
2. Six major groups of clasts can be distinguished. These clast groups can be subdivided into sixteen types and subtypes.
3. Lateral and vertical variations in clast concentrations can be detected and related to the progressive exposure and erosion of a volcanic-subvolcanic complex.
4. The source for the clasts of the Booster Lake conglomerate is the Bernic Lake volcanic-subvolcanic complex. The conglomerate matrix and associated greywacke are volcanogenic and possess detrital poikiloblastic tourmaline which seems to indicate a Bernic Lake source.
5. The depositional environment is believed to be that of a resedimented conglomerate located in the feeder and upper fan channels of a submarine fan in a transitional near shore-marine environment.
6. The transportational mechanism is proposed to be that of a subaqueous sedimentary gravity flow; either debris or grain flow.
7. Ductility contrasts of the clast types are high. D_2 deformation is inhomogeneous and intense enough in the eastern regions to produce gneissic conglomerates.

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8. The distribution of the conglomerate and greywacke indicates refolding of a D_1 flexural, north trending, folding episode refolded by a D_2 inhomogeneous, passive, east-west trending deformation.
9. Uniaxial flattening was the dominant type of strain in the fold closures, though uniaxial flattening and stretching of the clasts occurred in the fold limbs.

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APPENDIX I

Petrographic Description of Clast Types in the Booster Lake Conglomerate

Felsic Volcanic Clasts - Group F

1) Volcanic Sandstone Clasts - Type F_1

These fine to very fine grained clasts are typified by a white to light grey weathered surface and a dark to steel blue grey broken surface. Clasts range in size from granule to coarse pebble with the smaller clasts being subrounded, lens-like to subellipsoidal in shape. Larger clasts are subrounded to subangular, tabular to elongate in shape with feathered, angular to jagged edges. Massive granoblastic textures are dominant with minor lepidoblastic textures. The clasts are highly ductile. Figure 4 illustrates a typical clast which may contain up to 5 per cent quartz and feldspar grains. In the field, approximate minerals concentrations were defined as quartz 30 - 40%, feldspar 40 - 55%, biotite 5%, sericite and chlorite $<5\%$.

Table 2 presents modal analyses and reveals a variable quartz content (23 - 49%) and a high plagioclase content (31 - 43%). K-feldspar is mainly microcline (0 - 9%) and mafic content ranges from 8 to 26%.

In thin section, this clast type is characterized by fine grain size, good lepidoblastic textures, granoblastic polygonal quartz-feldspar matrix, low content of sericite, altered poikiloblastic plagioclase crystals, low epidote and moderate secondary calcite content.

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	CLASTS					SOURCE ROCKS	
Sample Number	6-3	7-6	8-2	21A-1	76-1	13-4	161
Quartz	45.4	45.0	23.0	34.4	27.2	41.2	43.0
Plagioclase	42.9	42.5	39.4	31.2	38.0	24.4	26.6
K-Feldspar	0	4.5	2.0	9.2	4.2	24.8	6.6
Biotite	7.7	6.5	15.4	23.6	25.6	4.4	13.8
Hornblende	0	1.5	8.6	0	0	0	0
Muscovite	0	0	0	0	1.0	4.0	8.2
Quartz Clasts	3.7	0	1.2	0	0	0	0
Feldspar Clasts	0.3	0	7.6	0	0	0	0
Epidote	0	0	2.8	1.4	4.0	1.2	1.2
Sphene	0	0	0	0.2	0	0	0
Magnetite	X	X	X	X	-	X	-
Hematite	-	X	X	X	-	X	-
Apatite	-	-	X	-	-	-	-
Chlorite	-	-	-	X	-	X	X
Sericite	-	-	X	-	-	X	X
Calcite	-	-	X	X	-	-	X
Garnet	-	-	-	-	-	-	0.6
Counts	T/S 350	T/S 250	T/S 500	T/S 500	T/S 500	T/S 1000	T/S 1000

TABLE 2 - Modal analyses of volcanic sandstone clasts (type F_1) and felsic volcanic rocks of the Bird River greenstone belt.

2) Porphyritic Felsic Volcanic Clasts - Type F_2

This clast type ranges in size from granule to cobble and typically is subrounded to subangular, tabular, blocky to elongate in shape. Some clasts were noted to have irregular and jagged edges. The weathered surface is white, grey to tan in colour with white plagioclase phenocrysts and clear to very pale blue quartz eyes. The broken surface is grey to black in colour with deep blue quartz phenocrysts. Foliation is poor to moderately developed with minor lepidoblastic textures. Compositional layering is also observed. This clast type is moderate in ductility and is shown in Figure 4. In the field, mineral content was estimated as quartz (matrix) 25 - 30%, plagioclase (matrix) 30 - 45%, quartz phenocrysts 10 - 20%, plagioclase phenocrysts 5 - 10%, biotite 10 - 15% and K-feldspar $<$5%. Towards the east, this clast type contains medium grained subidioblastic hornblende porphyroblasts.

Modal analyses are given in Table 3. Total quartz content ranges from 24 - 45% and total plagioclase content varies from 33 to 57%. Microcline and perthite are low in abundance ($<$1.2%), while biotite and hornblende range in concentration from 12 - 26%. The amount of total phenocrysts range from 17 - 24%, with quartz accounting for 6 - 20% and plagioclase phenocrysts ranging from 3 to 10%.

Distinguishing features are the rolled subidioblastic, highly sutured, polygonized quartz phenocrysts and the subidioblastic to xenoblastic, poikiloblastic, highly fragmented plagioclase crystals set in a fine grained recrystallized granoblastic quartz, feldspar and biotite matrix. Late

	CLASTS					SOURCE ROCKS			
Sample Number	6-3	7-2	7-6-3	8-2-3	21A	121	123	118	124
Quartz	18.3	26.8	25.0	22.7	25.8	24.4	24.3	25.2	34.4
Plagioclase	47.3	24.0	32.5	42.7	29.0	24.4	19.0	28.8	36.4
K-Feldspar	0.7	1.2	0	0	0.6	1.6	6.3	4.8	10.8
Biotite	11.0	26.0	19.3	5.7	20.4	7.3	17.2	20.1	2.4
Muscovite	1.7	0	0	HBL.6.2	0	13.3	7.7	3.3	3.2
Quartz Phenocrysts	11.0	12.0	20.0	5.7	19.6	21.7	14.4	10.0	9.4
Feldspar Phenocrysts	9.3	10.0	3.0	11.3	4.2	6.7	6.7	5.9	3.4
Epidote	0.7	0	0.2	5.7	0.4	0	2.0	1.8	0
Sphene	-	-	-	X	-	-	X	0.1	-
Magnetite	-	X	X	X	-	-	0.8	X	-
Hematite	-	X	X	-	-	-	X	-	X
Apatite	-	-	-	-	-	-	-	X	X
Tourmaline	-	-	-	-	-	0.6	-	-	-
Chlorite	X	-	X	X	X	-	-	-	X
Calcite	-	-	-	-	-	-	1.6	-	-
Percent Phenocrysts	20.3	22.0	23.0	17.0	23.8	28.4	21.1	15.9	12.8
Counts	T/S 500	T/S 500	T/S 500	T/S 300	T/S 500	T/S1000	T/S1000	T/S1000	T/S1000

TABLE 3 - Modal analyses of porphyritic felsic volcanic clasts (type F_2) and porphyritic felsic volcanic rocks of the Bernic Lake complex.

xenomorphic calcite fills interstices and also retrogresses along with epidote and sericite, feldspar crystals. Prismatic subidioblastic poikiloblastic slate-grey to blue pleochroic tourmaline is present.

Intermediate Volcanic Clasts - Group I

This group of clasts is distinguished in the field from the felsic volcanic clasts by the lower quartz content (15 - 20%), higher plagioclase content (50 - 60%), higher mafic content (15 - 20%), more abundant sericite, poorer developed foliation and a darker grey weathered surface.

1) Dacitic Volcanic Clasts - Type I_1

These clasts are fine to very fine grained and exist as granule to pebble-sized clasts. The clasts are subangular to subrounded, tabular, ellipsoidal to oblong in shape. The weathered surface is dull grey to white in colour, while the broken surface is dark grey to black. This clast type is moderately ductile and a typical example is shown in Figure 5. Foliation is absent.

In the field, limits for mineral concentrations were arbitrarily set as follows: quartz (matrix), 20 - 25%, plagioclase, 50 - 60%; quartz (phenocrysts), 2 - 5%; and biotite 15 - 20%.

2) Andesite Porphyry Clasts - Type I_2

The matrix, of this rare clast type, is a massive, fine to very fine grained, mafic-rich component that is light to dark grey on weathered surface. Subidiomorphic plagioclase phenocrysts are white to light grey on weathered surface, medium grained in size and constitute about 15 - 20% of the clast. Quartz phenocrysts are subidioblastic to xenoblastic and constitute less than 2% of the clast. This clast type is granule to small pebble in size. Subrounded to subangular and oblong, ellipsoidal, subrectangular to tabular in shape. The clast type is massive and moderately ductile.

Field examination arbitrarily determined the mafic content to average 70 - 80%, while feldspar phenocrysts accounted for 20 - 30% with minor quartz phenocrysts. A typical example is shown in Figure 6.

Mafic Intrusive Clasts - Group M

1) Fine Grained Granoblastic Leucodiorite Clasts - Type M_1

This fine to very fine grained clast type exists as granule to cobble-sized clasts, that are typically subangular to subrounded, elongate to ellipsoidal in shape. The clast type is moderate to poorly foliated and moderately ductile. A light grey to greyish black is the weathered surface colour. Some clasts possess minor reaction rims in which biotite has replaced hornblende around the clast edges. Minor phenocrysts of quartz, plagioclase and hornblende occur. In the field, mineral concentrations were estimated as biotite 15 - 25%, hornblende 20 - 25%, quartz 10 - 20% and plagioclase 35 - 40%.

In thin section, the matrix is a fine grained granoblastic mixture of quartz, plagioclase and minor microcline. Well developed lepido-nematoblastic textures are developed as well as mafic clots with subidioblastic biotite rimming the xenoblastic hornblende aggregates. Subidioblastic slate blue pleochroic tourmaline is present.

Distinctive features are the average small pebble size, granoblastic texture and mineral composition. A typical example is shown in Figure 4.

2) Medium Grained Blastic Leucodiorite Clasts - Type M_2

This rare clast type is distinguished in the field by the medium to fine grained size and the granule to pebble-sized clasts. The clasts are typically subangular, elongate, rectangular to tabular in shape. The characteristic feature is the extreme development of blastesis and segregation. Large blasts up to 5 x 10 mm are constituted, either of hornblende and biotite, or as lenses of quartz and feldspar, as shown in Figure 7. The weathered surface has a black and white knotted appearance, while the fresh surface is alternating light grey and black lenses.

In the field, an estimation of the mineral concentration was biotite 25%, hornblende 35%, quartz 15% and feldspar 25%.

3) Meladiorite Clasts - Type M_3

This clast type is characterized by the granule to cobble-sized clasts and medium to coarse grained size. Clasts are subrounded to rounded, oblong, ellipsoidal to tabular in shape. Foliation is absent and the clasts are moderately ductile. Weathered surface is a greenish-black to black in colour, while the broken surface is dark black. In the field, mineral concentration was estimated as hornblende 35 - 40%, quartz 10%

and plagioclase 55 - 60%. Typical examples are shown in Figures 5 and 8.

Table 4 presents modal analyses where quartz content ranges from 4 - 21%, plagioclase (An_{24-35}) varies from 13 - 44% and hornblende content ranges from 37 - 66%. K-feldspar is minor in content, < 1.6%, occurring mainly as microcline. Biotite ranges from 1 to 10%. Sphene, magnetite and epidote are common accessories.

In thin section, the meladiorite clasts display a relict diabasic and cumulate textures with subidioblastic to xenoblastic plagioclase laths settled between tabular subidioblastic, poikiloblastic, dark to blue green pleochroic hornblende. Minor plagioclase exhibits compositional zoning. Some clasts display nematoblastic textures. Rare xenoblastic slate-grey to blue pleochroic, poikiloblastic tourmaline are present in some clasts. Biotite and chlorite retrogress hornblende.

Mineral zoned meladiorite clasts, subtype M_{3-1}, were distinguished in the field. These massive, medium to coarse grained, pebble to cobble-sized clasts are characterized by the extensive, concentric, mineral zonations. Clasts are subangular to subrounded, blocky, tabular to oblong in shape. Ductility is poor. Outcrop weathered surface is dark brown, black, blue-green to green in colour. These mineral zones appear to be the result of extensive retrogression. A typical example of this zonation is shown in Figure 8.

4) Melagabro Clasts - Type M_4

This type of clast is characterized by the medium to coarse

	CLASTS				SOURCE ROCKS		
Sample Number	21A	21A-1	21B	61-5	114	114B	116
Quartz	4.2	20.6	8.4	18.2	15.3	14.6	4.7
Plagioclase	12.7	34.2	43.8	27.4	23.0	31.4	49.1
K-Feldspar	1.0	1.6	0	0	0	0	0
Biotite	8.8	2.4	4.6	1.0	0.8	13.0	0
Hornblende	65.9	37.2	41.2	47.8	55.4	38.0	41.5
Epidote	3.7	3.4	0.6	5.0	0	0.8	3.2
Sphene	0.1	0.6	1.4	0.6	0	2.2	0
Magnetite	0.3	0	-	0	0.1	0	1.5
Hematite	-	X	-	-	X	X	X
Tourmaline	-	X	-	-	-	X	X
Chlorite	2.4	X	-	X	-	-	X
Sericite	-	-	X	X	X	-	-
Calcite	0.9	-	X	X	-	-	X
An Component	An33-40	An38-31	An24-34	An30-35	An 40	An 40	An32-45
Count	T/S1000	T/S1000	T/S1000	T/S1000	T/S1000	T/S500	T/S1000

TABLE 4 - Modal analyses of meladiorite clasts (type M_3) and meladiorite rocks of the Bernic Lake volcanic-subvolcanic complex.

grained size and massive texture. The granule to pebble-sized clasts are rounded to subrounded, tabular to ellipsoidal in shape. A dark green to black coloured weathered surface and moderate non-ductility was observed. An arbitrary field estimation of the mineral concentration is as follows: hornblende, 50 - 65%; plagioclase, 35 - 50%; and biotite less than 5%. Many gabbro clasts possess 1 - 5 mm thick peripheral reaction rims consisting of biotite, chorite and hematite. A typical example is shown in Figure 9.

Variants of this clast type consist of approximately 90 - 95% hornblende plus minor plagioclase, biotite and retrogressive chlorite.

Felsic Intrusive Clasts - Group G

Visible gradations from clasts classified as porphyritic felsic volcanic to fine grained tonalitic intrusive clasts with minor phenocrysts were evident. An arbitrary field limit was used and backed by later petrographic work. Clasts identified as porphyritic felsic volcanic clasts contain on the average greater than 20% quartz and plagioclase phenocrysts in a very fine grained matrix. Those clasts classified as felsic intrusive in origin range from 8 - 15% phenocrysts, but the matrix is usually fine to medium grained. The felsic intrusive clasts possess larger aggregates of minerals, are more highly altered and granulated, and possess early poikiloblastic xenoblastic muscovite. The porphyritic felsic volcanic clasts exhibit a better development of biotite and mineral foliation. Tonalite clasts possess poor foliation. The shape and ductility of the clasts is also distinctive.

1) Fine Grained Tonalite Clasts - Type G_1

This clast type is characterized by the uniform fine grained size and low phenocryst content. The clasts are typically granule to pebble in size, rounded to subrounded and oval to oblong in shape. Foliation is absent and the clasts are strongly nonductile. Outcrop weathered surface is white to light tan in colour with a white to grey coloured broken surface. Field estimation of the mineral concentration is biotite 5 - 10%, quartz 30 - 35%, plagioclase 45 - 55% and K-feldspar $<5\%$. Figure 4 shows a typical fine grained tonalite clast.

In thin section,plagioclase is finely twinned and highly altered. Quartz occurs as sutured polygonized monomineralic aggregates. The clast as a whole is granulated, altered and fine grain. This clast type is a transitional phase between the porphyritic felsic volcanic and medium grained tonalite clasts.

2 - 3) Medium to Coarse Grained Tonalite Clasts - Types G_{2-3}

This is the most common type of felsic intrusive clast that is typically medium to coarse grained and varies from granule to boulder in size. Clasts are typically rounded, subrounded to subangular and oval, ellipsoidal, blocky, tear drop to tabular in shape. Outcrop weathered surface is white, tan to light grey in colour, while the broken surface is clear to white in colour. Foliation is absent. These clast types are strongly nonductile. A coarse grained variant, Type G_3, is distinguished in the field by the massive, rough, pitted weathered surface, high degree of fracturing and coarser grain size. Typical examples of the above two clast types are shown in Figures 4 and 5.

In the field, type G_2 clasts appear to be massive granoblastic in texture. However in thin section, and in some clasts observed in the field, minor phenocrysts are observed. An estimation of mineral concentration in the field set biotite as 5 - 15%, quartz 25 - 30%, plagioclase 40 - 45%, K-feldspar 5% and phenocrysts $<$5%.

Modal analyses given in Table 5a shows quartz content to vary from 25 to 43%, plagioclase ranges from 32 - 56%, K-feldspar (microcline and perthite) ranges from 0.5 - 2.0%, and biotite varies from 2 - 20%. Phenocrysts content ranges from 0 - 18%, averaging 14%.

In thin section a granoblastic matrix was observed with phenocrysts. Plagioclase is subidioblastic, poikiloblastic, fragmented, compositionally zoned, sometimes aggregated and sericitized. Quartz is highly undulose and occurs commonly as xenoblastic sutured monominerallic aggregates. Early poikiloblastic xenoblastic muscovite is observed. Retrograde chlorite is commonly found in fractures, along clast boundaries and replacing biotite. Important accessories include garnet, sphene, apatite and calcite.

4) Hornblende Tonalite Clasts - Type G_4

This distinct clast type occurs in the higher parts of the stratigraphic section as granule to cobble-sized clasts,

Sample Number	31	7-3	6-5	6-3	36	8-2	61-3	7-5	6-2
Quartz	30.2	30.4	25.6	28.2	25.8	24.8	42.0	38.6	43.4
Plagioclase	32.4	44.6	37.2	48.6	43.4	43.0	48.0	55.8	49.2
K-Feldspar	6.8	4.8	2.0	0.4	1.8	1.4	1.2	3.4	4.6
Biotite	10.4	8.4	19.8	6.2	14.2	9.8	8.8	2.2	2.8
Hornblende	0	0	0	0	1.4	10.2	-	-	-
Muscovite	0.5	3.0	0	1.8	0	0	-	-	-
Quartz Phenocrysts	8.7	2.8	7.2	9.8	4.8	0.6	-	-	-
Plagioclase Phenocrysts	8.8	5.8	7.8	4.6	8.6	8.0	-	-	-
Epidote	2.2	0.2	0.4	0.4	0	2.2	-	-	-
Sphene	X	X	-	X	X	-	-	-	-
Magnetite	X	X	X	X	-	-	-	-	-
Hematite	-	X	X	-	-	-	-	-	-
Apatite	-	X	X	X	X	X	-	-	-
Zircon	-	X	X	-	X	-	-	-	-
Chlorite	-	X	X	X	X	-	-	-	-
Calcite	-	X	-	-	-	X	-	-	-
Sericite	X	-	-	X	X	-	-	-	-
Percent Phenocrysts	17.5	8.6	15.0	14.4	13.4	8.6	-	-	-
Counts	T/S1000	T/S500	T/S500	T/S500	T/S1000	T/S500	R/S500	R/S500	R/S500

Table 5a- Modal analyses of medium grained tonalite clasts (type G_2).

Sample Number	Maskwa Lake 134	Maskwa Lake 9-1	Marijane Lake 37-1	Marijane Lake DT 174	Bernic Lake 119	Bernic Lake 121	Bernic Lake 125	Bernic Lake 119-2
Quartz	45.6	43.4	33.0	39.2	33.0	27.8	27.2	42.6
Plagioclase	8.0	30.2	27.4	23.4	30.3	26.8	35.4	42.8
K-Feldspar	29.9	24.8	38.0	34.0	2.9	3.4	2.6	9.0
Biotite	13.8	1.6	1.6	3.4	13.7	31.4	17.4	5.6
Hornblende	0	0	0	0	0	0	0	0
Muscovite	1.1	0	0	0	4.5	0.6	5.8	0
Quartz Phenocrysts	0	0	0	0	7.6	0.6	8.6	0
Plagioclase Phenocrysts	0	0	0	0	8.0	9.4	2.6	0
Epidote	1.4	0	0	0	0	0	0.4	0
Sphene	X	0	0	0	-	-	-	-
Magnetite	-	-	-	-	X	X	X	-
Hematite	0.2	-	-	-	-	-	X	-
Apatite	-	-	-	-	X	X	X	-
Zircon	-	-	-	-	-	X	-	-
Chlorite	-	-	-	-	X	X	-	-
Calcite	-	-	-	-	X	X	X	-
Sericite	X	-	-	-	-	-	-	-
Percent Phenocrysts	0	0	0	0	15.6	10.0	11.2	0
Counts	T/S1000	R/S500	R/S500	R/S500	T/S1000	T/S1000	T/S500	R/S500

Table 5b - Modal analyses of possible felsic intrusive source rocks; Maskwa and Marijane Lakes bodies and the Bernic Lake volcanic-subvolcanic complex.

or at Davidson Lake where it occurs as pebble to boulder-sized clasts in the "transitional" facies of the conglomerate and pebbly greywacke.

This clast type is very similar to the medium grained tonalite clasts except for the presence of medium to large grained poikiloblastic hornblende and minor biotite.

Clasts of Sedimentary Rocks - Group S

This clast group is characterized by high mafic content and extreme ductility.

1) Biotite Schist Clasts - Type S_1

This clast type is fine to medium grained, occasionally being very fine grained. Clasts range in size from granule to pebble, and are typically subangular to angular, tabular, elongate to ribbon-like in shape. The mafic content accounts for the susceptibility to deep erosion, surface oxidation and high ductility. Foliation is well developed, exhibited by lepido-nematoblastic textures. Outcrop weathered surfaces are black in colour. Figures 4 and 5 illustrate typical examples of this clast type.

Field estimation of the mineral content is as follows: biotite, 45 - 60%; hornblende, 5%; quartz, 10 - 15%; plagioclase 20 - 25%; and garnet $<$ 2%. Modal analyses are given in Table 6 and reveal that quartz content ranges from 8 - 21%, plagioclase varies from 27 - 34% and biotite content ranges from 18 - 63%. Hornblende is variable and occurs locally up to 35% (subtype S_{1-1}).

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	CLASTS						SOURCE ROCKS	
Sample Number	7-6-3	21A	21A-1	21A	8-1	8-2	65	46-2
Quartz	8.4	15.8	15.6	13.5	21.2	11.2	26.9	16.0
Plagioclase	28.0	33.2	33.2	34.0	27.2	29.6	31.5	24.0
K-Feldspar	0	0	0	0	1.4	0.4	3.9	2.8
Biotite	62.8	50.6	49.4	46.5	20.4	18.0	33.7	55.2
Hornblende	0	0	0	0	26.4	34.8	0	0
Muscovite	0	0	1.0	5.0	0	0	0	0
Epidote	0.8	0.4	0.8	1.0	3.4	6.0	4.0	0
Sphene	0	0	0	0	0	0	0	0
Garnet	0	0	0	0	0	0	X	2.0
Magnetite	-	X	X	X	X	X	X	X
Hematite	X	X	X	X	-	X	-	X
Chlorite	X	-	-	-	X	-	-	X
Counts	T/S500	T/S500	T/S500	T/S500	T/S500	T/S500	T/S100	T/S1000

TABLE 6 - Modal analyses of biotite schist clasts (type S_1) and possible source rocks.

Thin section petrography reveals a granoblastic polygonal quartz-plagioclase matrix and a coarser grained, higher content, lepido-nematoblastic biotite and hornblende.

In the eastern regions, and in the higher parts of the stratigraphic section, field identification as a subtype was given to a fine to medium grained hornblende blastic biotite schist clast (subtype S_{1-1}). It is combined with types S_1, as it only differs in the degree of hornblende and biotite blastesis.

2) Greywacke Clasts - Type S_2

This clast type is difficult to detect in the field from the greywacke matrix of the conglomerate. Only when definite clast edges could be discerned, was the greywacke regarded as a clast. Grain size is fine to very fine and the clasts are usually granule to small pebble in size. The clasts are subangular to angular, tabular, slabby to oblong in shape. Foliation is poor to well developed with minor lepidoblastic biotite in a fine grained granoblastic matrix of quartz and feldspar. Ductility is moderately strong and the clasts typically have a light grey weathered surface.

In the field, mineral content was noted as: biotite, 10 - 25%; quartz, 35 - 45%; plagioclase, 20 - 40%; plus minor hornblende. Modal analyses in Table 7 reveals that quartz content varies from 20 - 30%, plagioclase ranges from 23 - 43% and mafics range from 19 - 48%.

Sample Number	CLASTS 21A	CLASTS 6-3	CLASTS 21A-1	Greywacke Lens 77	Conglomerate Matrix 76	Conglomerate Matrix 8-2-1	Conglomerate Matrix 36	Associated Greywacke 24	Associated Greywacke 25	Associated Greywacke SB68-90	Associated Greywacke SB68-98
Quartz	30.0	28.4	22.0	21.1	21.8	22.0	20.1	36.8	34.4	16.0	13.4
Plagioclase	38.0	43.1	26.2	22.9	25.6	36.4	27.1	26.0	29.8	46.8	49.0
K-Feldspar	0	2.0	0	3.1	2.2	0	2.7	3.2	6.9	1.2	1.0
Biotite	31.2	18.8	36.8	22.2	5.0	30.8	37.2	32.9	25.4	34.8	36.0
Hornblende	0	0	0	16.2	42.8	2.8	8.4	0	0	0	0
Muscovite	0	1.0	1.0	0	0	0	0	1.0	1.7	1.2	0.6
Quartz Clasts	0	3.5	7.4	8.0	0	0	0	0	0	0	0
Plagioclase Clasts	0	2.2	6.0	1.9	0	0	0	0	0	0	0
Epidote	0.8	1.0	0.6	4.6	2.6	8.0	4.2	0.1	1.8	0	0
Sphene	0	0	0	0	0	0	0	0	0	0	0
Magnetite	X	X	X	-	-	X	0.3	X	X	X	X
Hematite	X	-	X	-	X	X	X	-	X	-	X
Tourmaline	-	-	-	-	-	X	X	-	-	-	-
Chlorite	-	X	-	-	-	-	-	X	X	X	X
Sericite	-	X	-	-	-	-	-	-	X	-	-
Counts	T/S500	T/S500	T/S500	T/S1000	T/S500	T/S500	T/S1000	T/S1000	T/S1000	T/S500	T/S500

TABLE 7 - Modal analyses of greywacke clasts (type S_2), hornblende-rich greywacke lens, conglomerate matrix, and associated greywacke.

Miscellaneous Clasts - Group X

1) Iron Formation Clasts - Type X_1

This clast type is medium to fine grained in size and the clasts range in size from granule to pebble. Subangular to subrounded, oval, tabular, blocky to subrectangular shapes are common. Outcrop weathered surface is clear to white in colour, with rusty red oxidation surfaces. Foliation is absent and the clasts are strongly nonductile; subsequently being highly fractured upon deformation. Mineralogically, the clasts are recrystallized cherty quartzites with minor pyrite and or hematite. An example of this clast is shown in Figure 10.

2) Tourmaline Sandstone Clasts - Type X_2

This rare clast type is typified by the fine to very fine grained size and granule to pebble-sized clasts. Clasts range from subrounded to rounded, elongate, oval to irregular in shape. Outcrop weathered surface is very dark black in colour. Clasts are moderately nonductile and Figure 11 shows a typical example.

In thin section, modal analysis documents the mineral content as tourmaline 77.4% and quartz 22.6%. Typically, the tourmaline is nonpoikiloblastic, light to dark green in pleochroism, idioblastic to subidioblastic, poorly sorted and randomly oriented in the beds. Quartz occurs as interstitial material. Bedding is defined by the varying contents of the two minerals and grain size. The bedding is on a scale of 0.5 - 2.0 mm. Microphotographs of the bedding and tourmaline grains are seen in Figures 57 and 58 respectively.

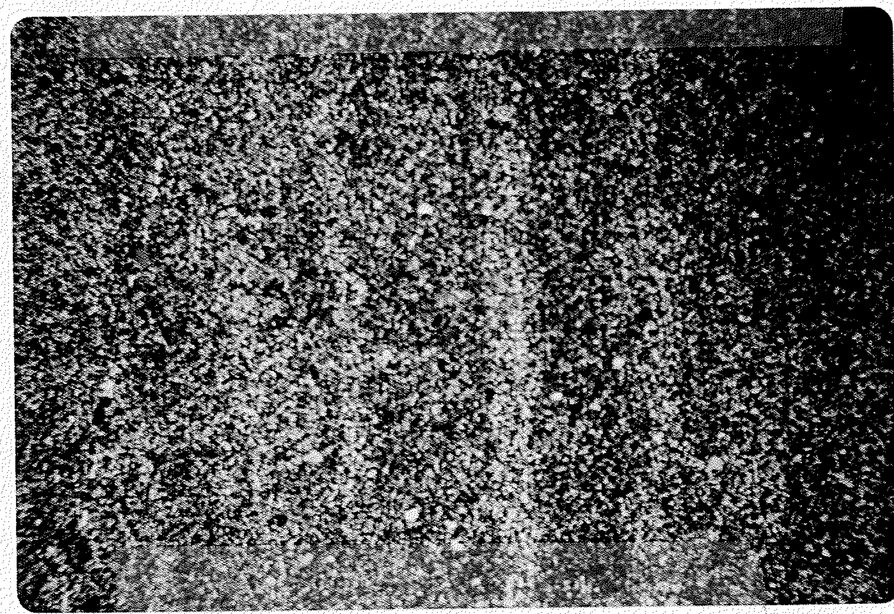


FIGURE 57 - MICROPHOTOGRAPHY OF FINE-SCALE BEDDING IN A TOURMALINE SANDSTONE CLAST (SLIDE 75-21A, 1X, STATION 21A).

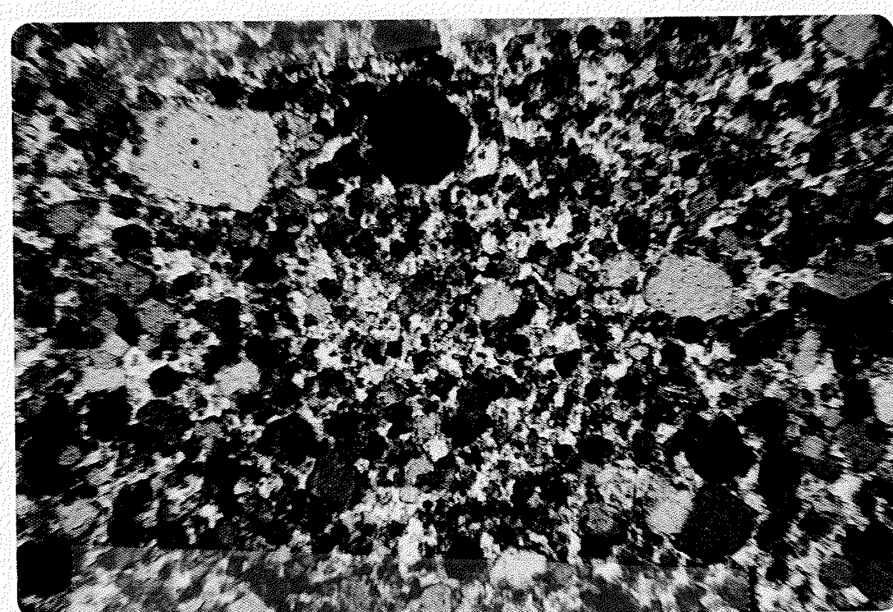


FIGURE 58 - MICROPHOTOGRAPHY OF TOURMALINE GRAINS IN A TOURMALINE SANDSTONE CLAST (SLIDE 75-21A, 10x, STATION 21A).

APPENDIX II - MEGASCOPIC MODAL POINT COUNTS OF CLAST TYPES AT STUDIED OUTCROPS

STATION LOCALITY	Volcanic Sandstone F_1	Porphyritic Felsic Volcanic F_2	Intermediate Volcanic I_1	Andesite Porphyry I_2	F.Gr. Granoblastic Leucodiorite M_1	M.Gr. Blastic Leucodiorite M_2	Meladiorite M_3	Melagabbro M_4	F.Gr. Tonalite G_1	M.Gr. Tonalite G_2	C.Gr. Tonalite G_3	Hornblende Tonalite G_4	Biotite Schist S_1	Greywacke S_2	Iron Formation X_1	Tourmaline Sandstone X_2	Matrix
21A	29.4	10.6	2.0	-	4.1	-	-	-	4.5	15.3	0.9	-	19.0	11.9	X	X	2.3
21B	29.1	14.2	5.0	-	1.7	-	0.9	-	5.0	11.8	0.9	-	10.6	15.1	-	-	5.6
21C	28.1	17.1	3.2	0.9	3.6	X	0.9	-	1.5	15.9	0.4	-	13.1	9.2	-	X	6.2
21D	32.1	13.2	4.0	1.5	2.0	X	7.2	X	2.8	13.0	0.6	-	11.4	6.9	-	X	5.3
21F	25.5	17.7	4.2	2.1	3.0	2.7	3.9	1.1	3.3	10.0	4.8	-	12.2	3.0	X	X	6.6
21G	20.9	18.6	5.2	1.8	3.4	0.5	11.0	3.4	2.9	6.9	1.5	-	10.9	7.8	-	X	5.6
21H	23.5	15.1	3.4	1.9	6.5	X	0.8	X	1.7	16.0	0.6	-	16.2	6.2	X	X	8.4
66A	14.0	5.6	-	-	-	-	-	-	-	3.9	-	-	6.6	-	-	-	69.9
66B	12.9	9.1	2.5	-	6.2	-	-	-	1.3	4.2	-	-	18.7	5.8	-	-	39.4
38	33.0	7.3	-	-	11.0	-	-	-	-	3.6	-	-	6.7	10.4	-	-	28.1
36	17.9	10.8	-	-	-	-	-	-	-	1.7	-	17.9	15.9	0.5	-	-	35.3
31	26.7	18.1	2.4	-	2.4	-	-	-	3.0	9.6	-	-	16.0	15.2	-	-	6.6
29	27.9	12.9	5.0	-	1.8	-	-	-	1.6	10.2	3.4	-	12.7	13.4	-	-	11.1
26	23.9	19.8	7.1	-	1.6	-	-	-	1.2	8.6	-	-	21.1	14.6	-	-	2.1
61	32.2	17.9	4.4	0.6	2.9	-	0.9	X	1.2	13.2	0.9	-	17.6	10.3	X	-	6.9
67	25.8	15.5	4.3	-	5.3	-	-	-	3.6	14.5	2.8	-	12.2	10.0	-	-	6.0
68	28.8	16.9	3.5	-	2.6	0.9	4.2	X	3.5	11.9	2.8	-	11.7	4.9	-	-	8.4
69	26.5	19.5	5.4	0.5	3.2	0.5	1.8	0.2	3.6	14.5	1.4	-	8.6	5.9	X	X	8.4

STATION LOCATION	F_1	F_2	I_1	I_2	M_1	M_2	M_3	M_4	G_1	G_2	G_3	G_4	S_1	S_2	X_1	X_2	Matrix
202	17.6	11.2	5.2	-	1.9	-	-	-	3.4	13.1	2.6	-	9.4	4.5	-	-	31.1
73	26.2	19.7	4.4	0.5	2.4	0.7	3.1	0.4	2.4	14.4	2.6	-	9.2	4.8	X	X	9.2
77	17.0	17.5	4.5	3.1	3.1	1.2	1.6	-	1.6	17.0	3.5	-	19.2	5.4	X	X	5.4
57	48.8	8.3	-	-	2.3	-	-	-	-	1.7	-	-	10.7	5.2	-	-	23.1
8	23.3	11.2	-	-	-	-	-	-	-	2.3	-	7.8	18.9	4.1	-	-	32.3
92	27.2	20.0	-	-	4.7	-	-	-	-	2.4	-	-	21.6	5.5	-	-	18.7
93	28.5	27.4	-	-	6.9	-	-	-	-	2.5	-	-	12.8	4.2	-	-	17.7
128	22.4	29.6	3.5	2.3	2.0	-	-	-	-	4.3	-	-	15.8	8.6	-	-	11.5
193	31.5	24.7	-	-	2.1	0.7	2.3	-	-	-	-	-	22.2	9.3	-	-	6.3
191	29.2	14.2	3.6	-	3.7	X	8.8	0.7	-	-	-	-	20.4	8.2	X	-	11.1
195	24.9	12.0	-	X	2.7	X	7.4	-	11.2	3.2	-	-	19.0	8.2	X	-	11.4
178	23.7	17.6	2.7	1.2	1.9	X	3.8	1.5	2.7	16.4	4.2	-	12.6	5.7	-	-	6.1
184	21.1	15.3	5.6	1.6	1.9	0.4	3.1	0.8	1.4	13.9	2.2	-	17.5	8.9	-	-	6.4
186	25.5	16.2	4.2	1.3	1.1	0.4	4.5	0.4	2.1	14.5	2.7	-	13.4	6.5	X	-	7.2
187	28.8	19.5	2.5	1.7	0.6	0.6	2.3	1.1	2.5	19.5	2.1	-	10.2	5.1	X	-	3.6
188	27.2	16.1	3.3	0.9	2.6	-	3.0	0.9	0.5	15.1	4.4	-	10.7	7.2	-	-	8.1
190	17.6	14.3	5.1	1.1	2.7	0.5	4.7	0.5	3.1	21.4	4.5	-	11.2	6.5	X	-	6.9
196	30.6	12.5	2.1	0.2	1.9	0.9	5.0	-	3.4	15.3	1.9	-	9.6	7.6	X	-	9.1
197	31.4	15.4	1.5	2.4	2.4	0.9	2.8	-	1.7	7.9	2.8	-	14.7	8.8	-	-	7.5
198	24.5	18.6	4.1	0.7	2.3	0.5	6.1	-	4.3	14.5	3.2	-	7.3	6.3	X	-	7.6
199	28.9	22.8	4.5	0.5	0.5	0.8	3.2	-	3.9	16.3	1.6	-	6.8	5.8	-	-	4.5
200	36.6	14.2	3.7	0.4	2.3	1.0	11.3	0.4	3.3	11.9	1.2	-	4.0	4.3	X	X	5.5
201	34.5	18.8	5.4	-	5.6	0.4	-	-	3.6	6.0	1.0	-	12.0	7.2	-	-	5.6
82	29.4	9.3	2.4	0.6	4.5	0.8	1.4	-	2.6	15.8	3.0	-	13.6	7.7	-	-	9.1
72	27.1	17.8	6.0	0.6	4.4	0.6	2.4	0.4	2.6	11.0	2.0	-	7.6	8.6	-	-	8.9
75	34.6	11.1	4.3	0.4	2.7	0.8	3.5	0.2	4.1	18.8	1.4	-	8.6	3.1	X	-	6.5
76	23.9	12.5	4.5	0.4	2.7	1.0	8.8	0.2	2.7	19.4	3.9	-	6.1	4.7	X	0.4	8.8

- All values are volume proportions of the clast types present at the studied outcrops

- X= clast present, not in significant amounts.

APPENDIX III

Sedimentary Textures and Structures and Internal Organizations of Conglomerates and Associated Greywackes in Ancient Sedimentary Environments

Abbreviations used in the following table:

Size; VC (very coarse), C (coarse), M (medium), F (fine) VF (very fine).

Shape; R (rounded), SR (subrounded), SA (subangular), A (angular).

Sorting; G (good), M (moderate), P (poor), V (variable).

Textures; X (well developed), / (moderately developed), O (absent or very poorly developed).

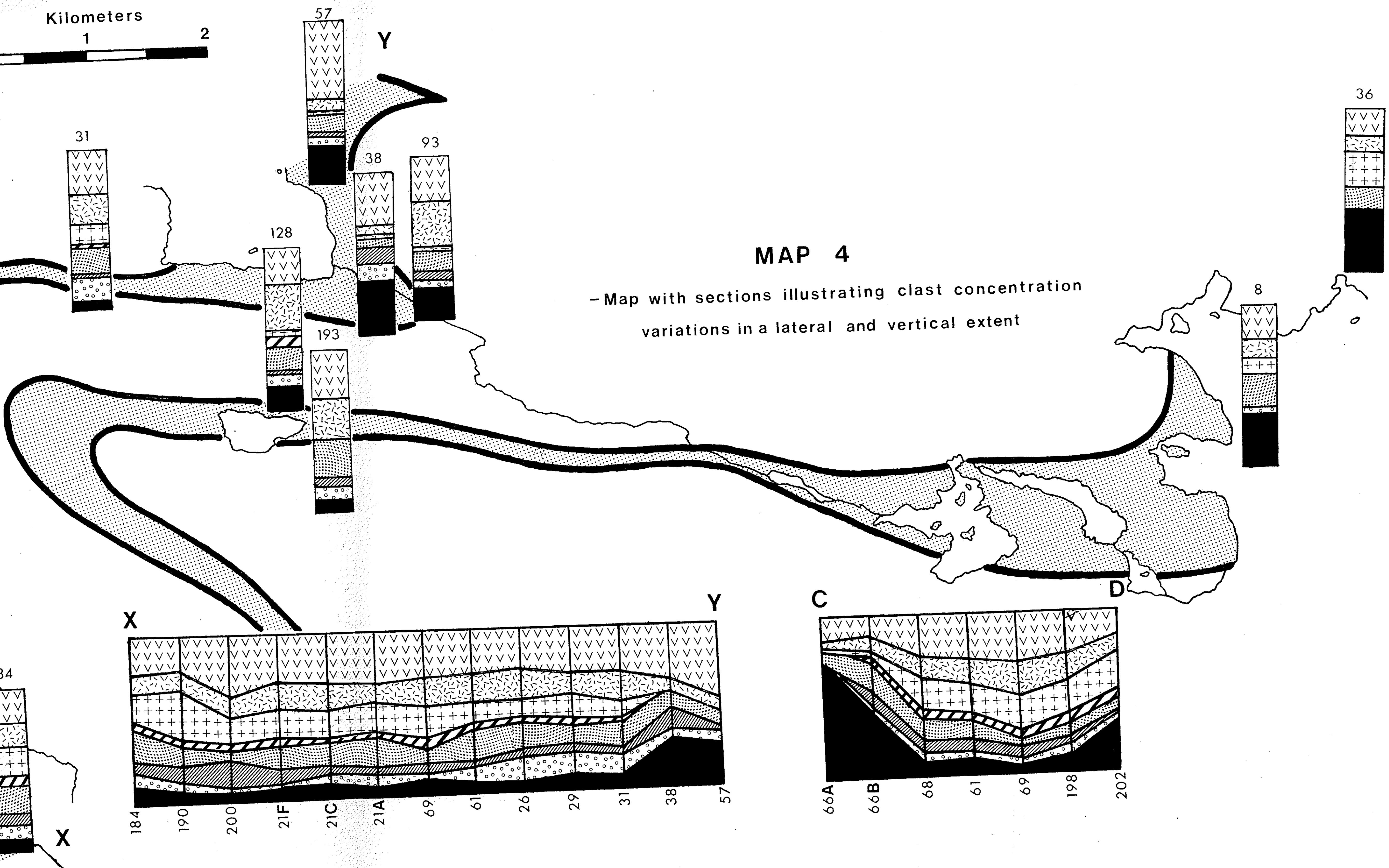
Amount of matrix; VL (very low), L (low), M (moderate), H (high).

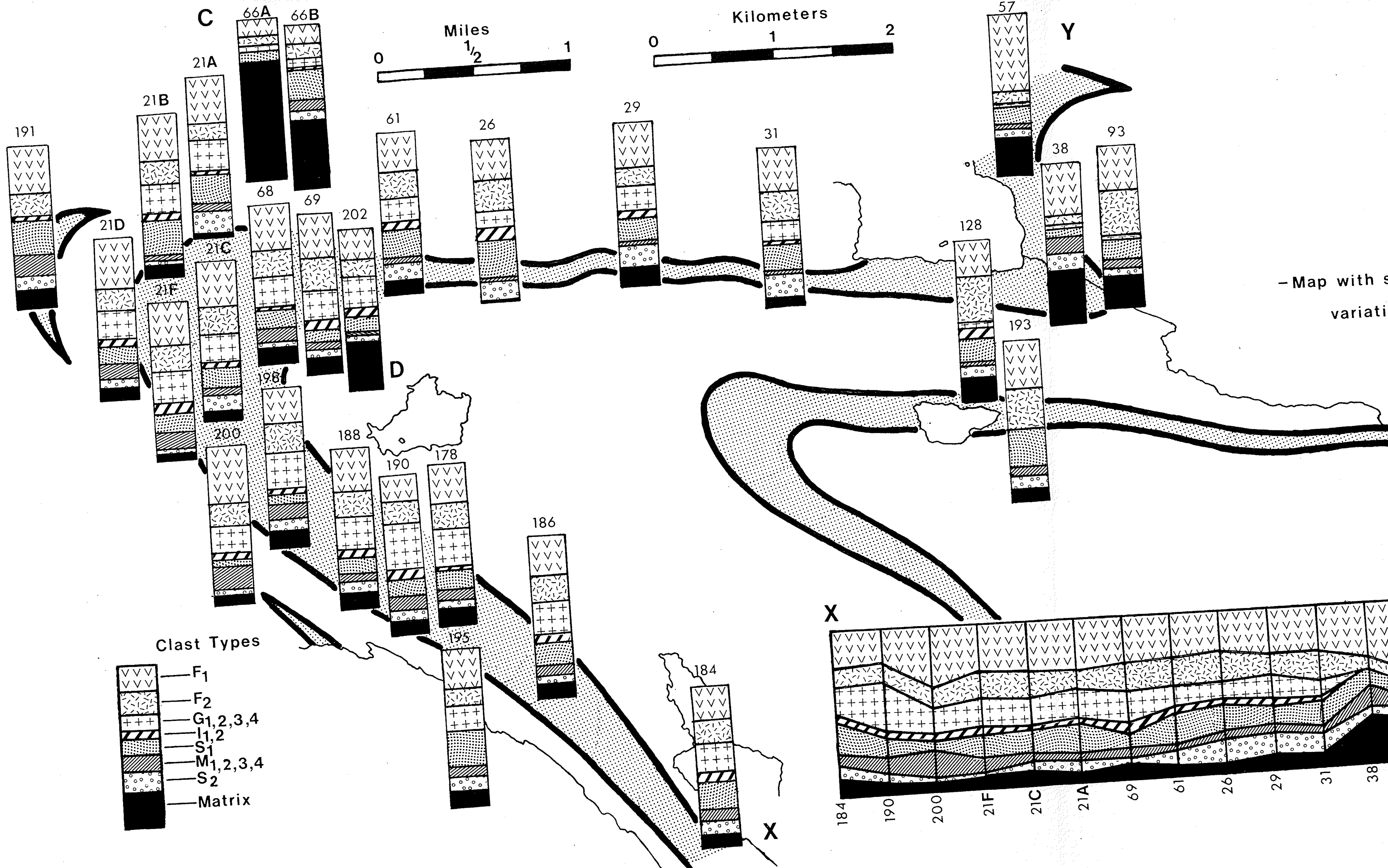
ENVIRONMENT		MARINE	BEACH	LACUSTRINE	FLUVIAL	TILLOID	(A-UNIT) FLYSCH	FLUXOTURBIDITE
Size	CLASTS	VF-C	F-VC	F-M	C-F	VC-F	C-M	VC-F
	Matrix	VF	F-VF	F-VF	F-M	F-VF	F	F
Shape of Clasts		R,SR	R,SR	R,SR	R,SR,SA	R,A	SR,SA	SR,SA,A
Sorting		G-M	P-G	G-V	M-G	P,V	M,G,V	P
Framework		Open-Closed	Closed	Closed	Closed	Disrupted Closed	Closed	Closed
Amount of Matrix		L-VL	L-H	M-H	M-L	M-H	M-H	L-M
Bedding	Massive	0	/	/	/	X	/	X
	Moderate	/	X	X	/	/	/	0
	Good	X	X	X	X	0	X	0
	Small-Scale	X	/	X	/	0	X	0
	Large-Scale	/	0	0	/	0	/	0
	Cross Beds	/	/	/	X	0	/	/
	Graded Beds	/	/	/	/	0	X	/-0
	Others	Regular, Thin	Thin, Patchy Lensoid	Laterally Continuous	Irregular Horizontal, Channel	Poor	Regular Consistent Rhythmic	Irregular, Thick
Laminations		Good Parallel	Cross and Parallel	Horizontal Disturbed	Minor	0	Good, Parallel Convolute	Cross
Slump Features		0	0	0	0	0	0	X-/
Scour and Channel Fill		/	/	/	X	0	/-0	X
Stratification		Good, Lateral Continuity	Poor Discontinuous	Good	Good, Parallel, Abundant	None	Excellent to moderate	Irregular Poor
Associated Sediments and Textures		-Extensive sandstone layers -F.Gr.Marine siltstone and shale -Finely laminated	-Cross-bedded Sandstones	-Evaporites -F. Gr. Sediments that are finely laminated -sandstones and shales with minor cross-laminations	-Well stratified sandstone -Shale -Floating clasts -Channel like forms	-Calcareous rocks -Finely laminated argillites -Dropped clasts -Arenaceous sediments	-Interbedded finely bedded sandstones and shales -good grading -Flame structures -Load casts -Rip-offs	-Discontinuous Argillites -C.Gr. Lenses of sandstone -Interbedded with normal turbidites -Beds thicken down source

ENVIRONMENT		ALLUVIAL FAN	SUBAQUEOUS FAN	BOOSTER LAKE CONGLOM-ERATE
Size	Clasts	VC-F	C-F	C-F
Size	Matrix	F-VF	M-F	F-M
Shape of Clasts		SR,R,SA,A	SR,R,SA	SR,R,SA
Sorting		P,V	P-M	P-M
Framework		Closed	Closed	Closed
Amount of Matrix		L-M	L-M	L
Bedding	Massive	X	X	X
Bedding	Moderate	/	/	/
Bedding	Good	0	0	0
Bedding	Small-scale	0	/-0	/-0
Bedding	Large-scale	/	/-0	/-0
Bedding	Cross Beds	/	/-0	0
Bedding	Graded Beds	/	0-/	0-/
Bedding	Others	Lenticular, Thick, Wedge, Blanket, Channels	Irregular, Constant	Constant Lateral Thickness, Minor Lenses
Laminations		0	0	Poor
Slump Features		0	0	0
Scour and Channel Fill		/	/-0	0
Stratification		Hori Poor Irregular	Horizontal Poor to Moderate	Poor Irregular Slightly Oblique
Associated Sediments and Textures		-Beds thicken to apex -Interbedded cross-stratified sandstones and pebbly sandstones -Sandstones: F.Gr. well sorted, Bedded Cross-Laminated.	-Massive and discontinuous sand lenses -Minor calcareous lenses -Minor shale -Sand lenses similar to matrix.	-Massive, poorly cross-laminated greywacke and pebbly greywacke -Minor calcareous greywacke accumulations.

MAP 4

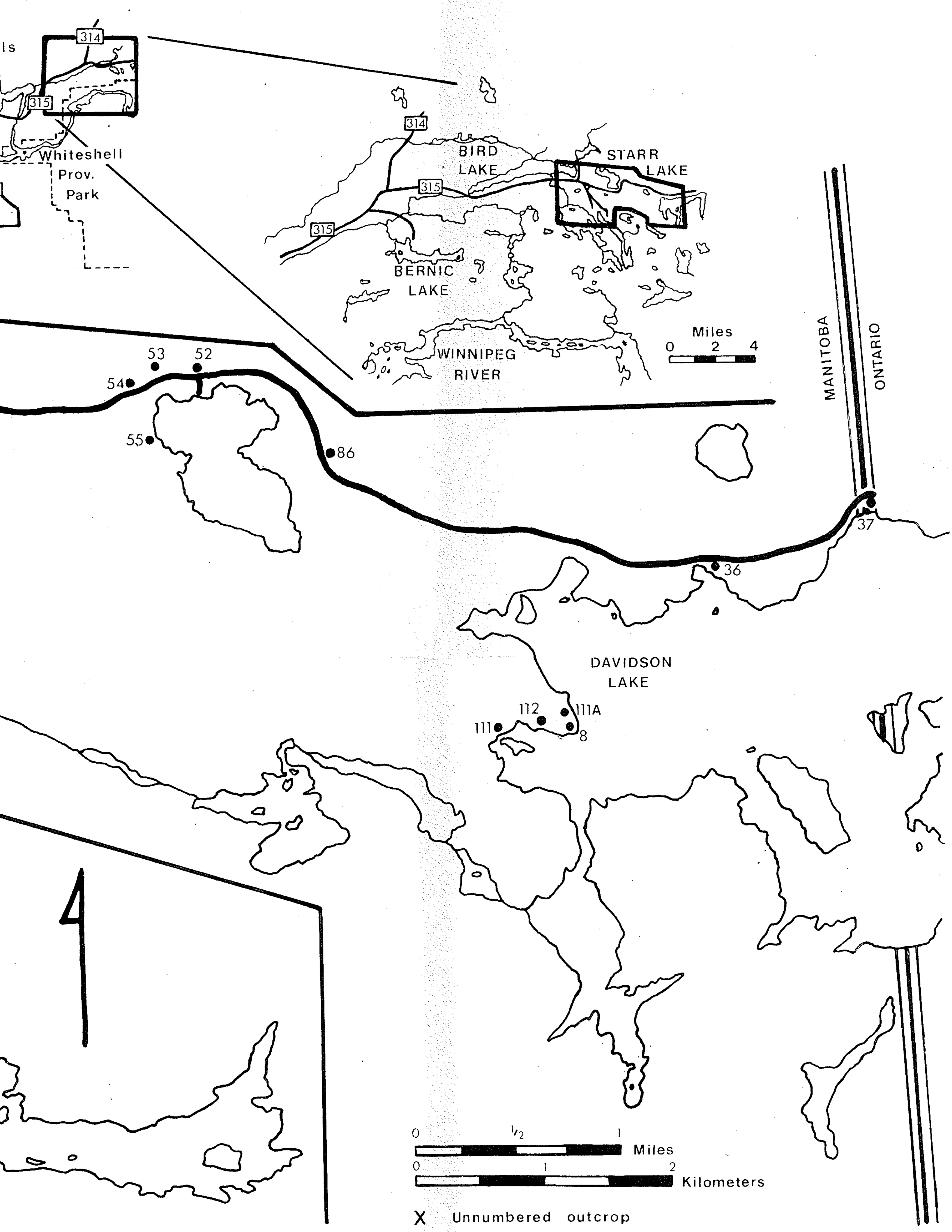
–Map with sections illustrating clast concentration variations in a lateral and vertical extent



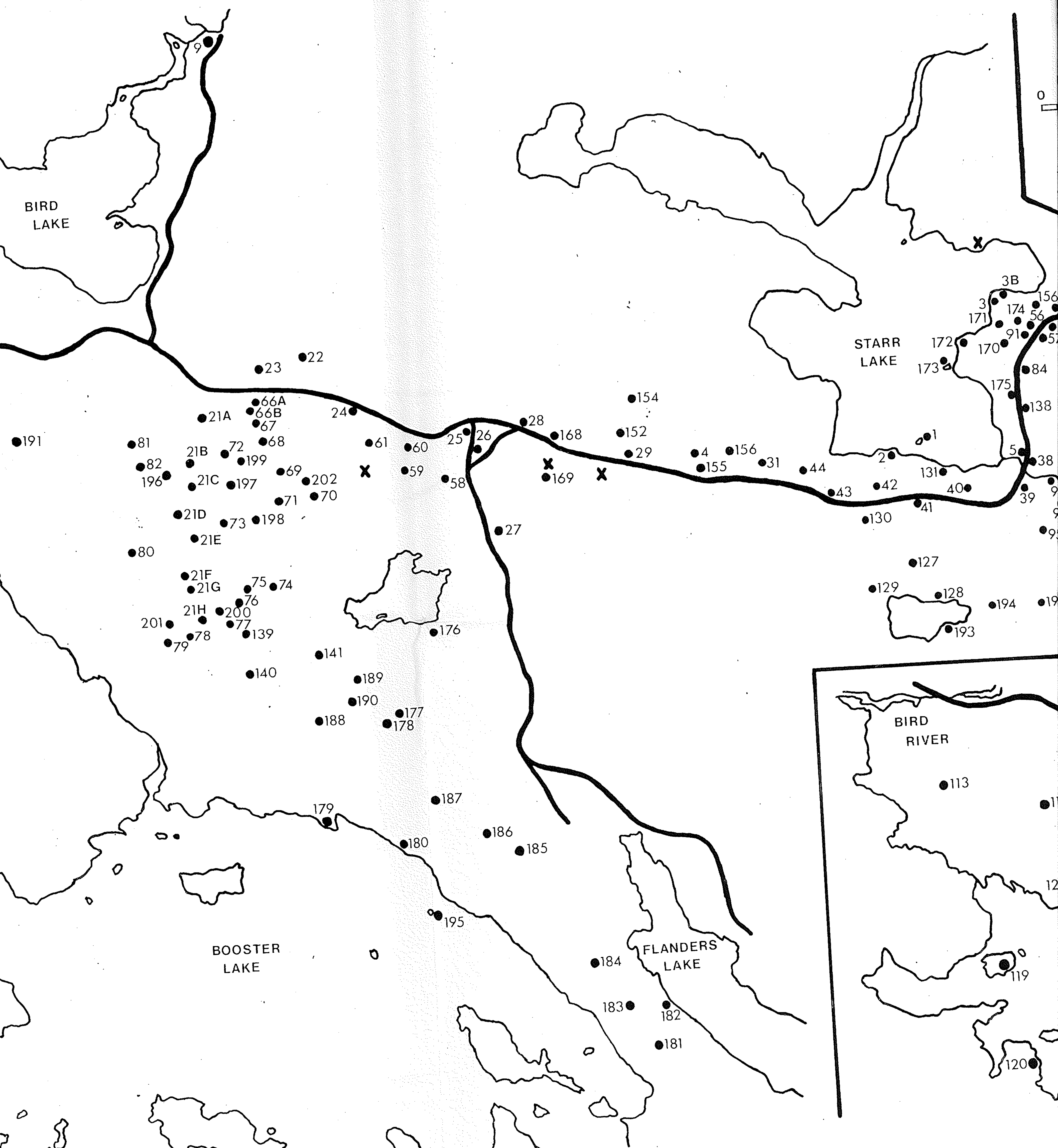


-Map with s

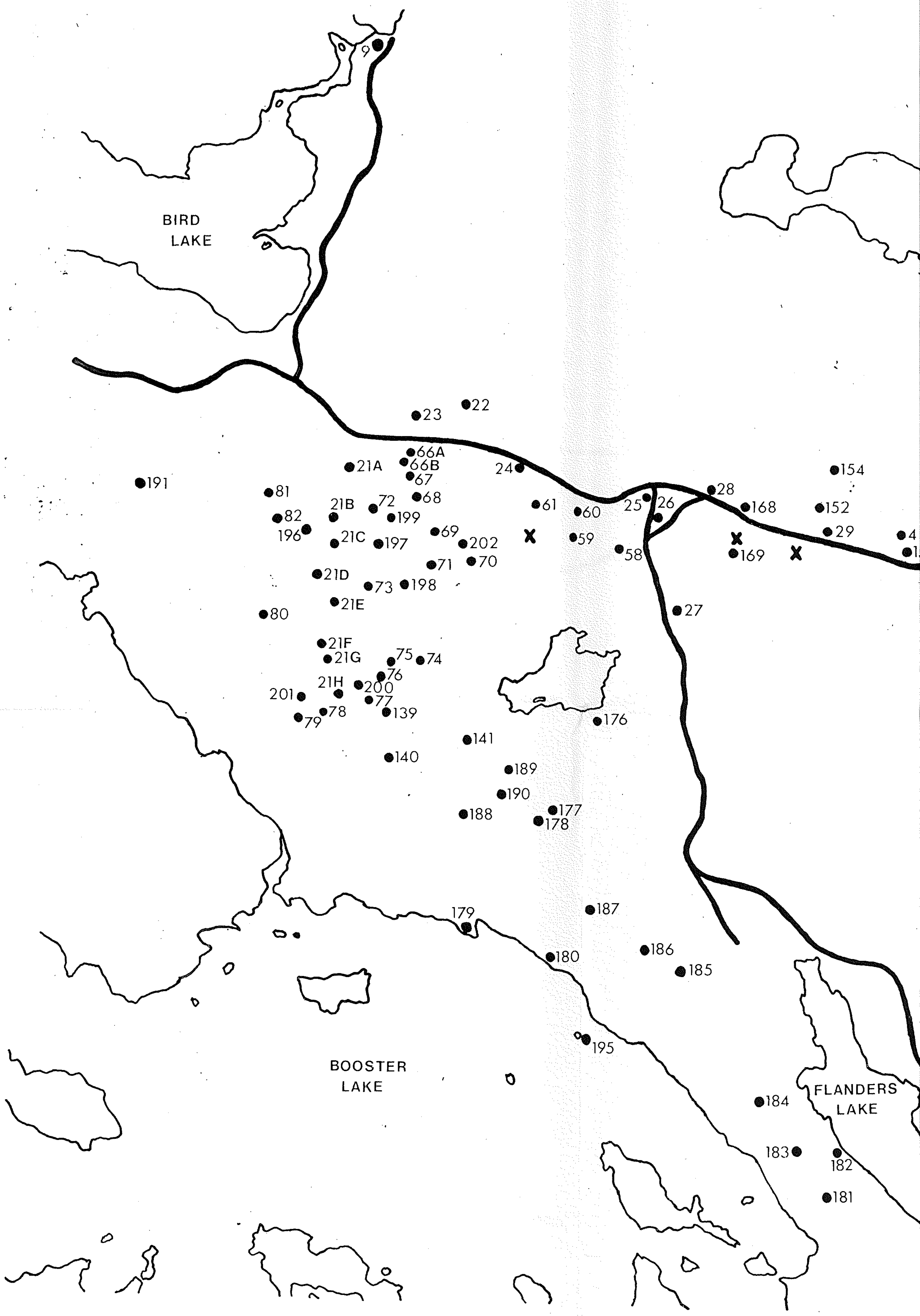
variatio



ls
314
315
Whiteshell
Prov.
Park
314
BIRD
LAKE
STARR
LAKE
315
315
BERNIC
LAKE
WINNIPEG
RIVER
Miles
0 2 4
MANITOBA
ONTARIO
53
52
54
55
86
37
36
DAVIDSON
LAKE
112
111A
111
8
4
0 1/2 1
Miles
0 1 2
Kilometers
X Unnumbered outcrop



MAP 1: Location and S


BIRD LAKE
BOOSTER LAKE
FLANDERS LAKE
9
22
23
24
25
26
27
28
29
58
59
60
61
66A
66B
67
68
69
70
71
72
73
74
75
76
77
78
79
80
81
82
139
140
141
152
154
168
169
176
177
178
179
180
181
182
183
184
185
186
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189
190
191
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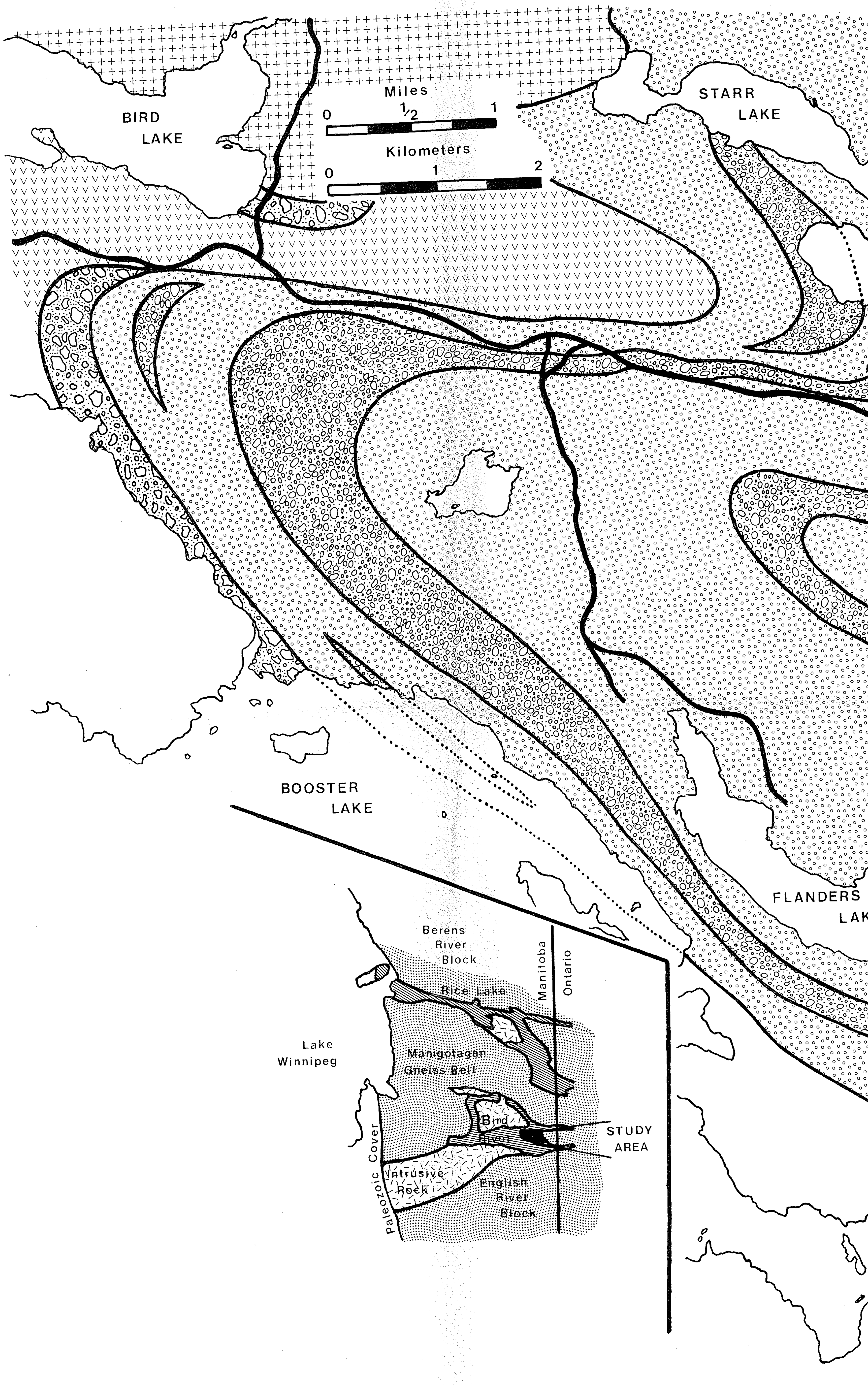
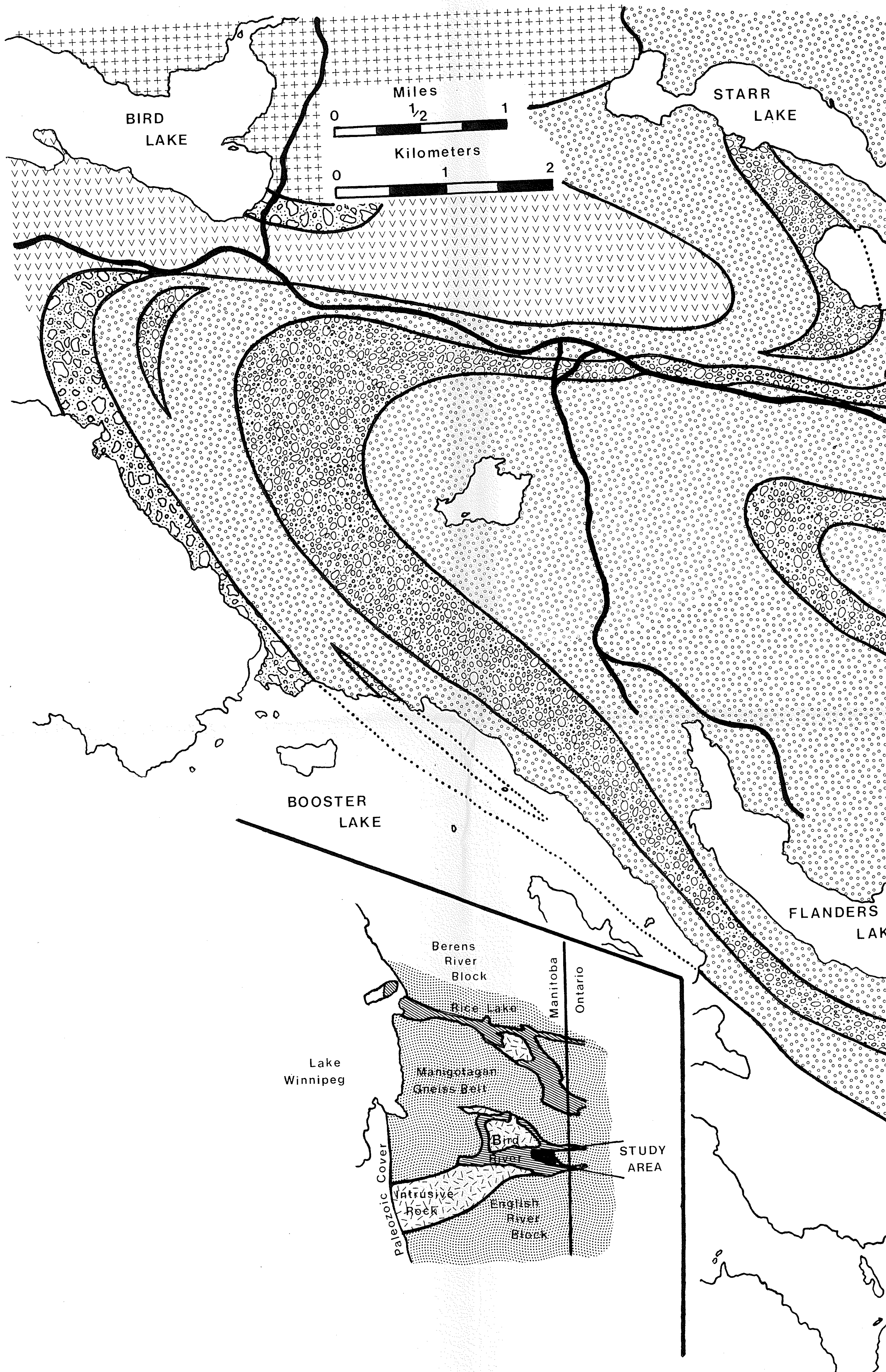
198
199
200
201
202
21A
21B
21C
21D
21E
21F
21G
21H

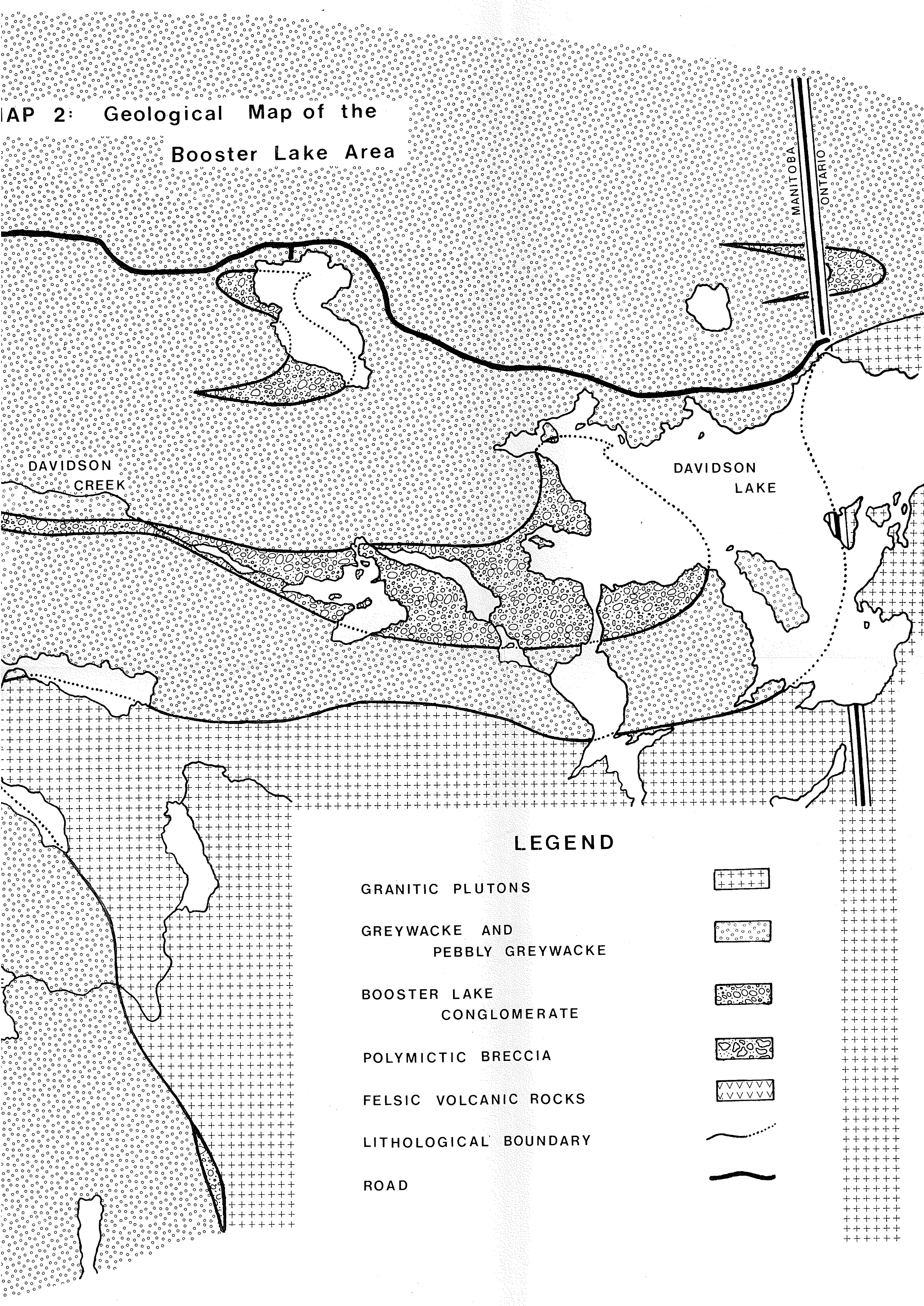
M



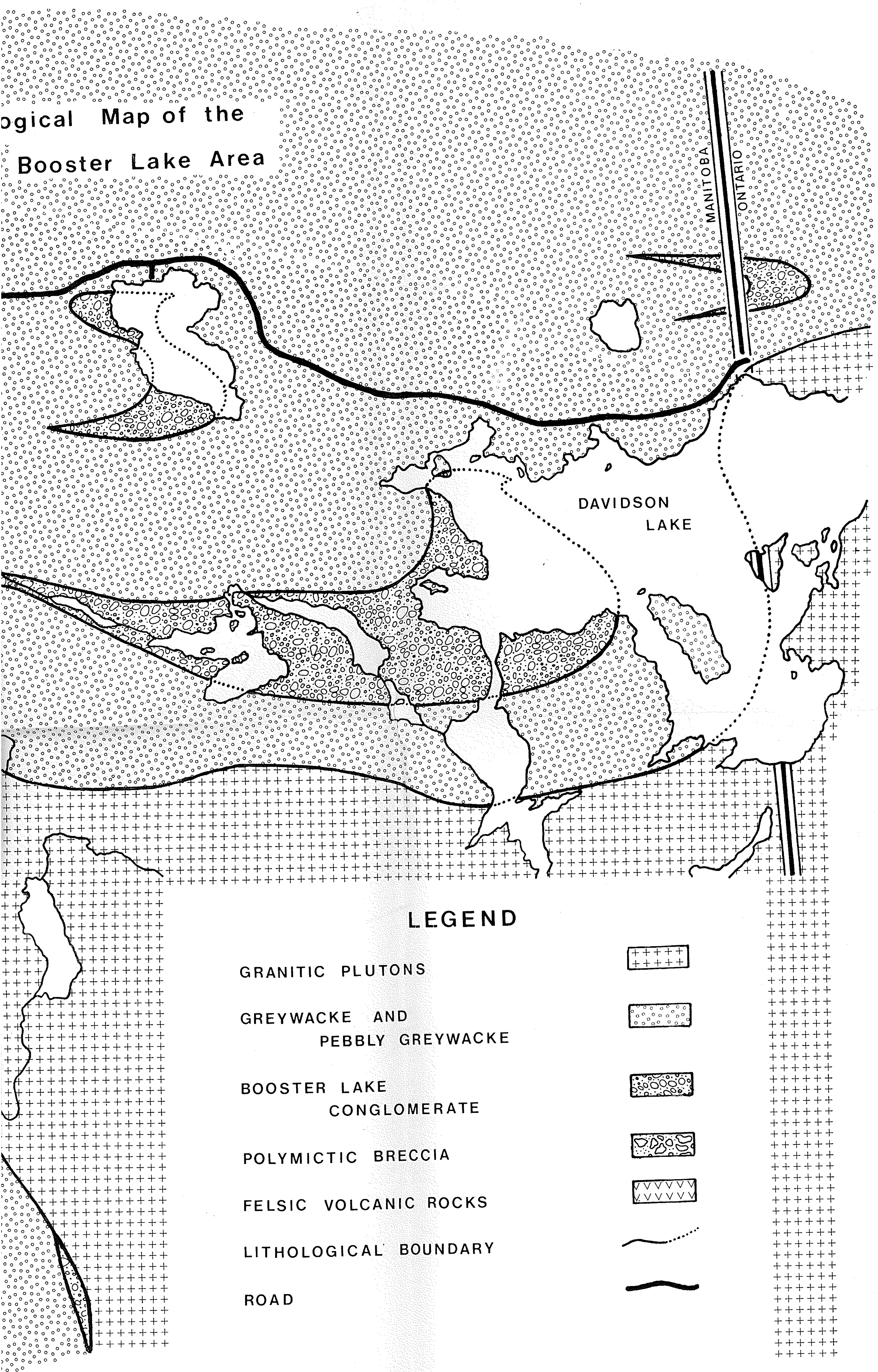
BIRD
LAKE
Miles
0
1/2
1
Kilometers
0
1
2
STARR
LAKE
BOOSTER
LAKE
FLANDERS
Berens
River
Block
Manitoba
Ontario
Rice Lake
Lake
Winnipeg
Manigotagan
Gneiss Belt
Bird
River
STUDY
AREA
Paleozoic Cover
Intrusive
Rock
English
River
Block

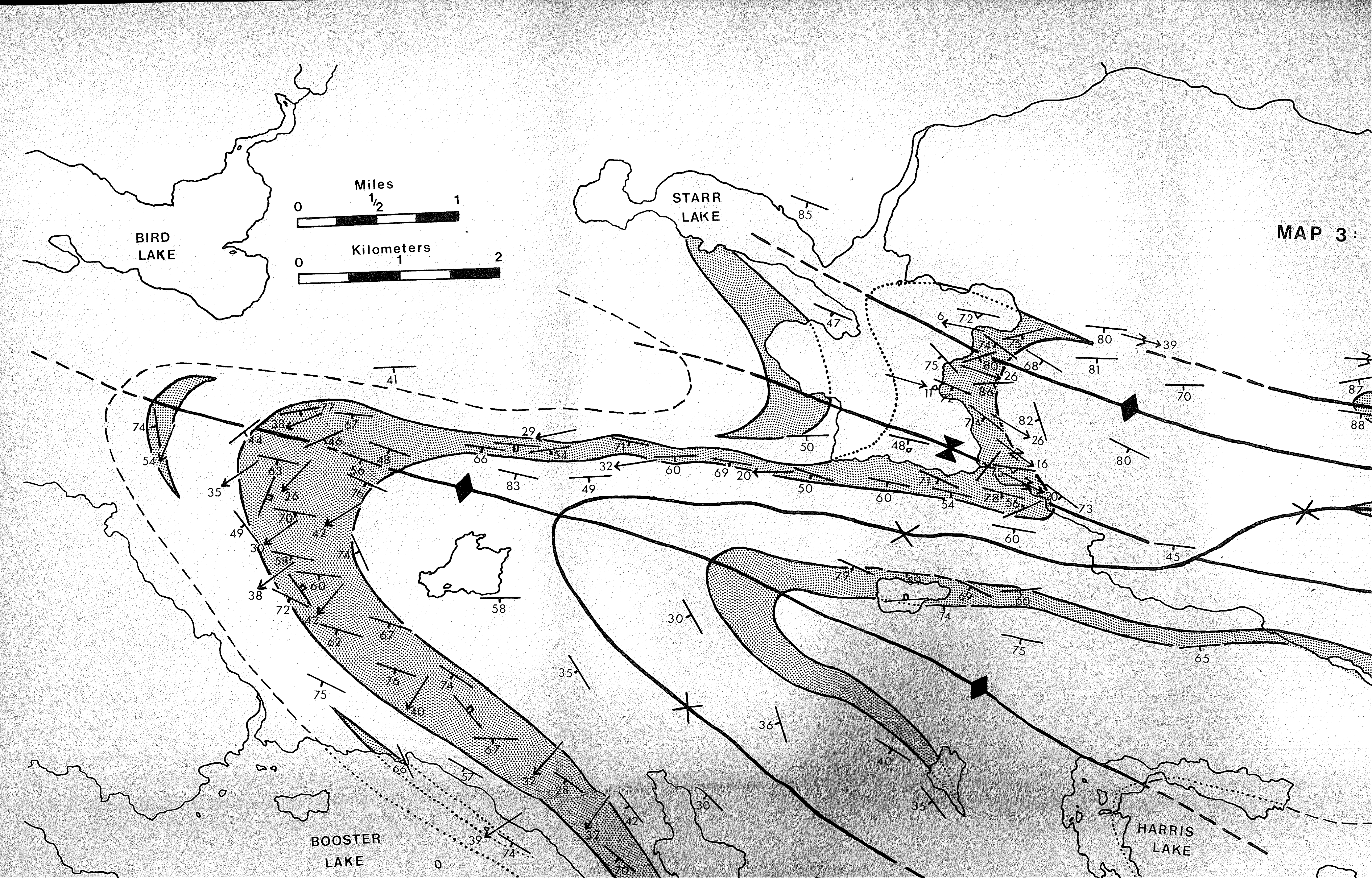


BIRD
LAKE
Miles
0
1/2
1
Kilometers
0
1
2
STARR
LAKE
BOOSTER
LAKE
FLANDERS
LAK
Berens
River
Block
Rice Lake
Manitoba
Ontario
Lake
Winnipeg
Manigotagan
Gneiss Belt
Bird
River
STUDY
AREA
Paleozoic Cover
Intrusive
Rock
English
River
Block

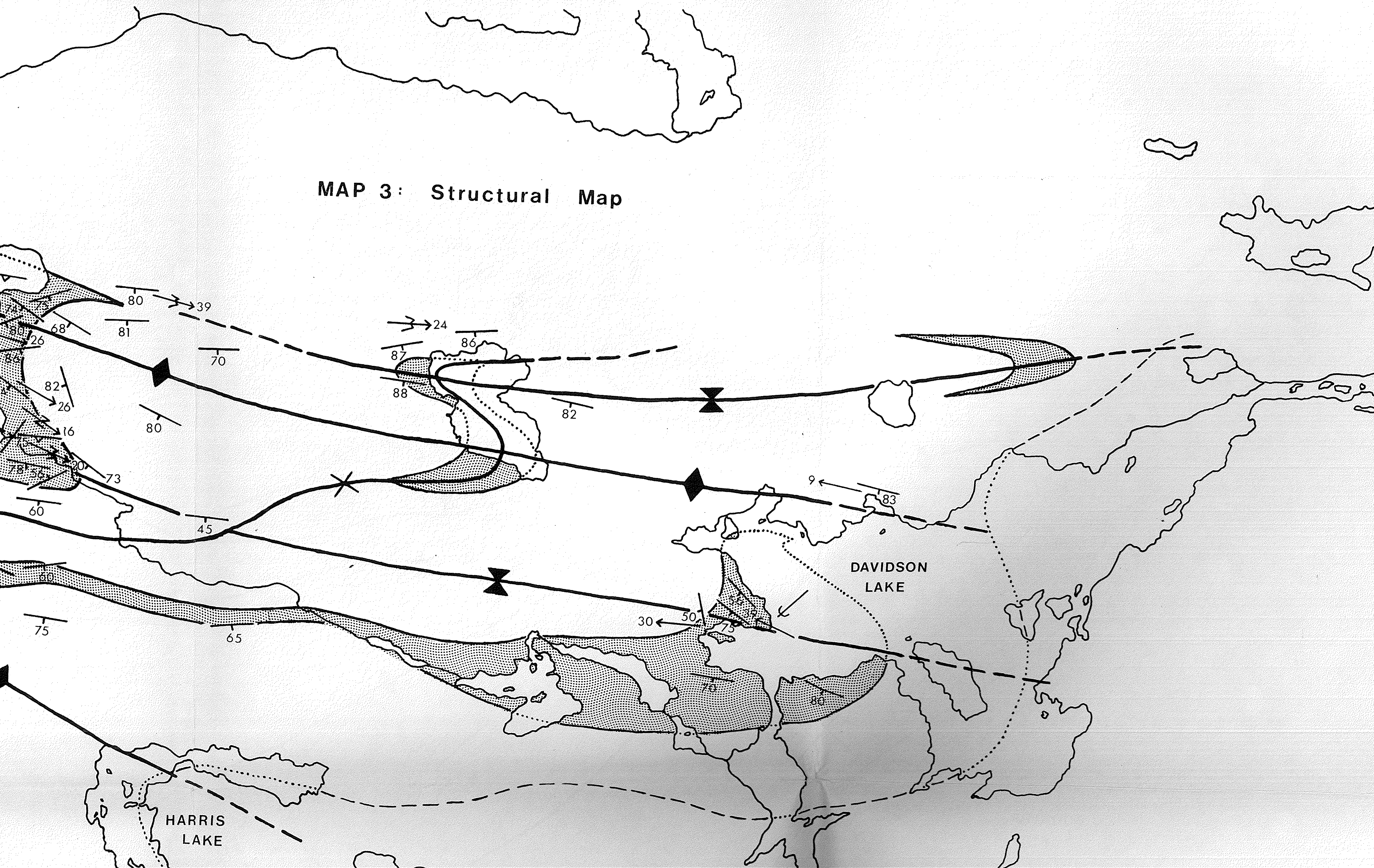


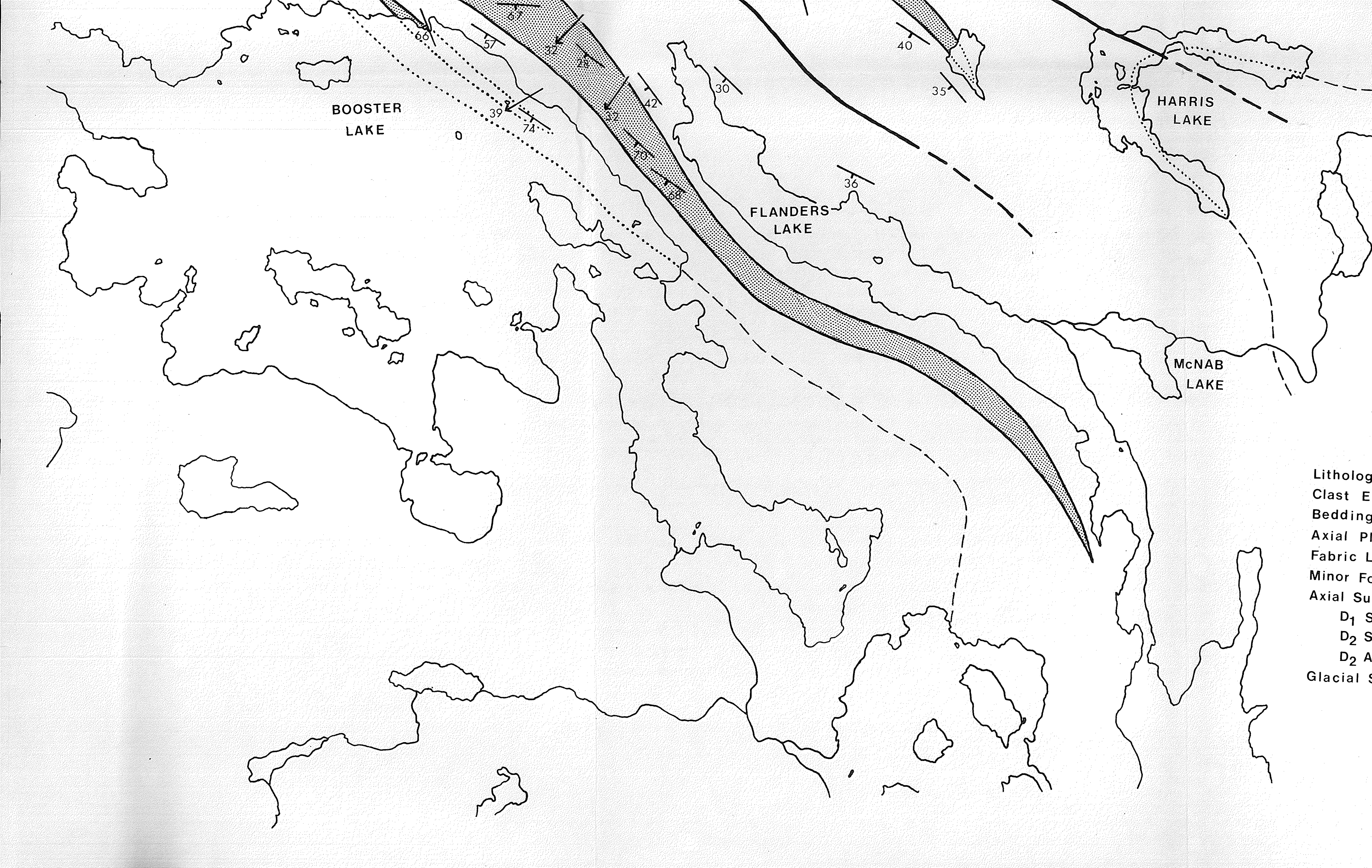
IAP 2: Geological Map of the
Booster Lake Area
MANITOBA
ONTARIO
DAVIDSON
CREEK
DAVIDSON
LAKE
LEGEND
GRANITIC PLUTONS
GREYWACKE AND
PEBBLY GREYWACKE
BOOSTER LAKE
CONGLOMERATE
POLYMICTIC BRECCIA
FELSIC VOLCANIC ROCKS
LITHOLOGICAL BOUNDARY
ROAD

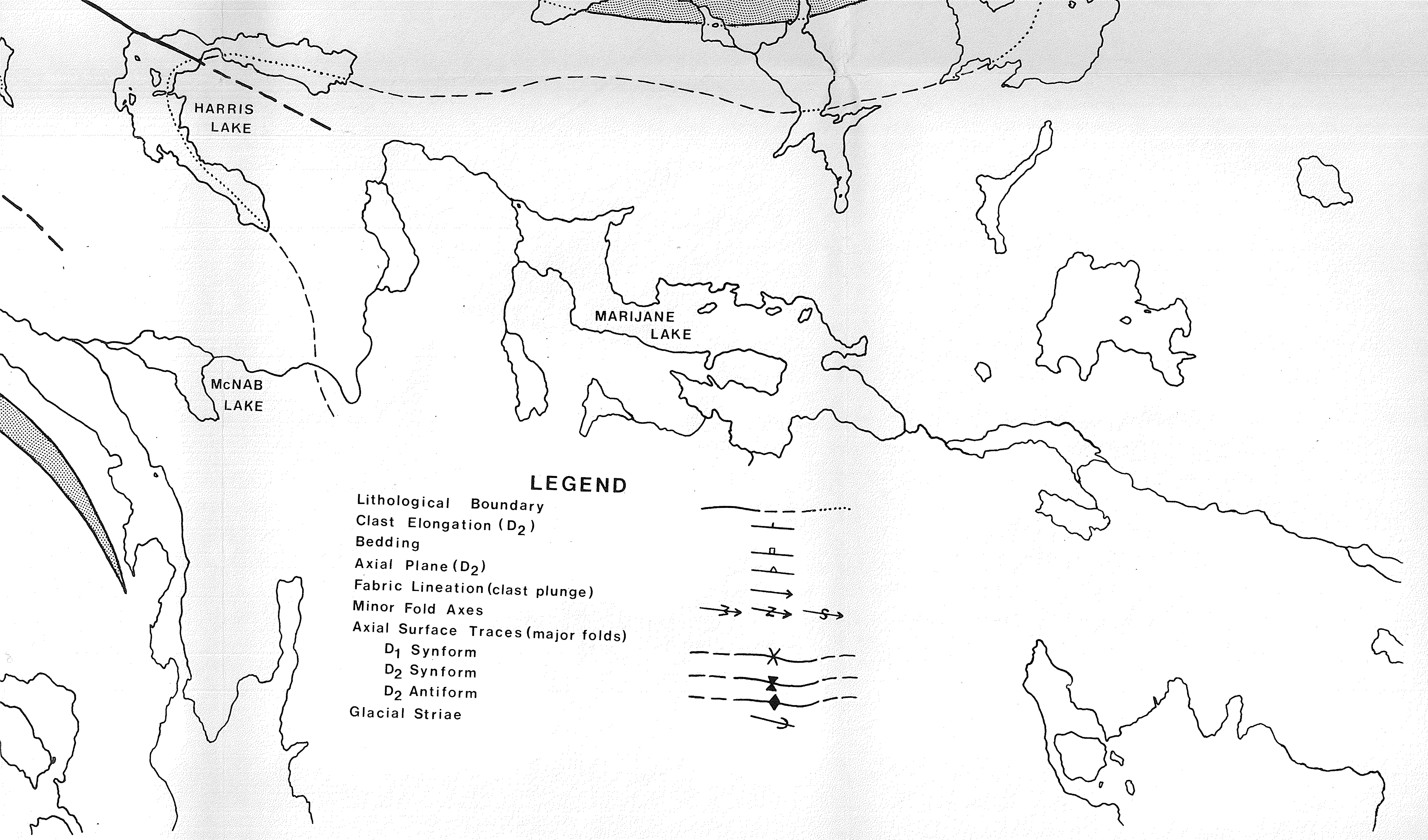

ogical Map of the
Booster Lake Area
MANITOBA
ONTARIO
DAVIDSON
LAKE
LEGEND
GRANITIC PLUTONS
GREYWACKE AND
PEBBLY GREYWACKE
BOOSTER LAKE
CONGLOMERATE
POLYMICTIC BRECCIA
FELSIC VOLCANIC ROCKS
LITHOLOGICAL BOUNDARY
ROAD



MAP 3:
BIRD LAKE
STARR LAKE
BOOSTER LAKE
HARRIS LAKE
Miles
0
1/2
1
Kilometers
0
1
2


MAP 3: Structural Map
DAVIDSON LAKE
HARRIS LAKE


BOOSTER LAKE
FLANDERS LAKE
HARRIS LAKE
McNAB LAKE
66
57
67
32
28
39
74
32
42
30
70
68
36
40
35
Litholog
Clast E
Bedding
Axial Pl
Fabric L
Minor Fo
Axial Su
D_1 S
D_2 S
D_2 A
Glacial S


HARRIS LAKE
MARIJANE LAKE
McNAB LAKE
LEGEND
Lithological Boundary
Clast Elongation (D_2)
Bedding
Axial Plane (D_2)
Fabric Lineation (clast plunge)
Minor Fold Axes
Axial Surface Traces (major folds)
D_1 Synform
D_2 Synform
D_2 Antiform
Glacial Striae