VOLCANIC STRATIGRAPHY, STRUCTURE AND METAMORPHISM IN THE COURAGEOUS-MACKAY LAKE GREENSTONE BELT, SLAVE PROVINCE, NORTHWEST TERRITORIES

by

Henry C.H. Dillon-Leitch

A thesis submitted to the School of Graduate Studies
in partial fulfillment of the requirements for the
degree of M.Sc. in Geology

UNIVERSITY OF OTTAWA

OTTAWA, CANADA, 1981

ABSTRACT

A steep homoclinal succession of volcanic rocks in the Courageous-MacKay Lake area extends about 70 km north-south, is 2 to 7 km wide, and is bounded by intrusive granitoid rocks to the west and conformably overlying turbiditic sediments to the east. Greater than 80 percent of the volcanic and associated intrusive rocks are mafic, including basaltic flows, pillow lavas, pillow breccias, and gabbroic sills and dykes. Amygdaloidal, pillowed, and massive flow andesites, locally present in the northern part of the upper 2.5 km of the section, are intercalated with massive and volcaniclastic rhyolitic to dacitic rocks. These felsic rocks occupy the top 2 km in the centre of the belt and thin felsic units extend north into mafic rocks. A thin, laterally continuous rhyodacite breccia within underlying mafic rocks is used as a marker to separate two cycles of volcanism.

It is suggested that during the first stage of volcanism a narrow, elongate, low angle, basaltic shield-like volcano formed, possibly on a sodic granitoid basement. Eruption of rhyodacite block-breccia concluded the cycle. The second cycle of volcanism began with extrusion of basaltic and vesicular andesitic lavas, the latter indicating a shallow subaqueous environment. A major felsic eruptive edifice formed in the central portion of the belt, flanked to the north by thin, but extensive volcaniclastic units. As felsic volcanism waned, continued basaltic extrusion took place in the northern part of the belt.

Structures, particularily in the sediments, indicate that the rocks were subjected to four phases of deformation. During an early phase (D_{0A}), the east-facing, steeply dipping homocline in volcanic rocks may have been tilted into position by the intrusion of sodic granitoid rocks to the west. Major, upright, F_{0B} folds in the sediments, with axial traces trending northward,

and also curving around sodic granitoid bodies, suggest east-west shortening (D_{0B}) across tilted beds, with strain modifications near rising plutons. A northeasterly striking S_{1A} foliation, solely preserved in biotite porphyroblasts, may reflect northwest-southeast compression (D_{1A}) during greenschist metamorphic conditions. S_{1A} is transposed into an S_{1B} cleavage, which is steeply inclined, strikes northward, and is generally parallel to bedding, but transects F_{0B} folds where they wrap around granitoid bodies. It is suggested that during D_{1B} deformation compression reverted to an east-west direction. Small, open to tight, F_2 folds and a steep, northwest-southeast axial planar cleavage (S_2) indicate northeast-southwest compression with high local strain. A weak northeast-southwest crenulation (S_3) of earlier foliations marks the last phase (D_3) of deformation, apart from late stage faults. S_3 seems to have formed in response to northwest-southeast compression.

Metamorphic conditions were at a peak during D_2 deformation, ranging up to upper amphibolite facies at either end of the belt, where cordierite, andalusite, and sillimanite isograds cross the sedimentary rocks, and cummintonite and sillimanite isograds cross the northern volcanic rocks. It is visualized that thermal doming of regional isotherms was associated with the intrusion of granite plutons.

RÉSUMÉ

La région de Courageous-MacKay Lake a une étendue nord-sud de 70 Km par 2 à 7 Km. Elle consiste en une série homoclinale de roches volcaniques et intrusives mafiques, à fort pendage limitées à l'ouest par des complexes granitiques, et qui, à l'est, repose en concordance, sur des grauwackes. La série comprend des coulées basaltiques, des laves en coussins brèchiformes et des dykes et filons-couche de gabbro. Des coulées à andesite en coussins, massives et avec amygdules sont localement présentes dans la partie nord des premiers 2.5 km de la série supérieure, et sont intercalées avec des laves massives et pyroclastiques à rhyolite et à dacite. Ces roches felsiques occupent les deux premiers km de la partie supérieure de la zone de roches vertes et des unités felsiques minces s'étendent au nord jusque dans les roches mafiques. Les deux cycles de volcanisme sont séparés par une mince unité continue de brèche à rhyodacite. La géologie suggère que durant les premiers stades de volcanisme, un volcan de type basaltique (à cone très aplati) s'est formé sur le socle granitique. Le cycle s'est terminé par l'éruption d'une breche à gros bloc de composition rhyodacite. Le second cycle a débuté par l'extrusion des laves à andésite vésiculaire et des basaltes. Un édifice felsique s'est formé dans la partie centrale de la zone, flanqué au nord par des unités pyroclastiques minces. Lors de la fin du cycle, des basaltes ont été déposés dans la partie nord de la zone.

La structure, particulièrement dans les sédiments, indique que les roches ont été soumises a quatre phases de déformation. Durant la phase initiale (D_{0A}), la série homoclinale, faisont face à l'est, a été basculée par l'intrusion de roches granitiques. Des plis serrés et verticaux, F_{0B}, dans les

sédiments ont des axes orientés au le nord, et ils sont aussi courbés autour des complexes granitiques, suggérant une compression est-ouest (D_{0B}), au travers des couches inclinées, avec des modificatons à la déformation auprès desplutons en émergence. Une foliation S_{1A}, orientée vers le nord-est, est préservée dans des porphyroblastes de biotite, mais peut toutefois refléter l'influence d'une compression venant du nord-ouest – sud-est (D_{1A}) durant le métamorphisme au facies des schistes verts. La foliation S_{1A} est transposée au clivage S_{1B}. Le clivage a une inclinaison abrupte et est orienté vers le nord, généralement parallele aux strates, mais qui recoupe les plis F_{0B} là où il courbe autour des plutons. Durant la déformation D_{1B}, la compression a été réorientée vers l'est-ouest. Despetits plis F_2, ouverts et serrés, et le clivage du plan axial S_2, orienté vers le nord-ouest, indique une compression avec déformaiton locale et intense vers le nord-est – sud-ouest. Une crénulation de foliation antérieure (S_2) orientée vers le nord-est – sud-ouest, marque la derniére phase de déformation (D_3), excluant des failles tardives. S_3 semble être formée en réponse d'une compression nord-ouest – sud-est.

Le métamorphis me a été plus intense durant la déformation D_2. Il atteint le facies amphibolite à chaque extrémité de la zone de roches vertes, où les isogrades de la cordiérite, andalusite et sillimanite sont représentés dans les roches sédimentaires, et les isogrades de le cummingtonite et sillimanite sont présents dans la série volcanique de la partie nord. L'intrusion de plutons granitiques a été accompagnée du la formation d'un dome des isothermes régionaux.

TABLE OF CONTENTS

CHAPTER 4

CHAPTER 5

Page

CHAPTER 6

CHAPTER 7

Tables

Plates

Page

Figures

Maps

Appendices

CHAPTER 1

INTRODUCTION

Location and access

The Courageous-MacKay Lake greenstone belt is located in the Slave Structural Province (Figure 1), about 240 Km northeast of Yellowknife, N.W.T. (Figure 2). The area has one landing strip for wheeled planes. The rest of the volcanic belt is accessible by ski- or float-planes on the shores of Courageous, Matthews, and MacKay Lakes and frequently on the numerous small, shallow lakes within the belt. Mining companies have recently used a winter tractor road from Great Slave Lake to Courageous Lake to bring in drilling equipment. The larger lakes become ice-free anywhere from June 15th to July 10th.

Physical features

The Courageous-MacKay Lake area varies in elevation from 510 m to about 660 m. A.S.L. The most rugged terrain occurs in volcanic rocks of mafic composition. Felsic lavas have only minor relief and granitic rocks tend to form low, rounded hills. The sedimentary rocks have the lowest topographic expression, frequently only being exposed through frost-heaving. Contacts between rock types are commonly linear depressions filled with glacial debris. Faults transecting the volcanic rocks in the northern and southern portions of the belt have produced cliffs up to 30 m high.

Volcanic rocks are the best preserved. Within the volcanic belt the exposure ranges from 10 to 70 percent averaging about 40 percent. Granitoid outcrop exposure is variable, ranging from 20 to 60 percent and averaging about 30. The outcrop exposure is the poorest within the sediments, averaging less

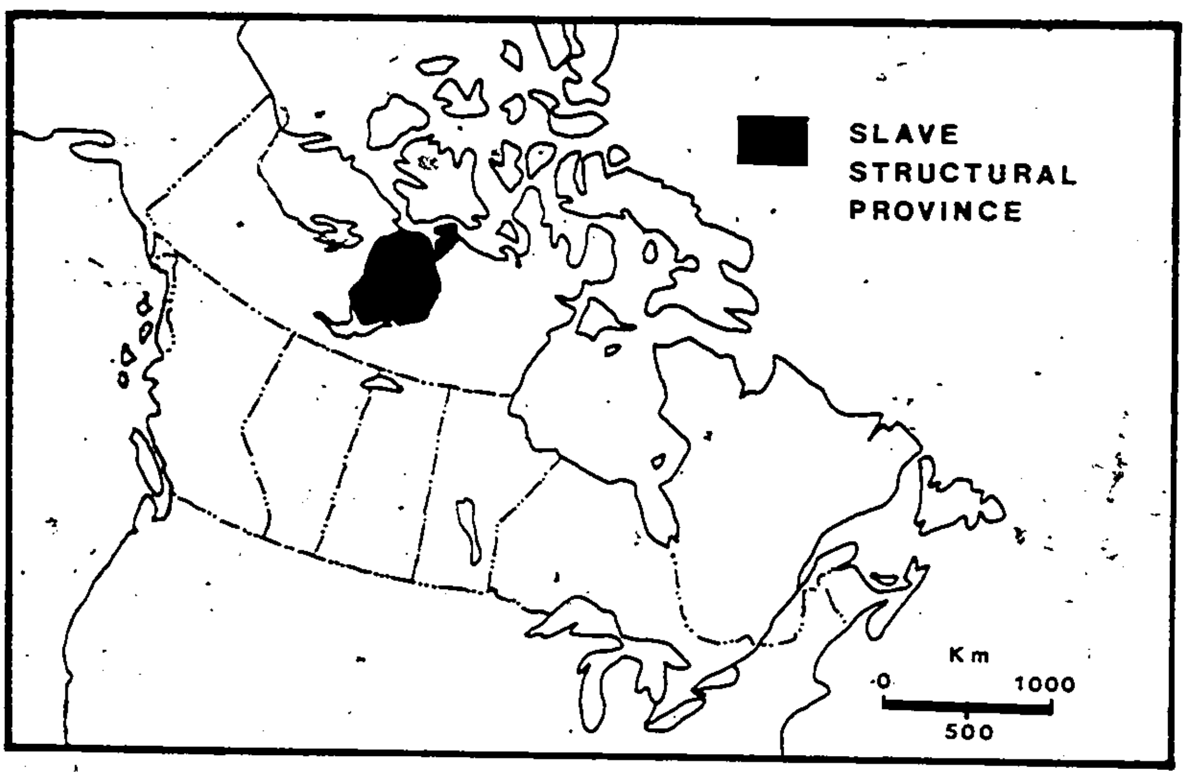
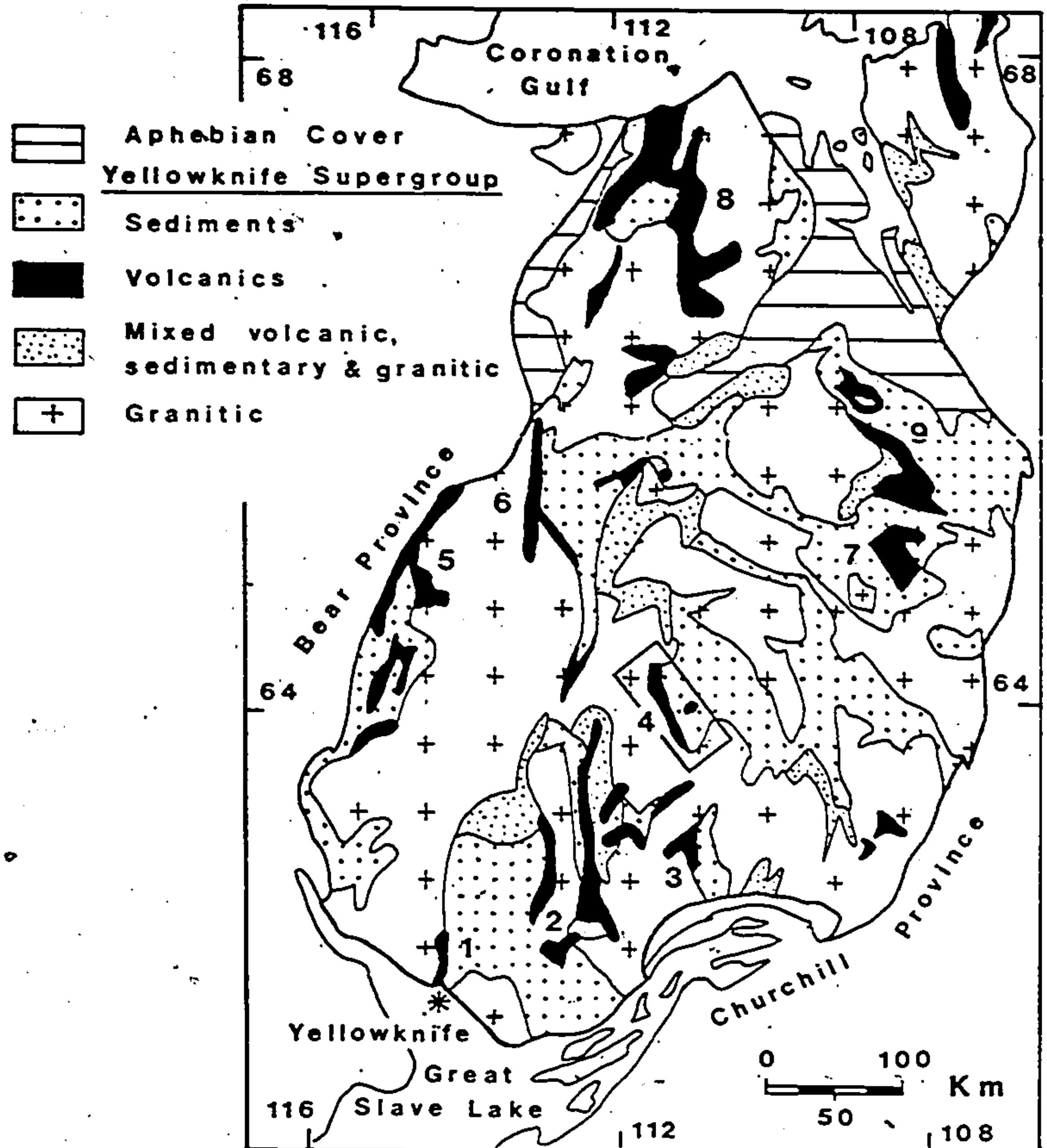


FIGURE 1. Location map.



1 YELLOWKNIFE BELT
2 ROSS LK, CAMERON – BEAULIEU RIVER BELT
3 BENJAMIN LAKE BELT
4 COURAGEOUS – MACKAY LAKE BELT
5 ARSENO – INDIN LAKE BELT
6 ITCHEN – POINT LAKE BELT
7 BACK RIVER COMPLEX
8 HIGH LAKE BELT
9 HACKETT RIVER BELT

FIGURE 2. General geology and location of volcanic belts in the Slave Province, after McGlynn and Henderson, 1970.

than 20 percent. Although supracrustal rocks are variably metamorphosed, they are referred to in their unmetamorphosed state.

Lichen cover is extensive. Freshly frost heaved material and areas around lake shores frequently have little lichen. Scraping glacial till away from the edges of many outcrops will reveal fresh rock.

Glaciation has produced a few widely distributed moraînes, especially on the western side of topographic highs, with east-west orientations. Sinuous, east-west trending, gravel eskers occur on the central and southern shores of Courageous Lake. Glacial striae have variable east-west orientations also. Isolated erratics, of various composition, are numerous in the larger granitic terrains and sand plains are found in sedimentary depressions.

The vegetation ranges from sparse shrubs in the southern part of the belt to almost nil in the north. Depressions within the sediments or protected slopes facing west in the volcanics contain stunted spruce trees less than 8 m high.

Previous work

Regional geological mapping that included the Courageous-MacKay Lake greenstone belt was carried out by Henderson (1944), MacKay Lake sheet, and by Folinsbee (1949), Lac de Gras sheet, at a scale of 1:253,000. The maps indicate that the volcanic rocks are preserved in a steeply dipping north-south homocline, and that the volcanic rocks are mainly mafic in composition. The preliminary maps of Folinsbee and Moore (1950) and Moore (1951) detailed the volcanic stratigraphy (at a scale of 1:18,000) for the central two thirds of the belt. Moore (1956) summarized the previous work at a scale of 1:24,000.

Present study

The purpose of this project was threefold: a) to complete the detailed mapping of the belt started by Moore (1956); b) to characterize the volcanic stratigraphy and development of the pile; and c) to study the deformation and metamorphism of the belt and relate this to regional patterns.

The steeply dipping, homoclinal structure of the volcanic rocks and lateral extensions of the belt to the east would enable a three dimensional view of an Archean composite volcanic complex.

Mapping took place during the 1978 and 1979 field seasons with a two man party. One inch to 1 mile airphotos were enlarged on mylar to a scale of 1:12,000.

Felsic and intermediate fragmental volcanic rocks were slabbed and polished so as to identify the shape and composition of fragments and phenocrysts. The granitoid rocks were slabbed, stained, pointcounted with a 2 mm grid using about 1300 counts per slab, and the modes were plotted on an Quartz-Plagioclase-Potassic Feldspar diagram with the divisions of Streckeisen (1976). Thin sections from most of the granitic rocks were made to confirm the potassic feldspar content and nature, the plagioclase zoning and anorthite content, igneous and deformational textures, and the accessory minerals. Approximately 400 thin sections from volcanic and sedimentary rocks were examined to identify textures, grading directions, fabric orientations and metamorphic assemblages.

The belt is divided into five map areas from north to south including the central portion of the belt not mapped in this study. This portion of Moores (1956) work is included for reference purposes when considering the volcanic stratigraphy and the structure of the belt as a whole.

Acknowledgments

The author would like to thank Professor W.K. Fyson for his guidance in the field, encouraging discussions and helpful suggestions during the preparation of the manuscript. My wife Jane, and J. Mooers provided excellent field assistance in 1978 and 1979 respectively. Dr. S. Roscoe (G.S.C.) kindly arranged for the use of tents during both field seasons. Dr. W.A. Padgham of D.I.A.N.D., Yellowknife, suggested and provided funding for much of the project. Mr. J. Lafleur and Dr. M.B. Lambert provided interesting and fruitful discussions regarding chemical and field work respectively. Mr. E. Hearn generously provided his time for photographic work.

CHAPTER II

GENERAL GEOLOGY OF THE SLAVE STRUCTURAL PROVINCE

Introduction

The term Yellowknife Supergroup was introduced by Henderson (1970) and has since been used to represent all Archean sedimentary, and volcanic rocks within the Slave Structural Province (McGlynn and Henderson, 1972; Lambert, 1977a, and Henderson, 1981). Local units of the Supergroup have been given group and formation names but these are not correlative for more than 100 Km (Henderson, 1970; Henderson, 1975; Bostock, 1976; and Henderson and Easton, 1977).

A map of the Slave Province (Figure 2) shows that: a) there are 20 or more volcanic belts scattered throughout the province; b) the belts are narrow, generally linear, and frequently trend north; and c) for the province as a whole there are less than 10 percent volcanics, 45 percent sediments, and close to 50 percent granitoid rocks (McGlynn and Henderson, 1970 and Henderson, 1981). Within this report the term granite and sodic granitoid refer to a general chemical composition while granitoid refers to chemically undetermined plutonic rocks. A large percentage of the sediments are highly metamorphosed or migmatized. The metamorphic grade within the Yellowknife supracrustal rocks ranges from low greenschist – to upper amphibolite – facies (Thompson, 1978) with contact metamorphism affecting rather narrow areas surrounding granite plutons.

Stratigraphy

Throughout the Slave Province the Yellowknife Supergroup probably overlies a granitoid basement (Henderson, 1981). At Point Lake (Fig. 2), for example, rounded clasts of granite and mafic volcanics form a conglomerate lying directly on weathered granite basement (Henderson, 1981). Most commonly preserved, however, is the volcanic-sedimentary sequence. This is comprised of a thick succession of mafic flows and pillow lavas which may be either intermixed with or transitional to intermediate and felsic lavas towards the top of the sequence. Overlying the volcanics there is generally a thick succession of greywacke-mudstone turbidites. Predominantly intermediate to felsic volcanic sequences in the Back River area (Lambert, 1978 and Frith, 1981) overlie and interfinger with sediments (see Figure 2). At the Yellowknife, Arseno Lake, Beaulieu River, and Courageous-MacKay Lake belts (Figure 2) volcanic-granitoid conglomerate is present at the volcanic-sedimentary contact (McGlynn and Henderson, 1970 and this report). Fluvial sandstones and quartzites are of limited extent.

The mafic volcanics exhibit tholeiitic trends and the felsic volcanics are predominantly calc-alkaline (Baragar, 1966, and Frith, pers. comm., 1981). The granitoid rocks range from quartz diorites, tonalites, through granodiorites, to granites (adamellites) (Baragar and McGlynn, 1976). Greywackes have a chemical composition similar to that of an average granodiorite (Henderson, 1981).

Gabbroic sills and dykes are present throughout the volcanic sequence, rarely in the granitoid rocks, and have not been reported in the sediments above the volcanics. The dykes and sills appear to have been penecontemporaneous with volcanism (Baragar, 1966; Lambert, 1977a).

Iron formation with oxide, sulphide, silicate and carbonate facies is rare, occuring mainly as thin, laterally continuous units in the Back River Complex

(Lambert 1977b, 1978) and in the Point-Itchen Lake area (Henderson and Easton, 1977) at or near the volcanic-sedimentary contact. Minor carbonates may also occur at this interface mostly as dolomite or carbonaceous mudstone.

McGlynn and Henderson (1970, 1972) report that the volcanics range in thickness from 300 m to 9 Km and the sediments from 600 m to less than 5 Km. The felsic volcanics range from 0 to 3.0 Km, averaging less than 500 m. Intervolcanic sediments and conglomerates can vary from 0 to 500 m thick. The volcanic piles are predominantly mafic, ie. Yellowknife belt, but a few are mainly intermediate to felsic, ie. Back River Complex. The mafic lavas appear to be mostly subaqueous in origin while the intermedite to felsic lavas exhibit subaqueous and subaerial environments.

The volcanic piles of much of the Yellowknife Supergroup tend to have basaltic lower components with upper intermediate to felsic domes or flows forming a composite structure. Lambert (1977b, 1978) reports a cauldron subsidence feature in the Back River Complex and notes subaqueous and subaerial environments.

The predominantly linear structure of the volcanic piles and the presence of volcanic-granitoid clast conglomerate suggest that the belts were structurally controlled loci of volcanism and tectonically active during the pile development. The sediments occupied basins while the mafic piles formed along the margins of grabben-like features. The Back River Complex is thought to represent felsic, basinal volcanism (Henderson, 1981).

Basement

The oldest known rocks in the Slave Province include those with geochronological dates of approximately 3.0 Ga from tonalitic fragments in a diatreme near Yellowknife, granite conglomerate at Point Lake (Henderson, 1981) and tonalite-granodiorite gneiss from the Indin Lake area (Frith et al., 1977). Contemporaneous granitoid basement and felsic volcanics from Yellowknife give U-Pb and Rb-Sr ($\lambda = 1.42 \times 10^{-11} a^{-1}$) dates of about 2650 to 2680 Ma (Henderson, 1981). Lambert and Henderson (1980) report an U-Pb age of 2660 ± 7 Ma for the felsic volcanics from the Back River Complex. Late stage granite plutons range from 2.65 to 2.5 Ga (Henderson, 1981) which Thompson (1978) has suggested as the peak of metamorphism.

Much of the evidence for basement is not geochronological, ie. the presence of amphibolite dykes in granitoid rocks. The dykes are presumed to have fed the overlying mafic volcanics, although the relationship has not been seen. Examples include, the Ross Lake area (Baragar and McGlynn, 1976) and the Benjamin Lake area (Heywood and Davidson, 1969). The tonalite body at Benjamin Lake also has no obvious metamorphic aureole, as might be expected if the tonalite predates the volcanics. In the study area a similar lack of a metamorphic aureole and the presence of gabbroic dykes crosscutting foliated sodic granitoids suggests basement to the volcanic suite. Unconformities at the base of the volcanics, ie. Ross Lake, Benjamin Lake, and Point Lake (Baragar and McGlynn, 1976) indicate granitoid basement to the Yellowknife Supergroup.

Proterozoic dykes

Diabase dykes and dyke-swarms intruded all Archean rocks several times, with differing orientations, indicating changing tensional tectonic activity (Thompson, 1978). Most dykes have pre 2000 Ma ages given by K-Ar methods and are sheared in post 2000 Ma faults. Typically the diabase is steeply dipping and variably magnetic.

Structure

As mentioned earlier many of the volcanic belts within the Slave Province have northerly trends while a few trend northeasterly or north-westerly (Figure 3). These trends are thought to have been controlled by deep-seated faults within the Province, which were followed by the margins of the granitoid batholiths and later in the Proterozoic by the major McDonald and Bathurst faults (Figure 3) (Fyson, 1981b). Structures reflecting at least three phases of deformation are present within metasediments over much of the Slave Province (Fyson, 1978).

σ_1 structures are defined by opposing facing directions of F_2 folds which have no cleavage fabric, and have not been identified throughout the province.

F_2 folds, which predominate throughout most of the Slave Province, are large scale with 1 to 10 Km long axial traces, upright to steeply-inclined, tight to isoclinal. Small scale F_2 folds are rare. Hinge zones, where exposed, are steeply plunging. Figure 3 shows the generalized F_2 trends for the southern half of the Slave Province. It can be seen that the F_2 folds often parallel the volcanic belts and the margins of large granitoid batholiths and in detail curve around small, late? plutons. The associated schistosity is well defined in both the sedimentary and volcanic rocks by aligned quartz, muscovite, chlorite, biotite, amphiboles and opaques. Fyson (1981a) notes a predominant westward overturning of F_2 folds across much of the province towards marginal plutons. The marginal plutons may have influenced the direction and degree of overturning. Fyson (1981a) has suggested that two stages of regional compressive strain accompanied by subsidiary gravitational sliding could have produced the observed fanning and fold overturning.

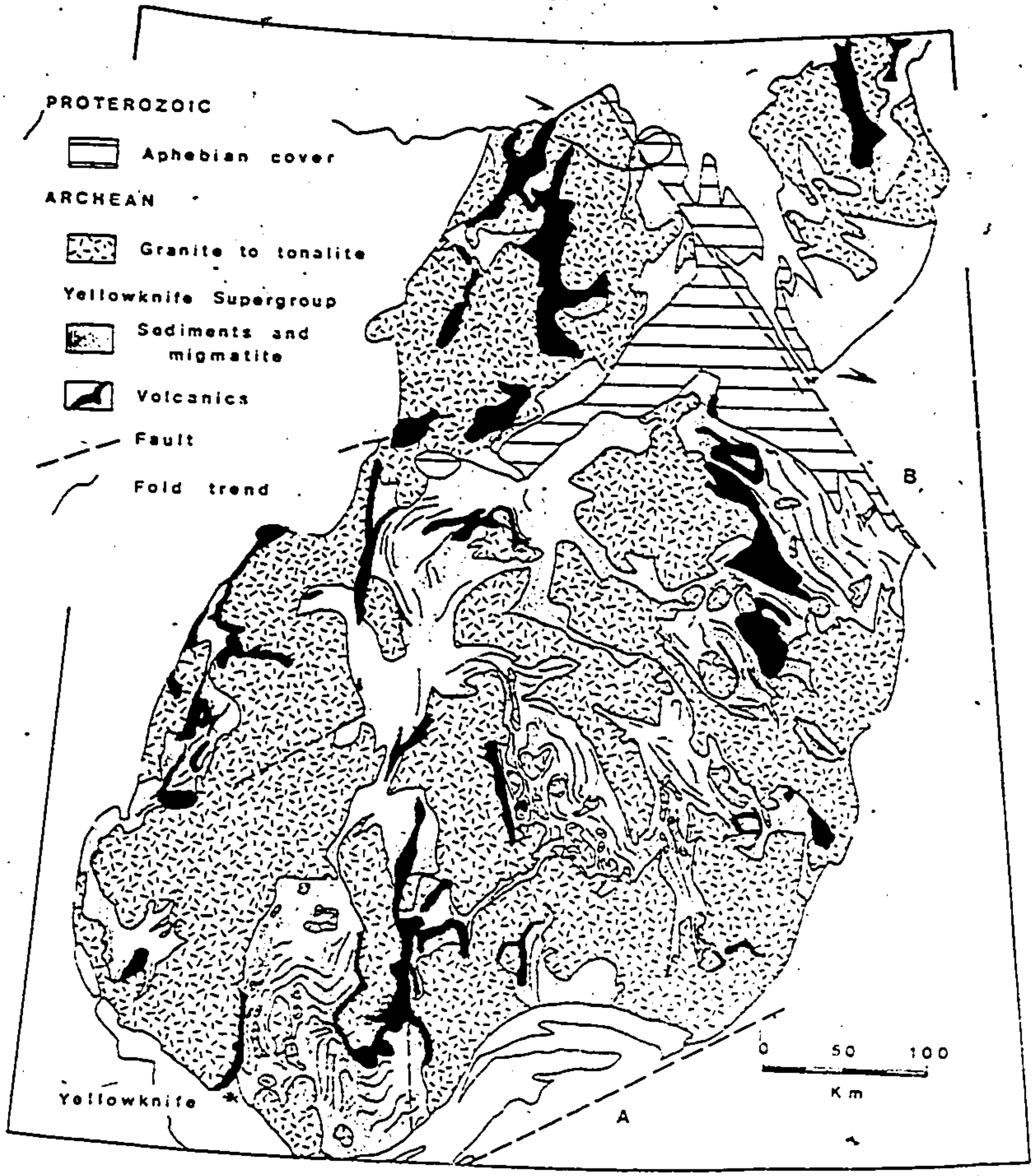


FIGURE 3. Slave Structural Province fold trends (F_2).
A – McDonald Fault
B – Bathurst Fault

The third phase of deformation produced small, less than 1 Km. long, folds with an axial-planar, regional S_3 cleavage. Small scale F_3 folds are common in quartz veins and thinly bedded units. The S_3 cleavage can vary from a segregation cleavage to an open crenulation of S_2 or a strong penetrative alignment of quartz, muscovite, chlorite and biotite (Fyson, 1975 and 1980a). Quartz inclusion trails in biotite porphyroblasts indicate the original S_2 orientation and the amount of D_3 rotation (Fyson 1975, 1980). Late-stage, open crenulations of S_3 are discontinuous and scattered throughout the Slave Province. In general the D_3 fabric is rarely observed in the volcanics. S_3 has been reported in granitoid rocks by Fyson (1980) and Tirrul and Bell (1980).

Metamorphism

The Yellowknife Supergroup supracrustal rocks range from a low greenschist facies to an upper amphibolite facies grade of regional metamorphism. The pressure conditions appear to have been low, similar to Miyashiros (1973) Abukuma Plateau type (cf. Thompson, 1978). Maximum temperature and pressure estimates are about 600°C and 3.5 Kb (McGlynn and Henderson, 1972). The metasediments range from a chlorite, muscovite and biotite greenschist facies through staurolite, cordierite, and biotite low-amphibolite facies to an andalusite, sillimanite ± kyanite upper-amphibolite facies (Thompson, 1978). The presence of rare kyanite may only reflect local, high pressure conditions. Biotite and cordierite-andalusite porphyroblasts are common prograde features. The lack of staurolite may be controlled by the lack of Fe in the metasediments (Thompson, 1978). Felsic metavolcanic rocks show similar prograde reactions with the development of cummingtonite, anthophyllite, and clinopyroxene at higher grades instead of the alumino-silicte minerals. Mafic metavolcanics range from chlorite – albite – carbonate greenschist facies assemblages to plagioclase – epidote – actinotite hornblende – garnet bearing amphibolites (McGlynn and Henderson, 1972). Most of the Yellowknife Supergroup rocks are of amphibolite grade. The metamorphic grade does not depend upon the thickness of the belts but rather the level of exposure and the proximity of potassic granitic plutons. Thompson (1978) suggests that the peak of metamorphism for the Slave Province occurred at about 2600 Ma with D_1 and D_2 before the peak and D_3 after the peak.

CHAPTER 3

GENERAL GEOLOGY OF THE COURAGEOUS-MACKAY LAKE AREA

Introduction

The stratigraphy, lithology, and chemical composition for Yellowknife Supergroup rocks in the Courageous-MacKay Lake area are similar to that reported for the supergroup near Yellowknife (Henderson and Brown, 1966) and in the Ross Lake, Cameron-Beaulieu River area (Lambert, 1977a). In detail, however, there are some appreciable differences; for example in the thickness of the volcanic pile, the relatively minor amount of andesitic material, and the presence of a large rhyolitic centre. Figure 4 gives the general geology of the area and Figure 5 divides the belt into map areas, 1 to 5, referred to in the text. The central portion of the belt was not investigated by the author. Map 3 (Moore, 1956) is included to show the complete stratigraphy of the volcanic belt and is critical for developing a model of volcanic evolution. The scale of map 3 is 1:24,000, all the other maps are at a 1:12,000 scale. The distribution of the principal volcanic units for the whole belt is shown in Figure 6.

The volcanic rocks of the Courageous-MacKay Lake greenstone belt are subalkaline; following the classification of Irvine and Baragar (1971) they form three compositional groups: mafic lavas (basalts), intermediate lavas (andesites), and felsic lavas (dacites and rhyolites). Field classification involved a weighing method designed by S. Roscoe (G.S.C) using the specific gravity ranges of 2.80 to 3.15 for basalts, 2.75 to 2.85 for andesites, and 2.68 to 2.76 for rhyolites and dacites (cf. Lambert, 1977a).

The chemical analysis of the volcanic rocks in Chapter 4 supplemented the field observations in identifying the rock types.

COURAGEOUS—MACKAY LAKE GREENSTONE BELT

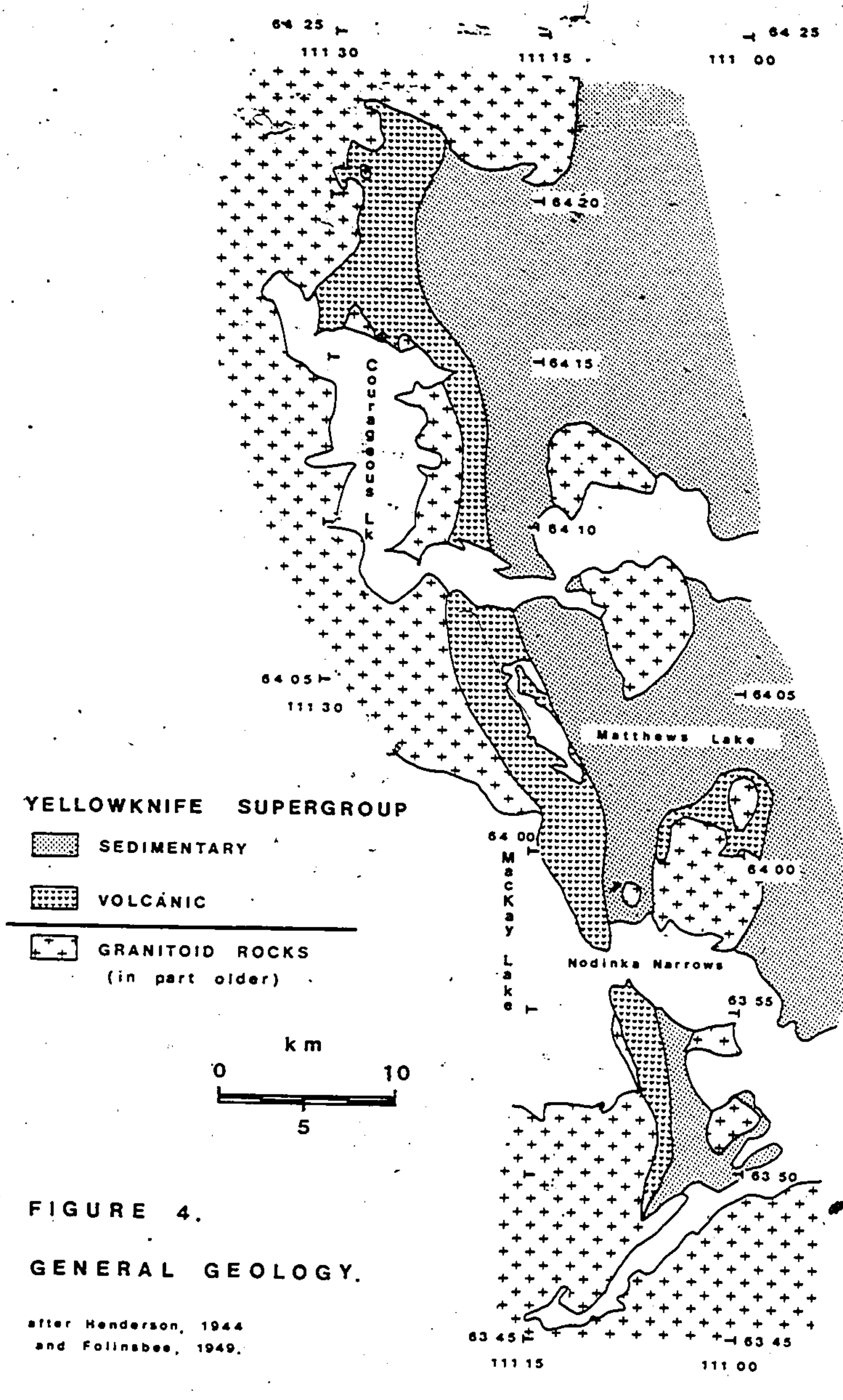


FIGURE 4.

GENERAL GEOLOGY.

after Henderson, 1944
and Folinsbee, 1949.

COURAGEOUS—MACKAY LAKE GREENSTONE BELT

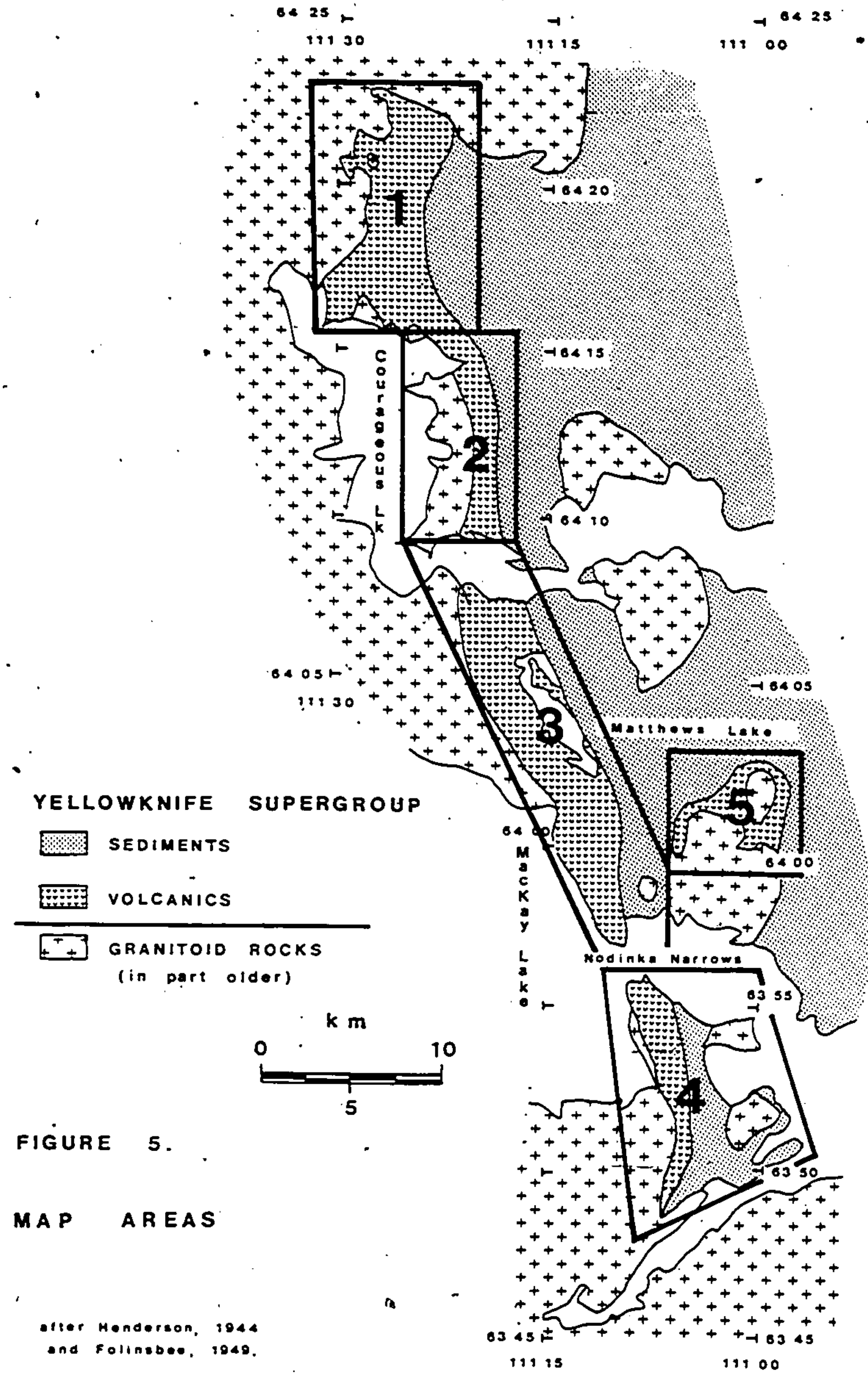


FIGURE 5.

MAP AREAS

after Henderson, 1944
and Folinsbee, 1949.

COURAGEOUS - MACKAY LAKE GREENSTONE BELT

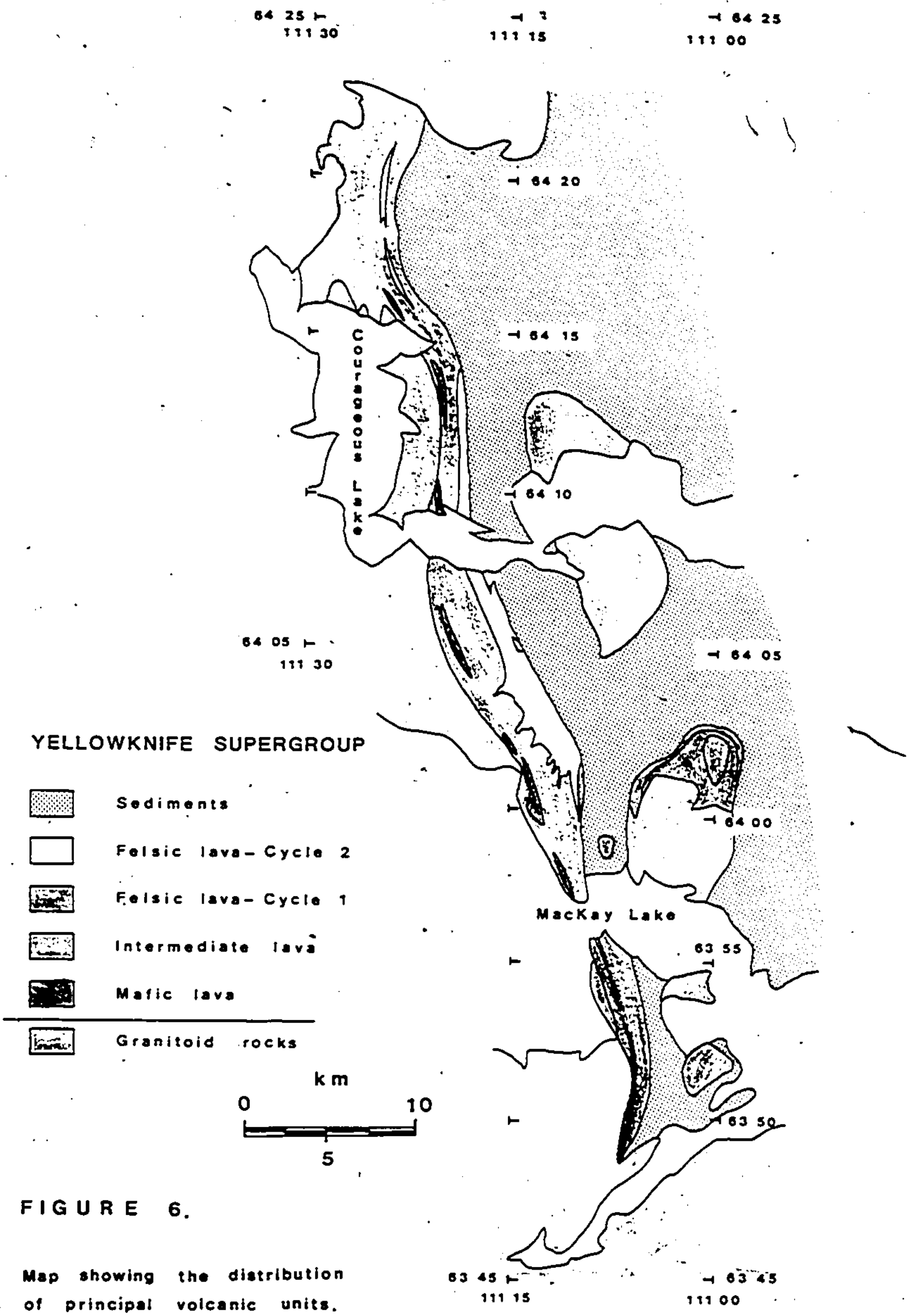


FIGURE 6.

Map showing the distribution of principal volcanic units.

PROTEROZOIC			Diabase: 7 (Mackenzie dyke swarm)	
PROTEROZOIC			Great Unconformity	
ARCHEAN			Pegmatite: 6 Granite: 5a (synkinematic)	
ARCHEAN			Intrusive Contact	
ARCHEAN	YELLOWKNIFE SUPERGROUP		Turbidites: greywacke and slate-4a, granitoid and volcanic conglomerate-4e volcanogenic chert-4d,	
ARCHEAN	YELLOWKNIFE SUPERGROUP	CYCLE 2	Rhyolite to dacite: domes or massive flows-2a volcaniclastics-2b,c,d quartz-feldspar intrusions-2f	
ARCHEAN	YELLOWKNIFE SUPERGROUP	CYCLE 2	Andesite: massive flows-1e, pillowed flows-1d and volcaniclastic breccia-1h	
ARCHEAN	YELLOWKNIFE SUPERGROUP	CYCLE 2	Basalt: massive flows-1a, pillowed flows-1b, feldspar phyric massive flows-1e, feldspar phyric pillowed flows-1f and flattened pillows-1g	
ARCHEAN	YELLOWKNIFE SUPERGROUP	CYCLE 1	Rhyodacite: breccia-2e	Intervolcanic conglomerate -4c ± mudstone-4b
ARCHEAN	YELLOWKNIFE SUPERGROUP	CYCLE 1	Basalt: massive flows-1a, pillowed flows and minor pillow breccia-1b	
ARCHEAN			? Unconformity ?	
ARCHEAN			Basement?: granodiorite-5b, tonalite-5c, and trondhjemite-5d	

FIGURE 6a. Stratigraphic succession in the Courageous-MacKay Lake area.

Sub-vertical, consistently east facing volcanic rocks in maps 1, 2, 3 and 4 are exposed along most of the belt so that the map pattern in Figure 6 gives the distribution of volcanic units. Figure 6a shows the stratigraphic succession. Map area 5, lying east of area 3 provides a third dimension in an east-west direction. Tectonic flattening and possible inter-unit shearing suggest that the thicknesses estimated from the maps are minimums. The degree of flattening during horizontal shortening is discussed in Chapter 5.

Overlying the volcanic rocks are greywacke-slate metasediments and rare conglomerate. Within the volcanic pile thin units of conglomerate and mudstone occur at various stratigraphic levels. These inter-volcanic sediments appear to have been derived predominantly from the enclosing volcanics, whereas clasts in the overlying sediments suggest a volcanic and granitoid source.

Sodic granitoid batholithic rocks, mainly granodiorite, tonalite, or trondhjemite, may be basement to the volcanics. Granite plutons appear to have been emplaced during deformation. Shearing during horizontal compression and granite intrusion has obscurred the granitoid-volcanic contacts.

Proterozoic diabase dykes, of two or more generations, crosscut all the Archean rocks.

Mafic and intermediate volcanics (unit 1)

Distribution and thickness

The mafic and intermediate volcanics are predominantly basalts with minor andesite. The basalts (subunits 1a, b, e, f, and g) range in apparent total thickness from a minimum of about 5 km in map 1 to less than 1 km in other areas. Large basalt zenoliths up to 1 Km across in granitoid rocks in map areas 2 and 3 suggest that before the emplacement of the granite plutons the basalts were in the order of 3 to 5 Km wide for much of the belt.

Andesites (subunits 1c, d and h) are mainly restricted to the eastern side of the succession in the northern part of the belt (maps 1 and 2). They outcrop in an area that extends 13.5 Km northward along strike and ranges from 0.5 to 1.75 Km wide. Intermixed are minor basalt, rhyodacite and rhyolite. Minor fragmental rocks along the volcanic-sedimentary contact in map 5 may also be of andesitic composition.

Gabbroic sills, dykes, and intrusive bodies are present throughout the basal, mafic portion of the volcanic pile. Their relation to the mafic and intermediate lavas is discussed later.

The basalts and andesites interfinger with and overlie felsic volcanics close to the upper contact in map areas 1 and 2. Basalts underlie the main felsic concentration in map 3. In maps 1, 2, 3 and 4 minor felsic units occur surrounded by basalts at the base of the pile.

Where turbidite-facies sediments (unit 4a) overlie the mafic to intermediate volcanics, the contact appears to be conformable with minor interfingering. The contact with the underlying granitoid rocks is intrusive in detail but frequently appears conformable on the map scale. In general the upper and lower contacts are faulted. Inter-unit contacts are also frequently sheared or faulted.

Basalt lithology

Basalts range from a medium dark grey-green in greenschist and lower amphibolite facies grade areas to black-green in middle and upper amphibolite facies grade areas. The basalts are composed of massive flows (1a), pillowed flows (1b), feldspar phyric massive flows (1e), feldspar phyric pillowed flows (1f), and a highly flattened, "banded basalt" (1g).

The complete sequence of massive flows grading into overlying pillowed flows and a suceeding layer of pillow-breccia and hyaloclastite (Lajoie, 1979), as often seen at Yellowknife, is not observed in the Courageous-MacKay Lake area. However, parts of this sequence are seen; for example, massive and pillowed flows alternate throughout much of the section (see Plate 1) and more rarely pillowed flows may alternate with pillow-breccia and hyaloclastite, as at Yellowknife (Plate 2).

The massive basalt flows are thick, up to 200 m, and laterally continuous for up to 3 Km. The basal portion of the volcanic pile in maps 1, 2, and 3 is predominated by massive flows. The grain size ranges from 0.5 mm to 4.0 mm. The margins of the massive flows are generally fine-grained while the cores tend to be coarser. The contacts with other rocks are rarely observed.

The central portion of the volcanic pile in map 1 contains an equal abundance of pillowed flows and massive flows. Towards the upper sedimentary contact pillowed flows are much more abundant than massive flows. This change from predominantly massive flows to predominantly pillowed flows stratigraphically upwards is noted in maps 2 and 3 also. The basalts in map areas 4 and 5 are predominantly pillowed flows.

Plate 1. Pillowed basalt overlying a massive flow. Note fractured top of the massive flow. Light coloured patches are quartz and feldspar alteration. The longest pillow is 3 m long. From the south shore of Nodinka Narrows, map 4 (63°56', 111°08').

Plate 2. A thick sequence of pillowed lavas overlying a thin unit of pillow-breccia and hyaloclastite. Note the thin and irregular nature of the pillow-breccia horizon. From the Yellowknife area.

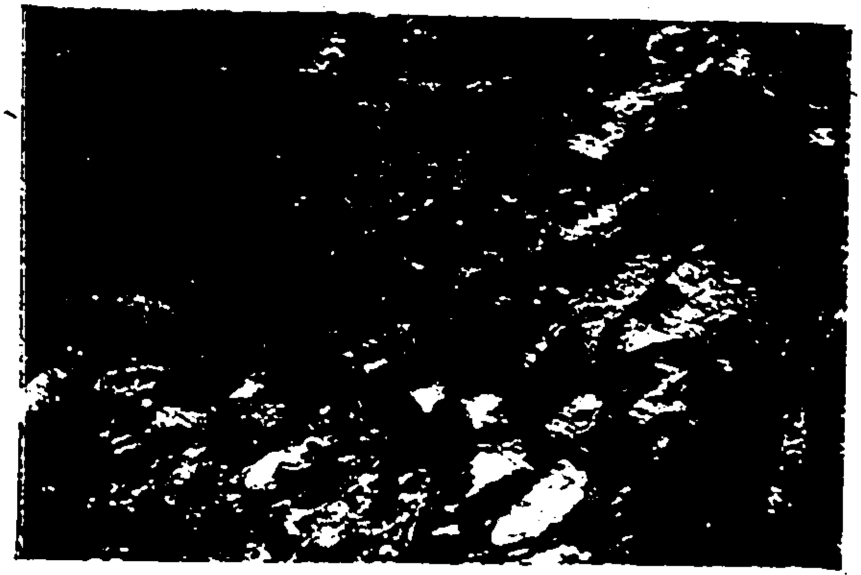


Plate 1.

Plate 2.

Basalt pillows exposed on subhorizontal surfaces range from equidimensional bodies 20 cm across to ellipses 0.2 m to 0.5 m by 0.4 m to 3.0 m. The third dimension, rarely observed, suggests a tube-like configuration. Large bun-like pillows (Dimroth et al., 1978) are rare. Pillow selvages have few re-entrants. Interstitial material is minor. Pillow selvages range from 0.5 cm to 2.0 cm wide. The small pillow size, lack of re-entrants and the lack of interstitial material could suggest a rapid rate of flow extrusion.

Pillow-breccia (Lajoie, 1979) is also rare and occurs as small, 0.5 cm to 2.0 cm globules, that may occur with minor hyaloclastite to form a thin, discontinuous carapace above pillowed flows. Plate 3 shows the rounded-to angular forms with bleached, chilled rims. Plate 4 shows a vertical gradation from large chilled blocks to small chilled ameboid shapes.

Pillowed flows range from 50 m to greater than 250 m wide. Inter-flow pillow-breccia horizons are frequently highly deformed and unrecognizeable. This may make the thickness estimates of the pillowed flows excessive if intervening flows are not recognized.

In greenschist facies areas the pillowed basalts are fine-grained (0.2 mm) and microlites are common. In higher grade areas the grain-size may coarsen up to 2.0 mm and the microlites are replaced by epidote.

Feldspar phyric massive flows (1e) and pillowed flows (1f) appear to have a basaltic composition. They are common in maps 1 and 2 and to a lesser extent in map 3. These units are found within 1 Km of the upper volcanic-sedimentary contact. The thickness of the feldspar phyric massive or pillowed flows is rather uniform, about 100 m to 200 m. Strike length of the phyric massive flows are

Plate 3. Rounded and angular pillow-breccia fragments with chilled rims. Hammer head is about 16 cm long. From map 2 (64°15', 111°22'0.

Plate 4. Same location as plate 3. Large basaltic blocks overlain by rounded and chilled fragments. Note the fining upwards. Two metres to the right the fragments fine into a poorly stratified hyaloclastite. Hammer is 31 cm long. White spots near hammer are lichen.

Plate 3.

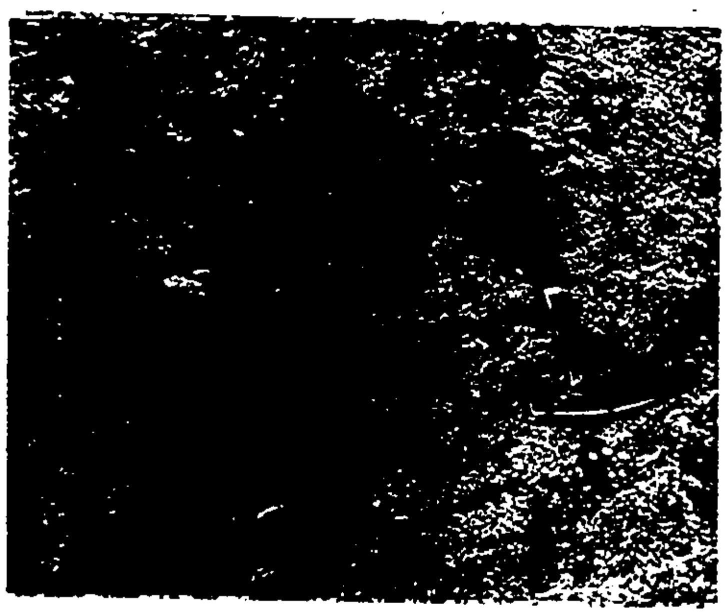


Plate 4.

generally small as the distribution of phenocrysts is quite variable and the flow may become aphyric. The strike length of the phyric pillowed flow in map 1 is about 9 Km. This subunit forms a marker horizon which gradually diverges northward away from the volcanic-sedimentary contact.

Plate 5 shows the feldspar phenocrysts to range from 0.2 cm to 1.5 cm. The phenocrysts are frequently fractured and have a ragged, subrounded outline. Within massive flows (1e) the phenocrysts range from sparse to abundant and appear to locally grade in size vertically and laterally. However, within the pillowed flows (1f) the feldspar phenocrysts do not show lateral and vertical size gradations and the phenocryst content is quite uniform (see Plate 6).

Banded basalt (1g), probably highly flattened pillowed flows, is present along or close to the volcanic-sedimentary contact in map 1. This subunit is only recongized in middle amphibolite and higher-grade areas and appears to be a subgneissic development of alternating quartz and feldspar rich bands with amphibole rich bands (see Plate 7).

Andesite lithology

Andesites weather a light, grey-green and are rarely recognized in amphibolite facies grade areas. The andesites appear to be restricted to maps 1 and 2. Minor amounts are present in map 5. It is possible, however, that andesites may be present in map area 3 as Moore (1956) denotes the presence of grey to light-green mafic volcanics beneath the main felsic volcanic concentration.

The andesites exhibit minor massive flows, an abundance of pillowed flows, and rare volcaniclastic breccias. The massive and pillowed flows are coarsely amygdaloidal. The amygdaloidal nature may be a diagnostic characteristic of the andesites.

Plate 5. Fractured feldspar phenocrysts in a massive flow basalt. Note how the larger phenocrysts are subhedral while the smaller phenocrysts tend to be subrounded or sheared. From map 2, (64°15', 111°20').

Plate 6. Feldspar phyric pillowed basalt. Phenocrysts are rounded to elongated. Elongation direction is parallel to the S_{IB} fabric. From map 1, (64°17', 111°24'0.

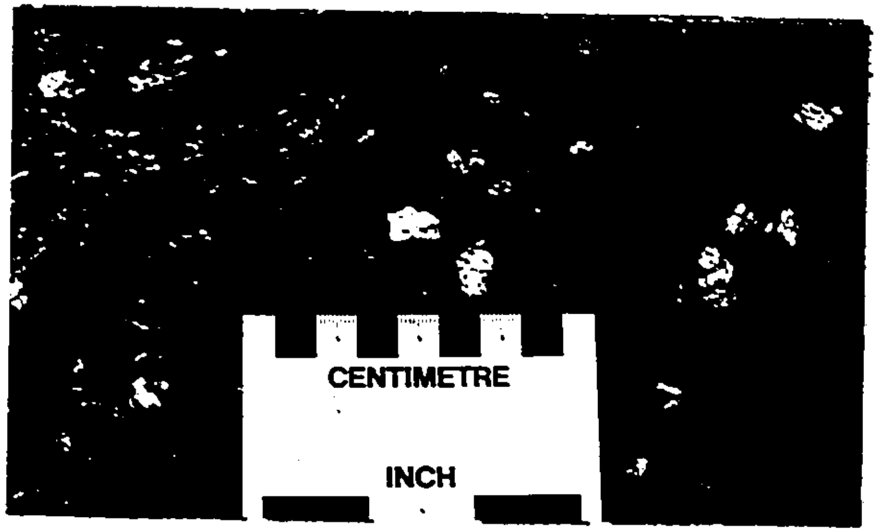


Plate 5.

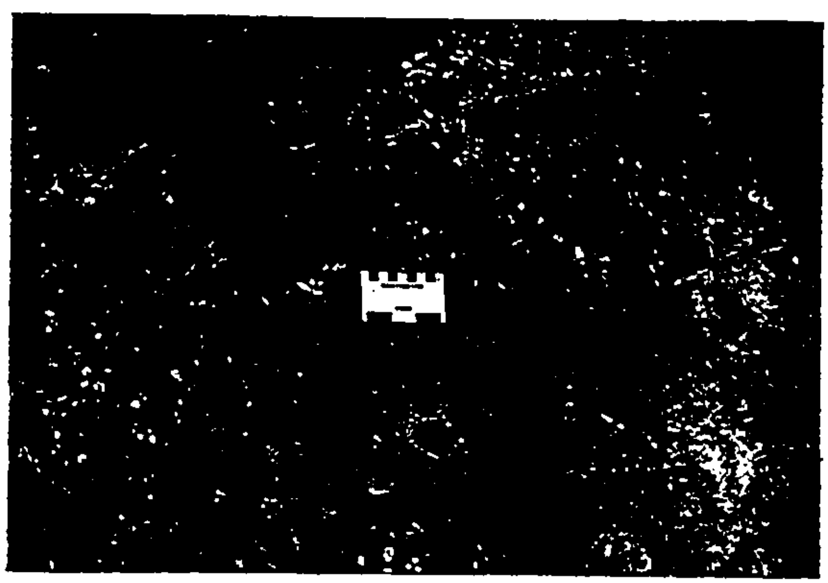


Plate 6.

The pillowed (andesite) flows range from 30 m to 200 m thick. The thickness of the massive flows ranges from 30 m to 50 m. The pillows have thin selvages, less than 1 cm, and tend to be smaller than their basaltic counter parts.

The vesicles in the massive and pillowed flows range from 0.2 cm to 0.75 cm spheres to ellipsoids with 1.0 cm long axes (Plate 8). Vesicles are filled with quartz, calcite and chlorite (see Plates 9 and 10). The quartz in the vesicles varies from single crystals to abundant sub-grains indicating various stages of recrystallization. The vesicular rocks contain plagioclase microlites up to 0.7 mm long.

Andesitic breccia units (1h), range up to 200 m thick, are rare and laterally discontinuous. Poorly stratified lapilli- to ash-sized andesitic fragmental units are thin, 10 m to 50 m thick, and may be intercalated with block-sized fragments. The size classification follows that of Fisher (1966).

Unit 1h is found in map 2 and map 5. In map 2 the exposures are thin and discontinuous. The exposure in map area 5 indicates that unit 1h rapidly decreases in thickness from the west to the east and interfingers with pillowed basalt flows.

The larger fragments are subrounded to subangular and range from 0.5 cm to less than 10 cm across. These larger fragments are generally monolithologic and often finely vesicular. Plate 11 shows the vesicles to be very abundant and to range form 0.1 mm to 3.0 mm in diameter. The coarse fragments do not appear to be vertically graded and the discontinuous exposure along strike obscures possible lateral grading. The matrix to the block-sized fragments is usually a dark-green, well-sorted and rounded ash. Thin sections show the matrix to contain quartz, andesine fragments, chlorite, minor amphibole, and opaques.

Plate 7. Highly flattened pillow basalt (1g). Note the subgneissic alternation of light and dark coloured bands. From map 1, (64°20', 111°24').

Plate 8. Vesicular pillowed andesite. Calcite has been weathered. Note the rounded forms. Elongate shapes are due to minor tectonic shearing. From map 1, (64°15', 111°22'0.

Plate 7.

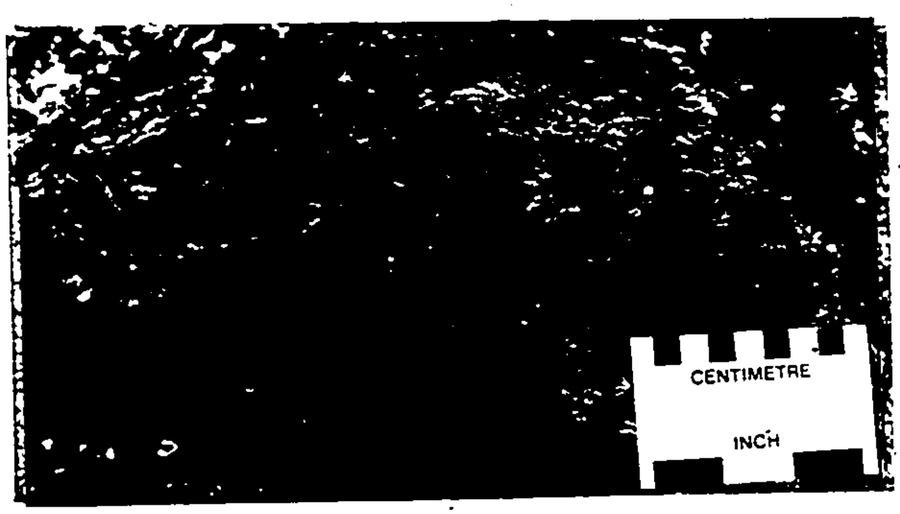


Plate 8.

Plate 9. Quartz filled amygdule from a massive andesite flow. Note chlorite fronds within the vesicle. The groundmass consists of fine plagioclase microlites and chlorite. From map 1, (64°15', 111°22').

Plate 10. Calcite filled amydules from the same sample as Plate 9. Lines are calcite twins.

Plate 9.

0·5 mm

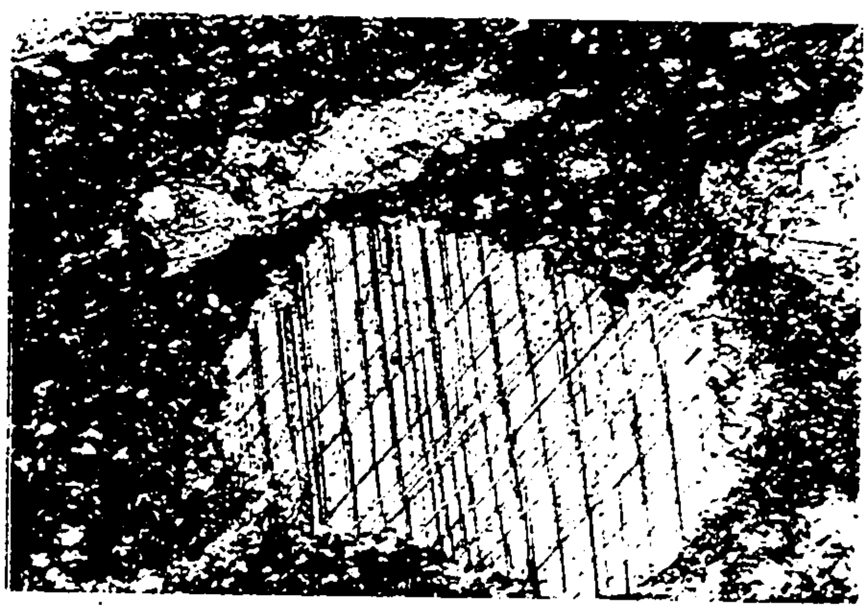


Plate 10.

0·5 mm

The ash- to lapilli-sized fragmental 1h units (map 2) are thinly-bedded and contain flattened fragments. The fragments are not obviously vertically graded but rather tend to fine along strike away from the coarser horizons. Accompanying the decrease in size the fragments become more rounded and minor felsic and mudstone clasts are present. This heterolithologic nature and the presence of under and overlying pillowed flows may suggest a subaqueous debris or mass flow form of transport.

Carbonated, silicified, and sheared rocks of basaltic and andesitic composition have been denoted 1m, 1n, and 1s respectively. These rocks are commonly found near large gabbroic bodies and near the volcanic-sedimentary contact.

Summary

The change stratigraphically upward from basalt to andesite may indicate a magma differentiation trend.

The predominance of massive flow basalt in the basal portion of map 1 may suggest rapid and proximal lava extrusion. The change to predominantly pillowed flows towards the volcanic-sedimentary contact may indicate a slower rate of magma effusion and /or a more distal source. In maps 4 and 5 the almost total lack of massive flows could indicate a location distal to the magma source.

The large and abundant vesicles in the massive and pillowed andesite flows indicates a shallow, less than 200 m deep, subaqueous environment (Moore, 1965 and Jones, 1969). The occurrence of the vesicles close to the volcanic-sedimentary contact may suggest that the environment became shallower with time.

The volcanic topography could have been nearly flat as indicated by the slight northward divergence of the pillowed feldspar phyric basalt from the volcanic-sedimentary contact. Dimroth et al. (1978) indicates that relatively flat slopes are required to develop large, continuous areas of pillowed flows.

The small width of the mafic volcanic rocks in maps 4 and 5, compared to the rest of the belt, would suggest that the volcanic pile thins to the south and to the east.

This configuration may indicate that the mafic volcanism was restricted to a linear, north-south, area and that a subaqueous, low-angle shield volcano (MacDonald, 1972) was formed. Although the mafic magma differentiated with time to produce andesitic lavas near the close of volcanism the presence of intercalated felsic volcanic rocks throughout the volcanic pile indicates early bimodal volcanism.

Felsic volcanics (unit 2)

A major concentration of salic lavas lies along the upper contact in the central portion of the volcanic belt (Figure 6). These lavas are about 2 Km thick, terminate abruptly to the south of Matthews Lake, and extend northward for more than 25 Km. Thin felsic units flanking the main body continue intermittently further north and south and appear to diverge gradually away from the overlying sedimentary contact. The main concentration of felsic lavas overlies mafic lava, which in turn overlies a discontinuously exposed felsic breccia. This breccia may represent an early cycle of felsic volcanism (Cycle 1). Quartz and feldspar phyric felsic dykes (see map 3) crosscut the lower felsic cycle and overlying mafic lavas to feed the larger major felsic concentration (Cycle 2).

Contact relations between felsic lavas and other volcanic or sedimentary rocks are rarely observed; where exposed contacts are sheared. Mapped extensions of thin (5 m to 30 m) felsic units are often tentative but where they are persistent they form marker horizons within large areas of mafic lavas, ie. maps 1 and 4. Minor amounts of felsic volcaniclastics outcrop above the sedimentary contact (map 2 and 3).

Distribution and thickness

The felsic lavas form massive bodies and fragmental units. Most of the massive lavas are rhyolitic and lie in the central part of the belt (map 3). Felsic units to the north (map 2) appear to be related to the major felsic concentration in map 3 (see Figure 6). These felsic lavas, between 64°10' and 64°14', are less than 600 m thick and appear to be made up of massive flows, domes and volcaniclastic rocks.

Figure 7 shows a simplified portion of map 2 (64°14', 111°20' to 64°15', 111°25'). Numerous faults offset rocks in this area and the lack of outcrop prevents extrapolation of thin units. Massive rhyolite occurs as 100 m to 350 m wide, stubby bodies. These massive units appear to be related to the large felsic body (Cycle 2) in map area 3 rather than to the matrix-rich Cycle 1 felsic rocks which only form smaller, volcaniclastic bodies.

The massive rhyolites grade vertically and laterally into block- or lapilli-sized rhyolite clastics. The vertical grading is rapid. Units 5 m to 100 m thick of block-size rhyolite breccia give way vertically to 50 m to 200 m units of lapilli-size rhyolite fragments. Laterally the size grading follows a similar pattern but large fragments persist up to 2 Km away from the massive rhyolite bodies.

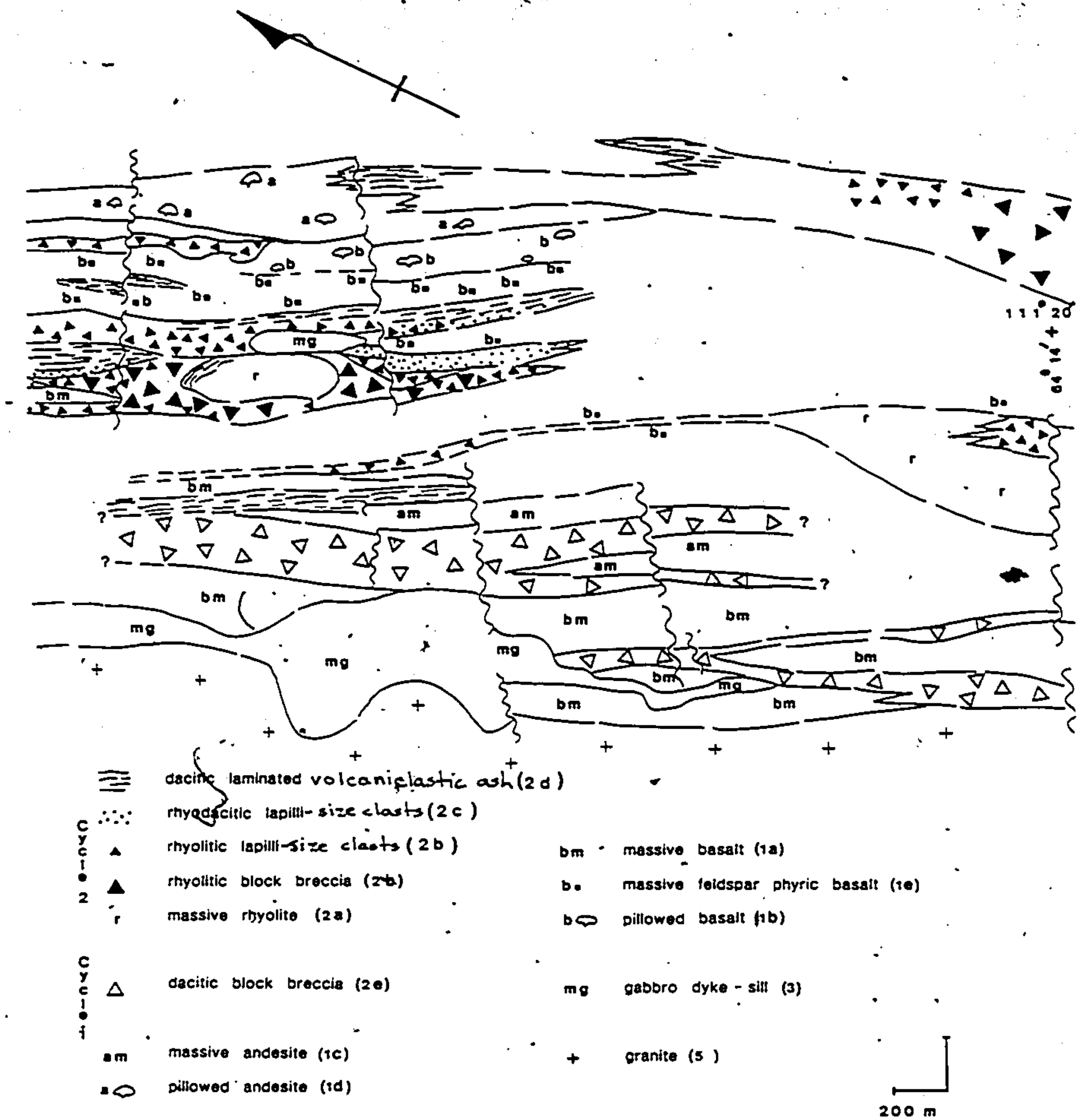


FIGURE 7. Lateral and vertical grading around massive rhyolite bodies (map 2). Numbers in parenthesis are map units.

Rhyodacite lapilli-sized clasts appear to be lateral equivalents of the Cycle 2 rhyolitic lapilli-sized fragments. The rhyodacitic clastics extend northwards from map 2 into map 1 where they thin to less than 200 m, contain fewer fragments over 2 cm, and exhibit faint bedding. The rhyodacite changes vertically and laterally into thinly bedded, finer-grained, dacitic material. Dacitic units are less than 100 m thick and extend laterally for over 5 Km in map 1. Similar thin, extensive dacitic units are present in the south end of the volcanic belt (map 4). The rhyodacitic and dacitic units in the central portion of map 1 are laterally continuous for up to 15 Km and appear to become stratigraphically lower to the north with respect to the volcanic-sedimentary contact in a similar manner to the feldspar phyric pillowed basalt (unit 1h) previously described. A, 10 m to 40 m wide, rhyodacitic unit continues along most of the belt in map 4. This unit becomes closer to the volcanic-sedimentary contact to the south, suggesting the belt thins to the south. However, the rhyodacites in map 4 appear to be stratigraphically related to the Cycle 1 volcanism whereas those rhyodacites in the north (map 1) are related to Cycle 2.

The apparent stratigraphic lowering of the felsic units, towards the northern extremity of the belt may reflect the initial low-angle paleoslope of the volcanic edifice or alternatively, these felsic units could have been in a different position laterally.

Minor amounts of quartz-feldspar rhyodacitic porphyry intrusive rocks occur in map areas 1 and 2, while these may have fed the massive rhyolitic bodies no direct relationship has been observed. In map 3 the rhyodacitic intrusive rocks are extensively distributed under the thickest accumulation of felsic volcanics where they appear to have crosscut all lower rocks. Moore (1956), map 3, indicates a general stratigraphic succession from massive to fragmental felsic lavas in the Matthews Lake area.

Figure 7 shows that the Cycle 2 felsic volcanics are intercalated with massive, feldspar phyric, and pillowed basalt flows, and massive and pillowed amygdaloidal andesite flows. Cycle 1 felsic volcanics appear to be intercalated with basalts rather than both andesites and basalts together.

Felsic volcanic lithology

The felsic lavas range from dacitic to rhyolitic in composition. Massive lavas tend to be rhyolitic. Felsic fragmental lavas range from rhyolite to dacite in composiiton. As the fragment size decreases, and the matrix content increases, the composition tends to become dacitic. This could be due to the addition of more mafic material during transport.

The massive rhyolite (2a) has a pink to cream colour, contains 2 to 10 percent quartz phenocrysts, and maybe amygdaloidal. Quartz phenocrysts, composed of single or many grains, range from 0.5 mm to 3.0 mm across and are generally subrounded. Vesicles, are filled with chlorite, calcite, graphite or hematite, vary from subrounded to flattened, and range form 0.2 mm to 4.0 mm in length (see Plate 12). The flattening is presumed to be tectonic and not flow derived. Feldspar phenocrysts (plagioclase or potassium feldspar) are rare. The groundmass is generally aphanitic but in high grade areas quartz grains may reach 0.1 mm to 0.3 mm.

Plate 11. Highly vesicular fragment from an andesitic breccia (1h). Vesicles are quartz filled. White lines are quartz filled fractures. Elongate vesicles have been tectonically deformed. Cross polarized light. From map 5, (64°02', 111°04').

Plate 12. Massive rhyolite (2a). White spots are quartz phenocrysts. Dark spots are chlorite, calcite, and hematite filled vesicles. From map 2, (64°14', 111°21').

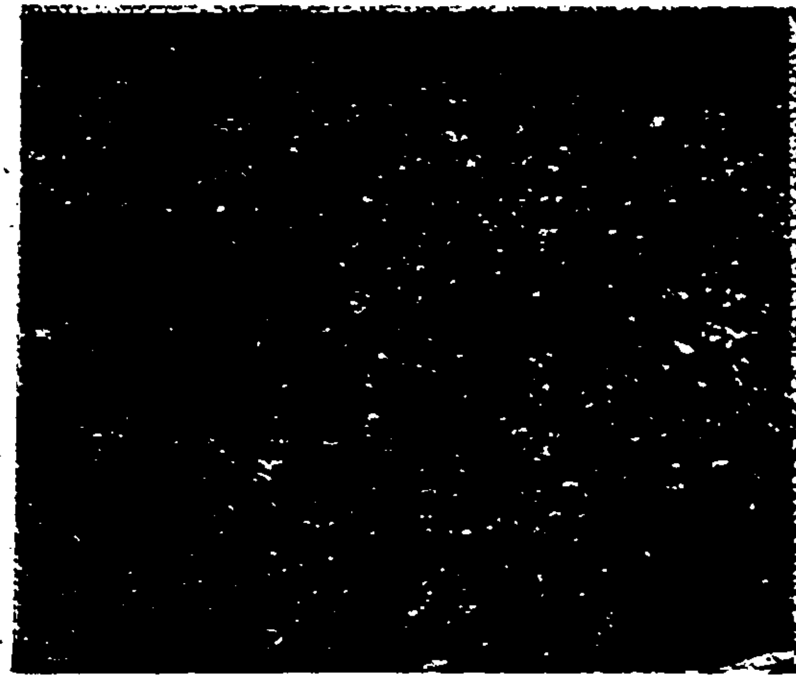


Plate 11.

1cm

Plate 12.

1cm

COLOURED PICTURES

Figure 7 shows two stubby bodies of massive rhyolite (2a). These bodies are under and overlain by block- to lapilli-sized breccias (2b). The small dome-shaped body, (64°14'30", 111°22') of massive rhyolite grades through a zone of fractured rhyolite to the block-size breccia. The fractured rhyolite may represent an autoclastic carapace (Parsons, 1969) at the side of the dome as the fractures seem to parallel the outline of the dome. The other massive rhyolite body in Figure 7 does not show this relationship and may not be a dome but rather a flow.

The block- to lapilli-sized rhyolite breccia (2b) weathers a pinkish-cream to greyish-white depending upon the degree of freshness and metamorphism. Weathered and high grade samples tend to be whitish. The fragments are generally subrounded with tabular to equant outlines. The fragments are poorly sorted and range from 1 cm to 15 cm in diameter in a 1 mm to 5 mm matrix (see Plate 13). Tectonic flattening may have produced moderate elongation in small fragments.

Generally the breccia is monolithologic and all the fragments are rhyolitic. However, fragments in some units may vary from vesicular to non-vesicular and may be quartz phyric or quartz and feldspar phyric. Some fragments contain internal fragments indicating multiple brecciation. Figure 7 shows the fragments size to decrease abruptly laterally from the massive rhyolite bodies. Occasionally, sparse, large fragments are often found up to 2 Km away along strike. Vertical grading is much more rapid taking place over 50 m or less. With the decrease in fragment size the matrix content increases and the rock colour becomes darker (see Plate 14). The matrix is usually composed of recrystallized rhyolite fragments, quartz, chlorite, and sericite. Cleavage is

Plate 13. Rhyolite lapilli-sized clastic (2b). The larger fragments are angular and contain euhedral to subangular feldspar phenocrysts. Quartz phenocrysts are minor. Orange colour is hematitic stain. Fractures are tectonic. From map 2, (64°15', 111°21').

Plate 14. Rhyolite lapilli-sized clastic (2b) fragment showing the squarish quartz and feldspar phenocrysts. Note the development of augen forms in the dark matrix around fragments. Fine white specks in the large fragment are flattened vesicles. Crossed polars. From map 2, same area as Plate 13.

Plate 13.

Plate 14.

COLOURED PICTURES

incipient, often in the form of thin bands of chlorite and sericite which anastamose around fragments. With increasing distance from the massive bodies the degree of sorting increases and vertical grading is not distinguishable.

Fine-grained quartz and felspar phyric rhyodacite (2c) weathers a light grey-green colour.. Fresh surfaces are light-grey. Abundant quartz phenocrysts, up to 15 percent, range form 0.5 mm to 3.0 mm across and exhibit squarish, often embayed outlines (Plate 15). The phenocrysts are composed of single or multiple subgrains. Feldspar phenocrysts, a minor component, are broken and highly altered plagioclase.

Fragments in the rhyodacite (2c) are small, generally less than 1 cm in diameter, and are often highly flattened and recrystallized. Plate 16 shows the flattened and often heterolithologic nature. The fragments range from sedimentary (mudstone) to various felsic origins. Some feldspar fragments are finely quartz and feldspar phyric, some are vesicular, and some exhibit wavy outlines suggestive of pumice.

The groundmass of the rhyodacite (zc) is a mixture of fine-grained, 0.01 mm to 0.05 mm, quartz with varying amounts of chlorite, sericite, calcite, and minor biotite. Opaques are very fine and minor. Plate 17 shows a sample from an amphibolite facies grade terrain. The groundmass and the fragments have been extensively recrystallized and are now almost indistinguishable.

Subunit 2d, a dacite, may be a more distal, matirx-rich equivalent of subunit 2c. The dacite is darker than the rhyodacite with colour banding and thin laminations varying from greenish-orange to medium dark-green.

Plate 15. Quartz phyric rhyodacite (2c). Many quartz phenocrysts are embayed. Fracturing is related to the development of the cleavage. Crossed polars. From map 1, (64° 17', 111°23°).

Plate 16. Heterolithologic rhyodacite (2c). The fragments have been tectonically flattened. White areas are quartz phenocrysts. Dark clast in the centre is mudstone. Greyish clasts range from quartz and feldspar phyric to vesicular. Plane polarized light. From map 1, (64° 17', 111°24').

Plate 15.

1cm

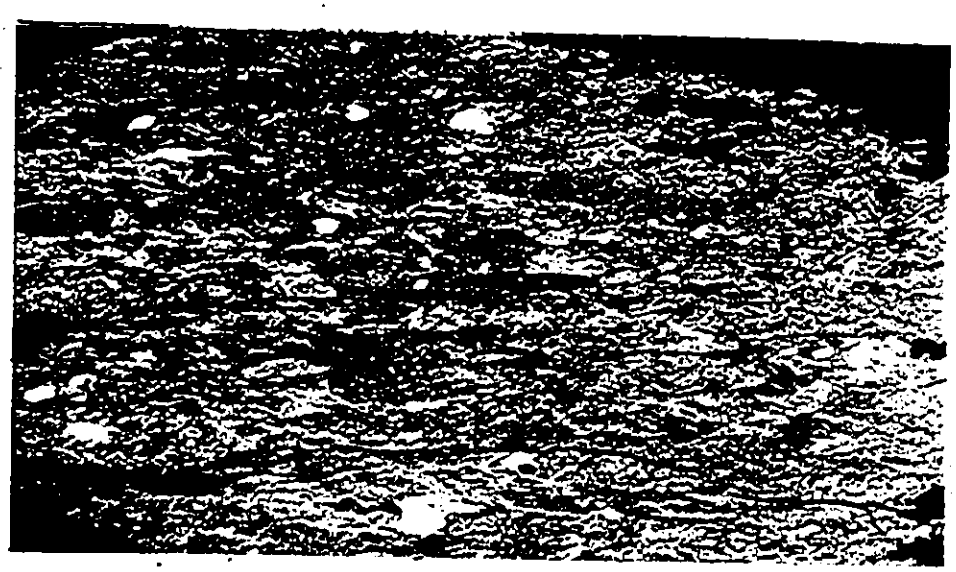


Plate 16.

1cm

COLOURED PICTURES

Quartz and feldspar phenocrysts are common, range from 0.1 mm to 3 mm across and are often flattened. Fragments are thin and elongated, up to 2 mm by 12 mm, and frequently show wispy shapes as outlined by changes in colour. Thin sections show a groundmass of 0.01 mm to 0.05 mm, equant quartz grains with abundant fine-grained chlorite, sericite, and calcite defining a cleavage. Plate 18 shows typical augen-like quartz-feldspar phenocrysts and discontinuous colour patches. Plate 19 shows a very dark, chloritic, sample with small quartz and feldspar phenocrysts, minor lithic rhyolite fragments and elongate dark patches.

Quartz-feldspar porphyry intrusives (2f) are massive dykes in map area 3 and massive rounded bodies in map areas 1 and 2. On weathered surfaces the rock is light-cream to a greenish-cream. Quartz phenocrysts are common, 2 to 10 percent, and 1 mm to 6 mm across. Squarish, subhedral quartz crystals are often embayed and fractured (Plate 20). Plagioclase phenocrysts, 1 to 5 percent of the rock, have anorthite contents up to 45 percent and are sausseritized and unzoned. Relict potassic feldspar phenocrysts generally have faint outlines and are now composed of masses of sericite. Rare microcline phenocrysts have been observed in less altered samples. Alteration to biotite, chlorite, calcite, magnetite, and leucoxene is minor. Foliated specimens occur near presumed contacts with other rocks.

Rhyodacitic block-to lapilli-sized breccia (2e) contains white weathering felsic fragments in a black-green chloritic matrix (Plate 21). The fragments are matrix supported, range from subangular to subrounded, and do not appear to exhibit any stratification. Fragments are 1 cm to greater than 20 cm in diameter, but average 2 cm to 10 cm. Round quartz phenocrysts, 1 mm to 8 mm

Plate 17. Highly recrystallized rhyodacite (2c). The quartz phenocrysts are composed of many grains. The felsic fragment in the centre right is difficult to distinguish from the groundmass. Plane polarized light. From map 1, (64°21', 111°26'0.

Plate 18. Colour banded dacite (2d). Highly flattened, grey patches are augen shaped quartz phenocrysts. Dark patches are chloritic. Orange colour may be related to hematitic alteration. From map 1, (64°19', 111°26'0.

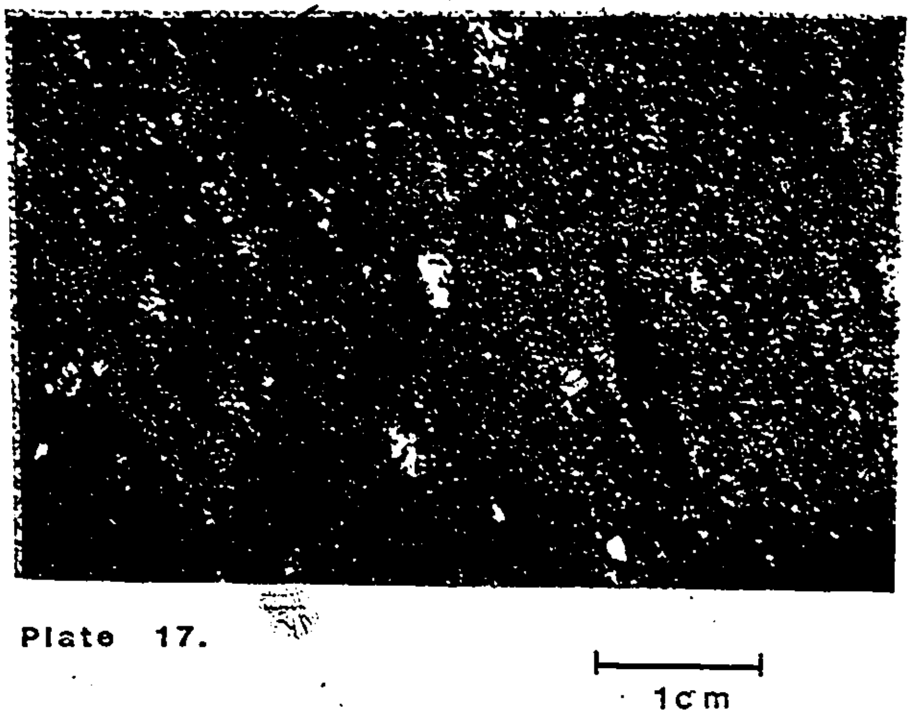


Plate 17.

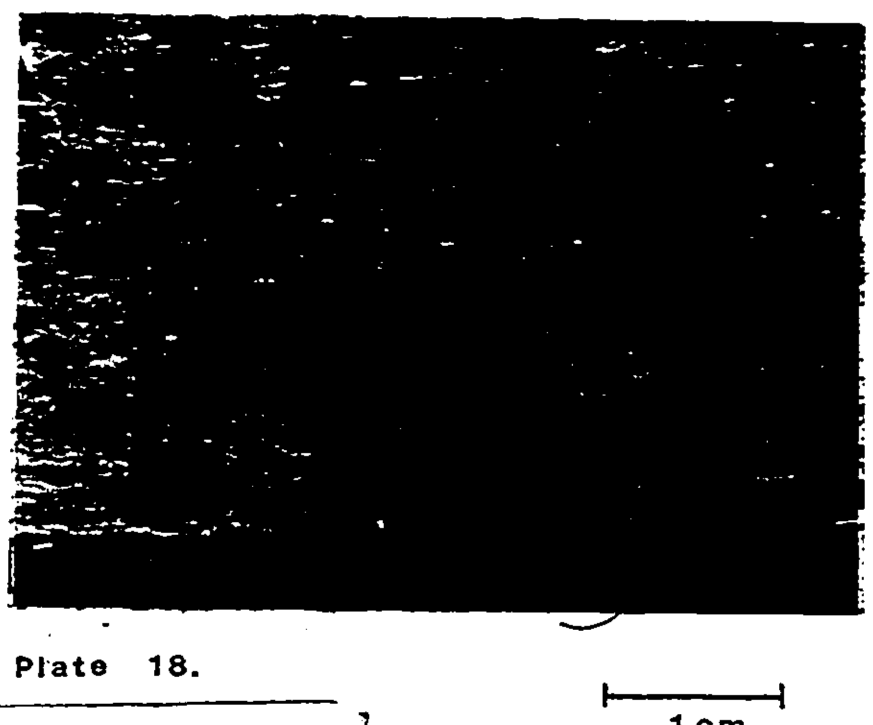


Plate 18.

COLOURED PICTURES

Plate 19. Dark green, chloritic, dacite (2d). Small white flecks are quartz and feldspar phenocrysts. Grey fragment in lower centre is rhyolitic. Dark colour patches are chloritic. From map 1, (64°16', 111°23').

Plate 20. Subhedral, embayed quartz phenocryst from a quartz-feldspar porphyritic intrusive body (2f). An altered, unzoned plagioclase phenocryst lies to the left. Uncrossed polars. From map 1 (64°17', 111°26').

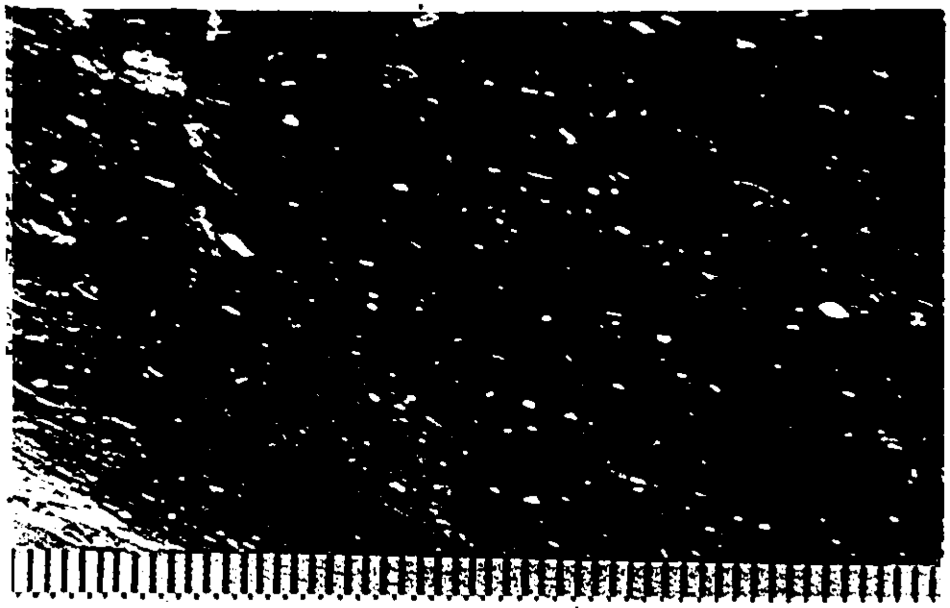


Plate 19

1cm

Plate 20.

0·5mm

COLOURED PICTURES

in diameter are present in both the fragments and the matrix. Small, 0.1 mm to 0.5 mm, quartz filled micro-vesicles are abundant in the large fragments (see Plate 21). The fragments are often fractured, probably after deposition. This breccia (2e) was thought by Moore (1956) to be andesitic but in fact has a specific gravity range of 2.69 to 2.75 suggesting a rhyodacitic composition. The geochemistry is discussed in Chapter 4.

Outcrops of the rhyodacitic (2e) block-breccia range from 10 m to 600 m wide and are very discontinuous laterally. In map area 2 the unit is less than 300 m wide. The patchy exposure pattern appears to be due to the low stratigraphic level of the unit where it is frequently intruded and engulfed by large gabbroic dykes and sills parallel to its strike.

Moore (1956) does not note any vertical or lateral changes in the 2e breccia in map 3. In map 2 the 2e breccia does not exhibit vertical grading or stratification. However, the fragments become less angular towards the northern part of map 2. The coarse, felsic clast conglomerate in the south part of map 1 appears to be stratigraphically and compositionally related to the 2e breccia in map 2.

Summary

There appears to have been two cycles of felsic volcanison in the Courageous-MacKay Lake volcanic belt. A coarse, rhyodacitic, clastic breccia (2e) (Cycle 1) close to the granitoid contact underlies a stratigraphically higher, thicker, and much more extensive felsic volcanic Cycle 2 (subunits 2a 2b, 2c, and 2d) (see Figure 6a). A widespread system of quartz and feldspar phyric dykes (2f) crosscut the Cycle I felsic breccia and the intervening mafic lavas to feed what

Plate 21. Rhyodacitic block-breccia (2e). Large fragments are finely vesicular and contain quartz phenocrysts. Matrix is highly chloritic and contains small rounded felsic fragments and rounded quartz phenocrysts. Fracturing appears to have been tectonic. From map 2, (64°13', 111°21').

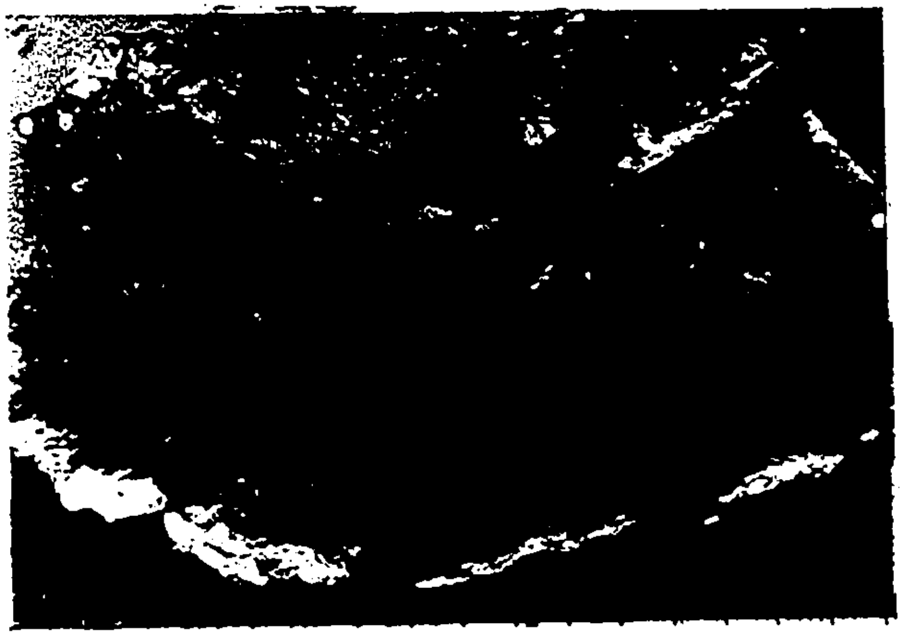


Plate 21.

1 cm

COLOURED PICTURES

appears to have been a major felsic eruptive centre (map 3). Small, massive and dome-like rhyodacitic bodies, in map 2, are located on the northern flank of this felsic edifice. The flanking bodies were subaqueous as indicated by the surrounding pillowed lavas. It is not known if the major felsic eruptive centre was subaqueous or subaerial. The thin felsic units in the north end of the belt diverge slightly away from the upper sedimentary contact suggesting a low-angle flank paleoslope.

Gabbro (Unit 3)

Introduction

Gabbroic rocks are found throughout the Courageous-MacKay Lake volcanic belt in varying amounts. The portion of the belt north of Nodinka Narrows on MacKay Lake (Figure 4), excluding map area 5 to the east contains the bulk of these rocks. Gabbroic units frequently extend up to 3 Km or more along strike, are moderate (220 m) in thickness, and predominante at the bottom of the stratigraphic section. On the basis of scattered outcrops Moore (1956) has suggested cross-cutting relationships indicating that the gabbro forms large sills and dykes. The contacts are difficult to recognize in the field and are frequently sheared although there is a tendency for finer grained rocks towards the margins. As in the rest of the Slave Province, a portion of the gabbro is considered to be genetically related to the mafic lavas (units 1a, 1b, 1e, 1f and 1g) even though no dykes or sills have been traced into extrusive equivalents.

Distribution and thickness

Gabbro sills and dykes may be found throughout the volcanic section, however, the largest bodies and the majority are located close to the contact between the volcanics and the underlying granitoid rocks. Large, irregular-shaped gabbro bodies within the lower mafic lavas of the central portion of map 1 could represent subvolcanic magma chambers or sheets. A large dyke appears to connect a major sill and overlying dykes just north of the central portion of Courageous Lake (maps 1 and 2, Figure 8). This dyke cross-cuts sodic granitoid rocks but not late phase granitic rocks. Similar relationships elsewhere in the Slave Province have suggested that sodic granitoids are basement to the volcanics of the Slave Supergroup (Heywood and Davidson, 1969 and Baragar and McGlynn, 1976).

The sills are large, tabular bodies, 150 m to 500 m thick, which extend up to 10 Km along strike (see maps 1, 2, and 3). A dyke in map areas 1 and 2 is about 10 Km long, ranges from 30 m to 200 m wide and feeds two sills. Cross-cutting relations are, however, not obvious as shown on maps 1 and 2 because of small angles between the dykes and the strike of the country rock. Angular relationships of less than 10 degrees are virtually unmeasureable in the field. Gabbro bodies within 1 Km of the volcanic-sedimentary contact are minor.

Moore (1956) reported that several of the gabbro sills in map 3 have engulfed minor mafic lavas and sediments. These schlieren remain parallel to the local trends, and are minimally altered. The sills have fine-grained margins about the schlieren indicating rapid injection into cold rocks.

Lithology

The gabbroic rocks are generally massive and weather a light grey-green to black-green depending upon the metamorphic grade. Varying ratios of felsic to mafic components (plagioclase to hornblende) are common. The grain size ranges from 0.2 mm in chilled margins to 10 mm in centres of sills. Clots of glomeroporphyritic amphibole (after pyroxene) are up to 1 cm across. The amphibole grains are 4 mm to 8 mm long with interstitial plagioclase. Feldspar phyric gabbro is common. The plagioclase phenocrysts vary from sparse to 15 percent, are 0.2 cm to 4.0 cm across, and have subangular to subrounded forms (see Plate 22). In a few localities clots of plagioclase phenocrysts form spheres up to 25 cm in diameter (Plate 23). These mega-phenocrysts appear to be at the top of a large irregular gabbro body (map 1 at 64°18', 111°28') possibly representing a magmatic segregation. Elsewhere a dyke-sill complex (map 1 at 64°16', 111°24') has a lower non-porphyritic gabbro sill and an upper feldspar phyric sill. An apophyse of the lower sill is feldspar phyric as is part of the dyke feeding the sills (see Figure 8). Nearby are massive and piliowed flows of basalt that are feldspar phyric (Figure 8). The percentage of phenocrysts in the sills that are porphyritic varies considerably. Feldspar phenocrysts in some massive basalt flows or fine-grained gabbro sills grade vertically in size and percentage. These massive units tend to be less than 100 m wide and of variable extent.

The essential minerals in the gabbros are plagioclase (An_{45} to An_{60}), ortho-and clino-pyroxene (pseudomorphed by amphibole) and quartz. Accessory minerals include magnetite, ilmenite, rulite and pyrite. Olivine-rich gabbro is rare. The groundmass consists of plagioclase laths, fine amphibole and fine opaques.

Metamorphism of the gabbro has resulted in extensive mineralogical changes. Clinozoesite replaces plagioclase. Actinolite, tremolite and epidote

Plate 22. Plagioclase feldspar phyric gabbro. Note the fractured angular to subrounded form. From a gabbro sill, note the coarse groundmass. The dark spots are lichen. The dark lines above the scale are fractures. From map 2, (64°15', 111°24').

Plate 23. Plagioclase mega-phenocrysts formed by clots of plagioclase phenocrysts in a thin gabbro unit. Hammer is 31 cm long. From map 1 (64°18', 111°28').

Plate 22.

Plate 23.

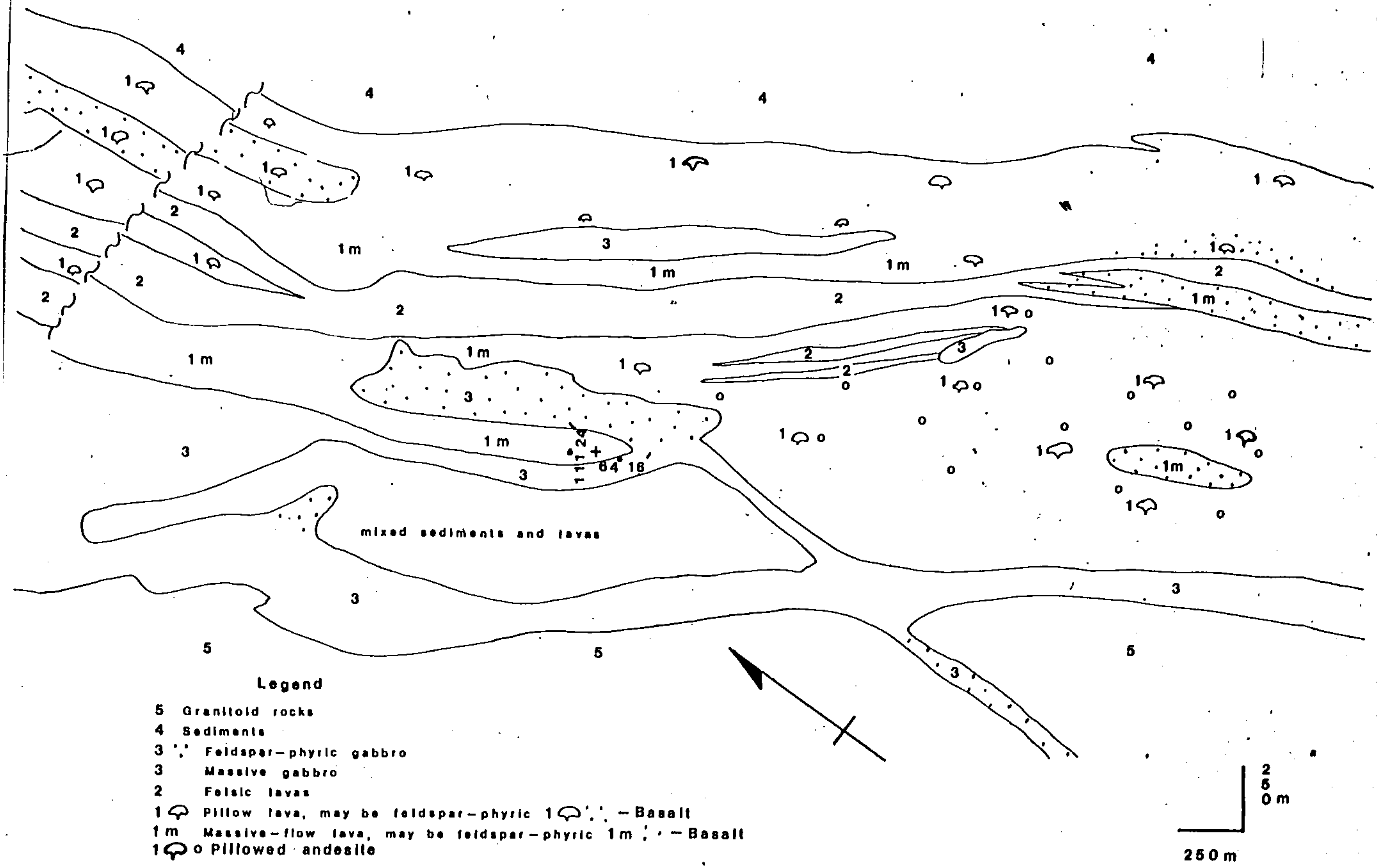


FIGURE 8. Gabbro sills, and, dykes near 111° 24', 64° 16', map areas 1 and 2.

replace hornblende which has pseudomorphed pyroxene. Minor antigorite, serpentine, and opaques represent altered olivine. Ilmenite is frequently rimmed by leucoxene. Biotite and chlorite are rare alteration products of amphiboles. Calcite is minor and variable.

Summary

A gabbro dyke crosscuts the sodic granitoid rocks in map 2 and mafic and sedimentary rocks in map 1 to feed two large sills. The lower sill is aphyric except for an upper apophyse while the upper sill is feldspar phyric. This may be due to the dyke tapping different magma chambers in time or the tapping of different phases within a differentiated magma chamber. The large thickness of mafic lavas in map 1, the abundance of sills in the lower central portion of map 1, and the close relationship between feldspar phyric gabbro bodies and basalt flows suggests that this area was a major subaqueous mafic eruptive centre.

Sedimentary rocks (unit 4)

Introduction

Sedimentary rocks, which form the eastern margin of the Courageous-MacKay Lake volcanic belt, conformably overlie the volcanic rocks. While the contact is rarely exposed, the sediments can be seen to interfinger with mafic and felsic volcanics in a few locations. The sediments above the volcanic pile range from slaty mudstone, greywacke and arkose to minor conglomerate. Moore (1956) reported quartzite on the north shore of the east arm of Courageous Lake. However, no quartizite was observed during this study. Within the volcanic pile minor amounts of slate or phyllite and volcanic-clast conglomerate occur close to the granitic contact (see maps 1 and 3). The only outcrop of conglomerate from above the volcanic-sedimentary contact is in map 5. The rock contains a mixture of granitic and volcanic clasts. The sediments are typically thickly-bedded greywackes and thinly-bedded mudstones (turbidites) which in amphibolite grades of metamorphism are represented by biotite, cordierite-andalusite schists. Beds are generally steeply inclined (Figure 24) and isoclinally folded. Moore (p. 15, 1956) has suggested that the sedimentary pile is "...at least 5,000 feet thick..." but due to the complex folding and incomplete exposure there does not appear to be any means of validating this estimate.

Stratigraphy

Many frost-heaved outcrops of greywacke and mudstone (4a) are lichen-free and exhibit grading and other depositonal features characteristic of the turbidite facies, but the whole Bouma facies cycle (Bouma, 1962) is never present (Figure 9a). Massive beds (division A of Walker, 1979) are relatively rare while graded A division beds are predominant. Typically alternating with thick A division beds are thin (E division) pelitic beds (Figure 9b). Cross-bedded or ripple cross-laminated C division beds and parallel laminated B division beds are rare. The sequence of bed forms is similar to that reported by Henderson (1975) for the Burwash Formation of the Yellowknife Supergroup.

Lithology

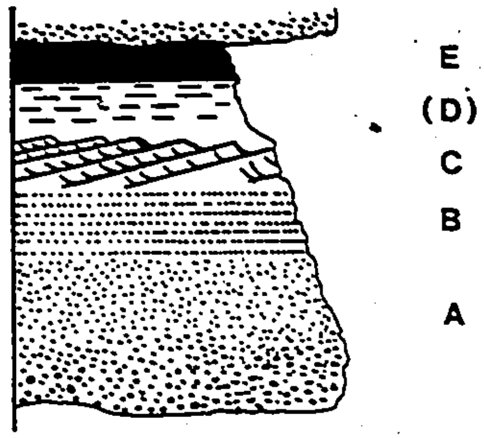
Greywacke-arkose

The greywacke-arkose beds (4a) range in thickness from 1 cm or 2 cm to greater than 3 m with an average thickness of about 0.2 m to 0.6 m. Thin

Plate 24. Frost heaved turbidites (4a) in a low grade area. Bedding and the S_{1B} cleavage are parallel forming the dominant surface of parting. Note the subvertical dip and the scarcity of outcrop. Outcrop in the centre foreground is about 1 m wide. From map 5, (64°03', 111°00').

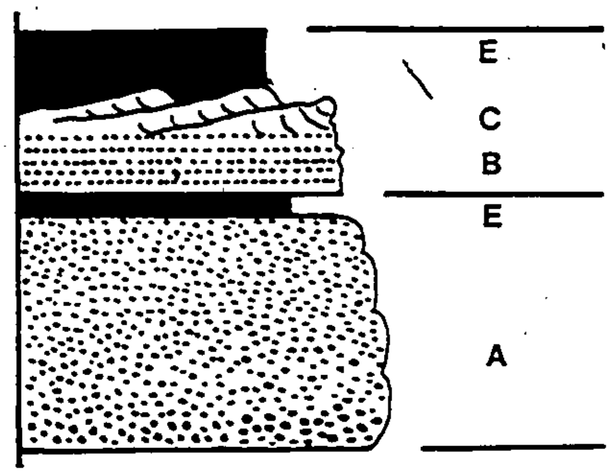
Plate 24.

BOUMA DIVISIONS



A— graded or massive sandstone
B— parallel laminated sandstone
C— ripple cross - laminated fine sandstone
D— faint parallel laminations of silt or mud (rare)
E— pelitic division

FIGURE 9 a. both figures after Walker (1979).



Typical A—E beds and rare B—C—E beds.

FIGURE 9 b.

A division beds, less than 1 m thick, tend to fine-upwards and be overlain by thin (1 cm to less than 10 cm) pelitic E division beds. Thick (1 to 3 m) A division beds are internally massive and are generally not overlain by pelitic (E) beds but more often by thin, graded (A) beds which then are overlain by pelitic E division beds.

The beds are laterally continuous and exhibit sharp bases and tops. Evidence of erosion is rare but scours and rip-up clasts are visible in low-strain areas, such as in map area 5 (Figure 25). Soft-sediment deformation features, like load or flame structures are uncommon and have been oriented by later tectonic deformation. Ball and pillow structures, dewatering features (Walker, 1979) are very rare (see Plate 26).

The grain-size range is very limited, from less than 3 mm to 0.2 mm. The coarser fragments are accentuated by the dissolution of the matrix, but a hand-lens is often required to obtain the grading direction. Clasts include quartz, oligoclase, rare microcline, chert or recyrstallized felsic volcanic fragments, and pyrite or magnetite. These are set in a fine-grained quartzo-feldspathic and chlorite-muscovite-biotite groundmass. The grains tend to be angular to sub-angular. With increasing metamorphic grade recrystallization eliminates grain-size grading. Nevertheless, a vague colour zonation related to an increasing pelitic content in the upper parts of the beds can be used as a criterion for assuming stratigraphic tops. Weathered surfaces are generally a light-grey becoming browner with increasing metamorphic grade.

Slate

The pelitic beds (4a) are thin, 3 mm to less than 10 cm, averaging about 2 cm to 4 cm. The top and bottom of the pelitic beds is sharply defined and

Plate 25. Rip-up pelitic clasts reoriented parallel to the S_{1B} cleavage direction and the pen. Faint laminations define bedding (S_0). Pen is 12 cm long. From map 5 (64°02', 111°02').

Plate 26. Soft-sediment ball and pillow dewatering structures in a massive A division greywacke bed (4a). White patches are lichen. Hammer is 31 cm long. From map 4, (63°54', 111°05').

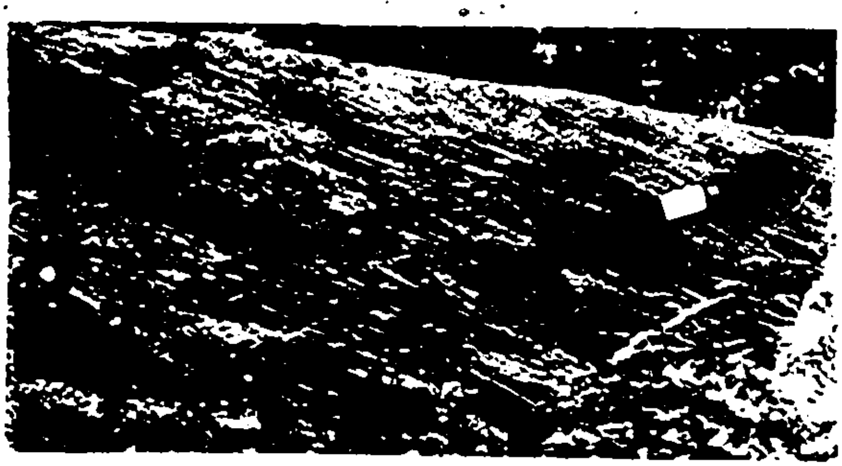


Plate 25.

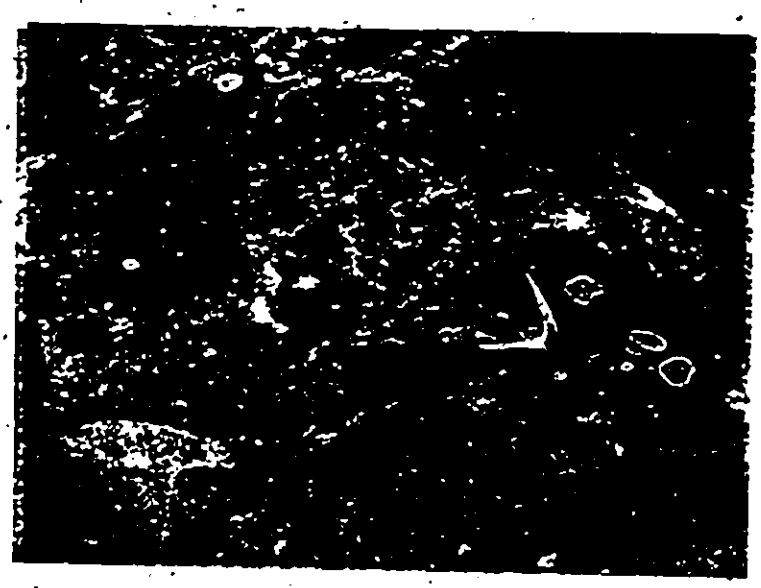


Plate 26

often weathers recessively. In greenschist facies areas the pelites are a black or dark-green colour. In amphibolite facies terrains the pelitic horizons develop aluminosilicate porphyroblasts, become a dark brown colour, and tend to weather less recessively.

Microscopically the slaty beds exhibit a vertical size grading of fine quartz and feldspar grains and increasing micaceous content. The grains range from less than 0.01 mm to 0.2 mm. The quartz-feldspar content is low, less than 30 percent, and quite variable. The remainder is composed of sericite, chlorite, biotite, and muscovite with minor magnetite, ilmenite, pyrite, and graphite.

Intervolcanic mudstone

A foliated slaty-mudstone to biotite phyllite (4b) is found within the lower part of the volcanic pile close to the granitoid contact in maps 1 and 3. Minor amounts are found within the Cycle 2 felsic volcanics less than 1 Km from the volcanic-sedimentary contact. The intervolcanic sediment (4b) differs from the sediments which overlie the volcanic pile (4a) in that it: 1) does not contain greywacke or arkose beds; 2) contains minor, rounded, fine quartz and feldspar grains; 3) contains abundant euhedral pyrite (1 mm to 3 mm), and 4) the beds are predominantly pelitic and very thinly laminated (1 mm to 10 mm). The overall thickness of sedimentary units within the volcanic pile varies from 10 m to 100 m. In map 1 mudstones (4b) underlie a volcanic conglomerate (4c) and may indicate a period of volcanic inactivity.

Volcanic conglomerate

An inter-volcanic volcanic-clast conglomerate (4c) occurs in map 1 (64°16', 111°25'). The conglomerate is a thin unit, in outcrop 30 m to 50 m wide and 1.5 Km long. It is underlain by 100 m of east facing slaty-mudstone (4b) mentioned above.

The volcanic clasts are well rounded to elongate with long dimensions 0.2 cm to 25 cm. Clasts include green, vesicular basalt and whitish, dacitic fragments (Plate 27). The volcanic conglomerate (4c) is reverse graded. The inter-volcanic slaty mudstone (4b) is overlain by a thin, 2 m thick, cross-bedded quartz-rich sandstone which grades into a poorly stratified pebble conglomerate (Plate 27). Overlying this is a coarse conglomerate which is not sorted or stratified (Plate 28). The large, poorly sorted clasts are clast supported while the stratified pebble conglomerate is matrix supported. The matrix is highly chloritic, similar to the matrix in the Cycle 1 breccia (2e). This volcanic conglomerate is at the same stratigraphic level as the 2e block-sized rhyodacitic breccia and has a similar composition.

Chert

Outcrops of thinly laminated chert? (4d) are rare and discontinuous. This subunit is found along the volcanic-sedimentary contact in maps 4 and 5. In map 4 the chert overlies pillowed basalts for much of the contact length. The outcrops are sheared, discontinuous and less than 10 m wide. Similarily a thin (5 m to 10 m) pyritic, cherty horizon is distributed along the eastern contact of the pillowed basalts in map 5.

Plate 27. Poorly stratified, volcanic pebble conglomerate (4c). Clasts are predominantly dacitic with minor vesicular basalt. Clasts are tabular to subrounded. From map 1 (64°16'30", 111°24'30").

Plate 28. Well rounded poorly sorted volcanic conglomerate (4c). Stratigraphically higher than Plate 27. Light coloured clasts are dacitic. Note vesicular fragments.

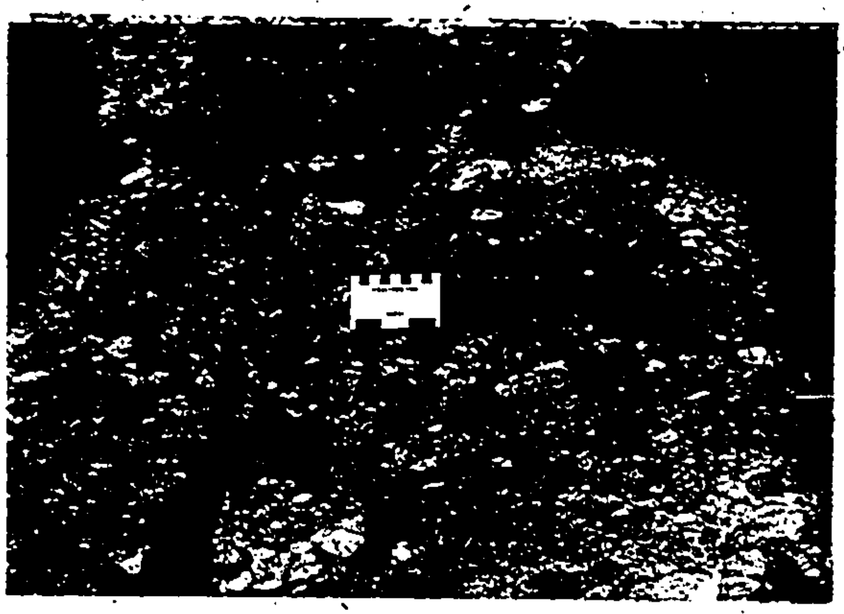


Plate 27.

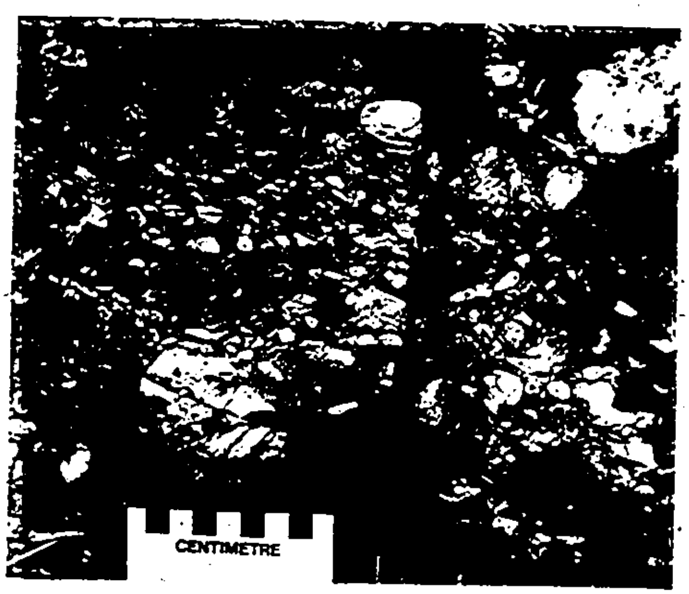


Plate 28.

The laminations are faint, 2 mm to 5 mm wide and often contain abundant pyrite. Pyrite forms euhedral crystals, 1 mm to 2 mm across, and may range up to 5 percent of the rock. The chert could be recrystallized rhyolite or a highly silicified sediment.

Granitoid and volcanic conglomerate

The only outcrop of the granitoid and volcanic-clast conglomerate (4e) is at 64°03', 111°02' (map 5). The conglomerate occurs in a small "U" shaped channel, about 10 m wide by 5 m deep, within greywacke (4a) about 200 m above the volcanic-sedimentary contact. The cobbles are well rounded, matrix supported, 5 cm to 25 cm in diameter, and are of mafic volcanic, plagioclase phyric dacitic and granitoid composition. The sand-sized, mafic volcanic matrix is highly chloritized and foliated in contrast to the cobbles which are completely unfoliated.

Summary

The greywacke-slate turbidite sediments are a proximal basin facies (Henderson, 1981). Lithic felsic volcanic fragments indicate that part of the sediments were derived from the erosion of the large accumulation of felsic volcanic rocks that caps much of the belt. The granitic and volcanic clast conglomerate (4e), located in the turbidites near the boundary with the underlying volcanics could indicate that some granitoid bodies were either in place and exposed or uplifted and eroded not long after volcanism.

The intervolcanic mudstone (4d) was deposited during restricted periods of volcanic quiesence. The predominantly felsic clast intervolcanic conglomerate (4c) appears to have the same stratigraphic level as the rhyodacitic block-breccia (2e) to the south. The reverse grading and the heterolithologic composition of unit 4c may represent increasing volcanic activity during a major eruption or reflect the mode of transport, ie. a debris flow (Walker, 1979). The tentative correlation of unit 2e with a distal equivalent (unit 4c) could imply a paleohorizon throughout much of the belt during the first felsic cycle.

The close of volcanism produced a thin pyritic cherty horizon in the south and eastern portions of the belt possibly indicating minor exhalative activity.

Granitoid rocks (units 5 and 6)

Introduction

The granitoid rocks were not mapped or sampled in detail. Traverses were usually terminated after 1 Km or less across these rocks. Contacts between the granitoids and other rocks are generally inferred as the outcrop is discontinuous. Along the western margin of the volcanic rocks the contact varies from apparently conformable in maps 2, 3 and 4 to visibly intrusive in maps 1 and 5. Contacts with sedi-mentary rocks are complex. Deformation has wrapped large scale (F_{0B}), folds around the granitoid bodies in maps 3, 4, and 5, whereas the folds are abruptly truncated in the north part of map 1 by the intrusion of a granitoid body.

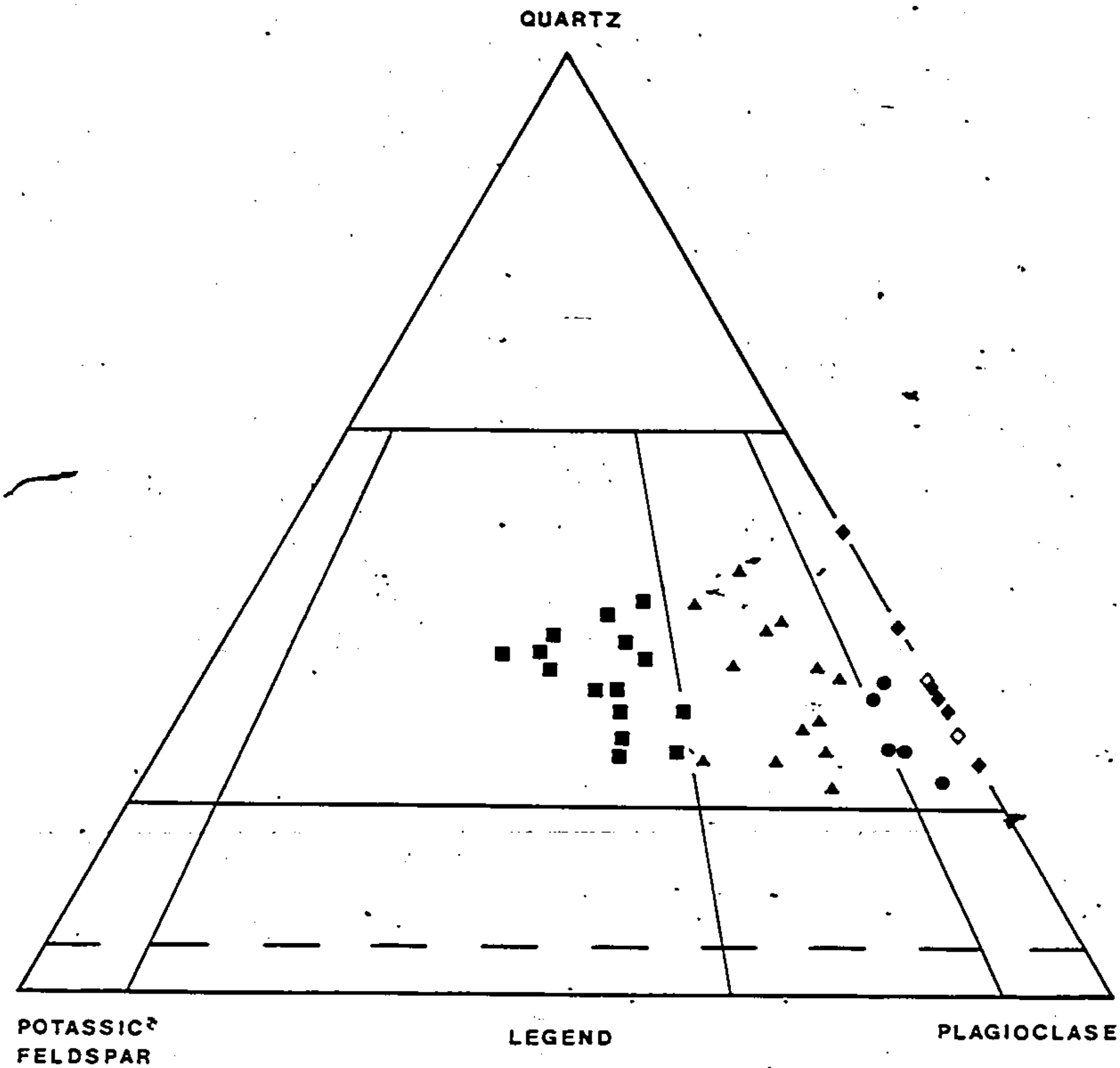
In map areas 2 and 3 the western granitoid rocks contain numerous subrounded to tabular mafic schlieren, with internal foliations paralleling the local trends, ranging from metre to kilometre size.

The granitoid rocks vary in composition from granite, granodiorite and tonalite to trondhjemite according to the classification of Streckeisen (1976). Leucocratic, coarsely porphyritic granite is readily identified in the field, whereas the sodic granitoids require staining. All the granitoid rocks contain biotite and less commonly hornblende. Figures 10, 11, 12, and 13 show the modal compositions, the specimen numbers, the spatial relationships of the various compositions, and the sample locations. Appendix 1 lists the modes and textural characteristics of each compositional group. The few chemical analyses are discussed in Chapter 4 and listed in Appendix 2.

Biotite granite

Biotite granites (5a) occur along the western margin of the volcanic belt (Figure 12) as linear intrusions into the volcanics in the north end of map 1, and as two small plutons within the sediments to the east of the volcanics in map 4. In general the granites form a zone, from 100 m to 3 Km wide, along the western margin of the volcanics. In some parts of map 1 however, granodiorite appears to be in contact with the volcanics (see Figure 12). Granite specimens 8, 9, 10, from close to the volcanic contact in map 1, have aligned biotite. All other granite specimens do not have a mineral alignment. Thermal metamorphic aureoles within the metasediments in maps 1 and 4 are related to granite bodies.

The granites are predominantly medium grained, often porphyritic and vary from a white-grey to dark pinkish orange depending upon the hematite content and the degree of weathering. Biotite content is usually less than 5 percent. Hornblende is rare. Quartz is equigranular while both plagioclase and potassium feldspar are tabular, up to 1.5 cm long, and porphyritic. Plagioclase feldspar in normally zoned and anorthite content ranges from 22 percent in rims to 29 percent in cores. Potassic feldspar is commonly microcline but may be anit-perthitic. Accessory minerals allanite, calcite, epidote, sphene, and zircon occur in trace amounts.



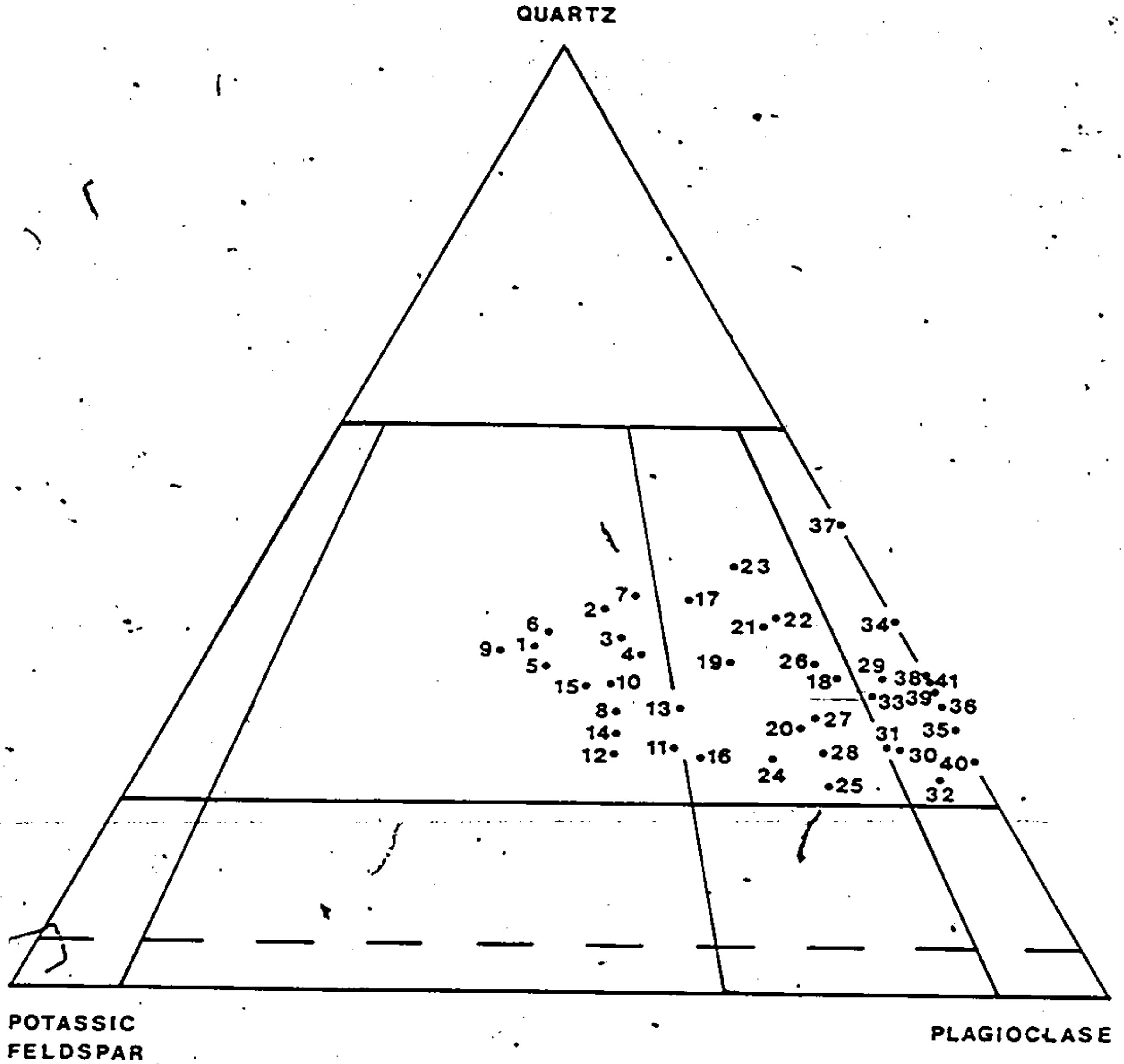
LEGEND

■ Biotite granite
▲ Biotite granodiorite
● Biotite — hornblende tonalite
◇ Biotite — hornblende trondhjemite
◆ Biotite trondhjemite

FIGURE 10.

Modes of granitoid rocks from the Courageous—MacKay Lake area. Sample locations and numbers shown in Figures 11 and 13.

divisions after Streckeisen, 1976.



1–15	Biotite granite
16–28	Biotite granodiorite
29–33	Biotite – hornblende tonalite
35,38	Biotite – hornblende trondhjemite
34,36,37–41	Biotite trondhjemite

FIGURE 11. Key to figure 10.

COURAGEOUS - MACKAY LAKE GREENSTONE BELT

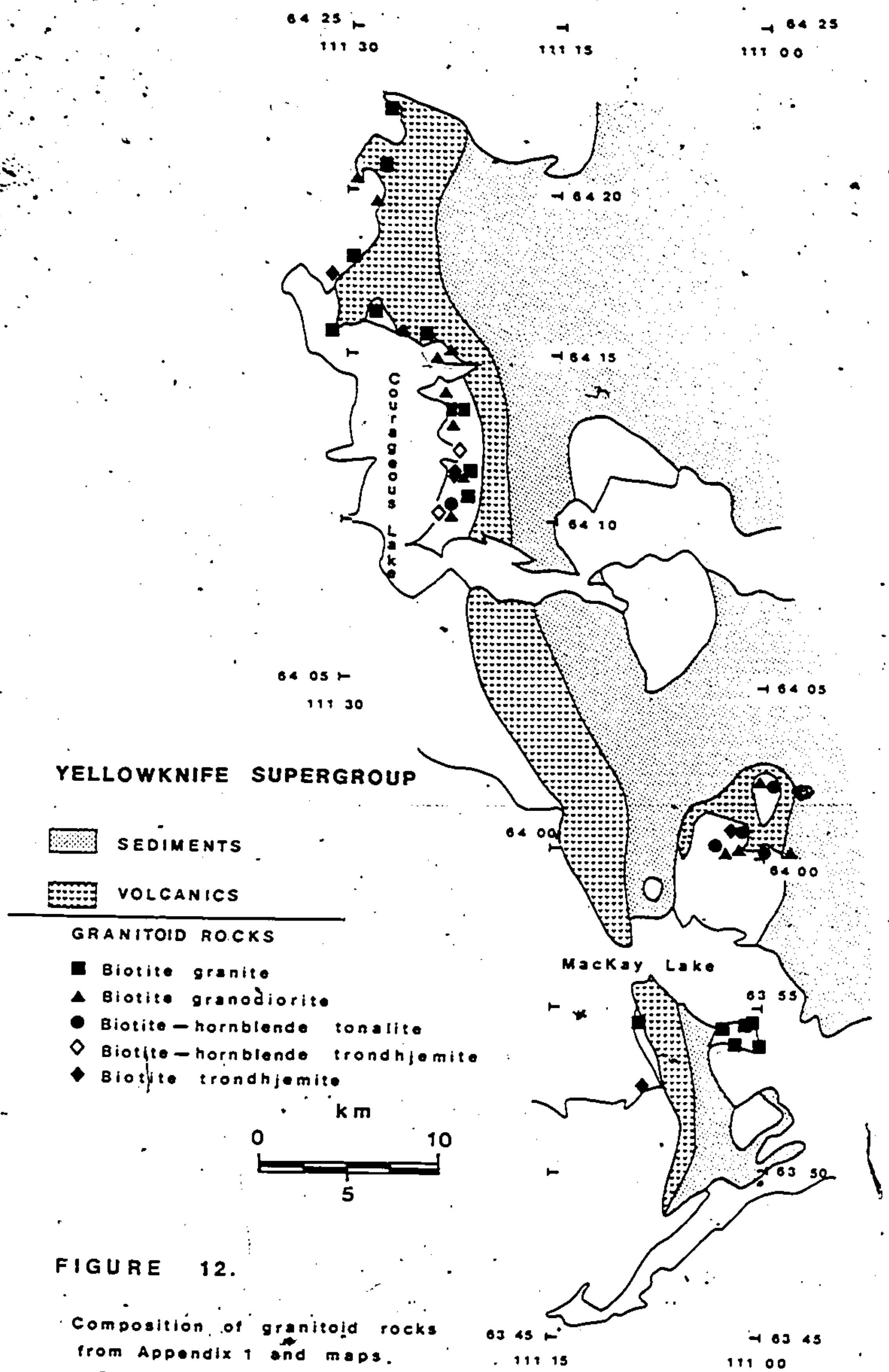


FIGURE 12.

Composition of granitoid rocks from Appendix 1 and maps 1, 2, 4 and 5.

COURAGEOUS - MACKAY LAKE GREENSTONE BELT

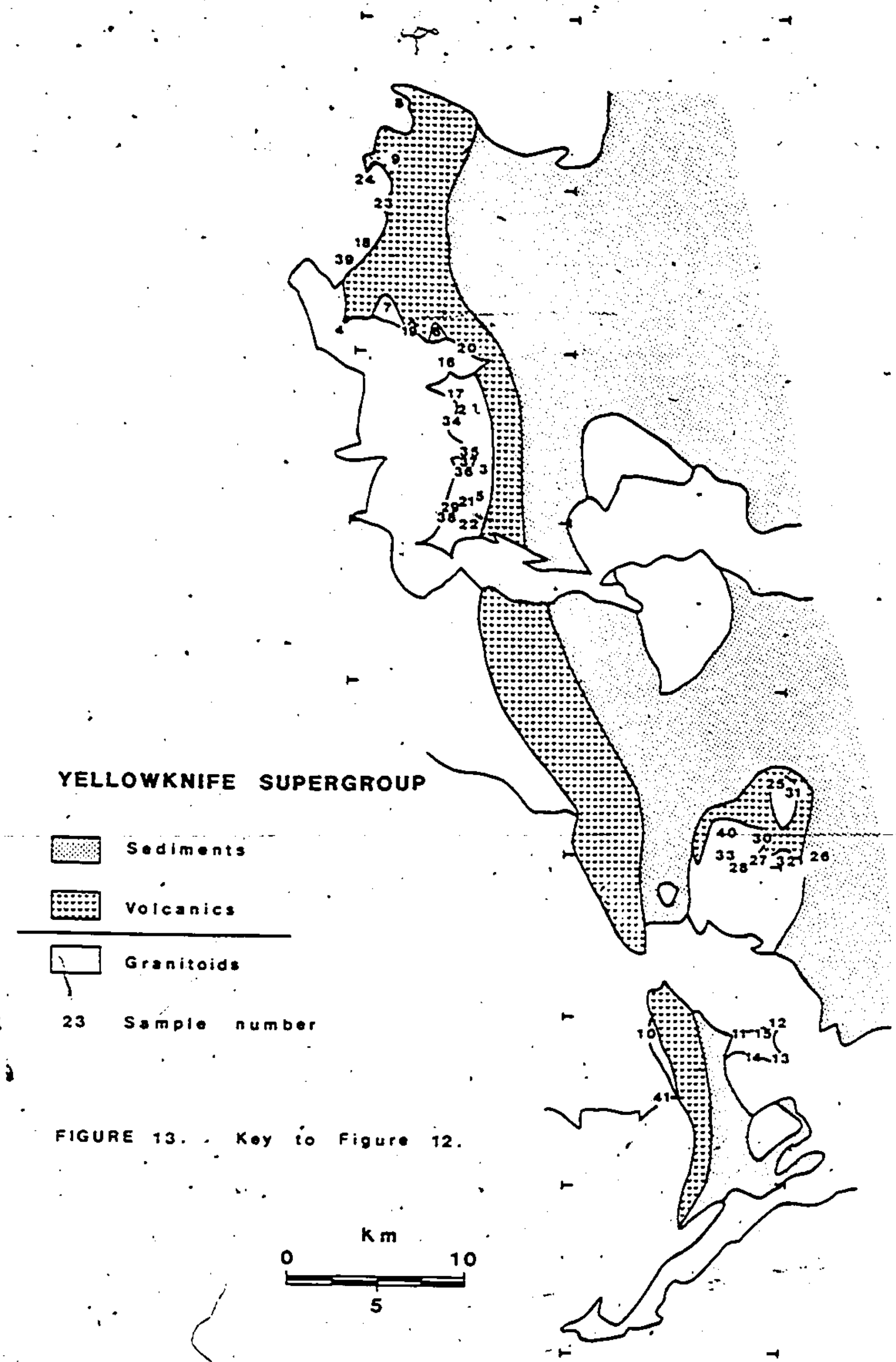


FIGURE 13. Key to Figure 12.

Biotite granodiorite

Biotite granodiorite (5b) along the western volcanic margin may occur in contact with the volcanics (map 1) but is generally separated from the volcanics by a zone of biotite granite. In map 5 the granodiorite is closest to the volcanics and separates the volcanics from granitoid rocks of tonalite to trondhjemite composition.

Biotite granodiorite is generally equigranular, fine- to medium-grained, and light pinkish-grey in colour. Porphyritic and cataclastic textures are rare. Euhedral biotite ranges from 4 to about 13 percent. Perthite and microcline are generally interstitial to the plagioclase feldspar and quartz. Normally zoned plagioclase phenocrysts have anorthite ranges of 22 to 28 percent (rim to core).

Biotite-hornblende tonalite and trondhjemite

Rocks of tonalitic to trondhjemitic composition, 5c and 5d respectively, are located in maps 1, 2, 4 and 5. In maps 2 and 4 they lie further west from the volcanic contact than the granite and granodiorite (Figure 12). In map 5 the tonalitic to trondhjemitic rocks are separated from the volcanics by a thin, 50 m to 1 Km wide, zone of granodiorite.

Unlike the granite plutons in maps 1 and 4 the tonalitic, trondhjemitic and granodioritic plutons to the east of the main volcanic belt (map 5) are not associated with a metamorphic aureole in adjacent sedimentary rocks. The small, southern pluton (64°02', 111°00') is surrounded by volcanic rocks which may have masked the thermal effects.

Rocks of tonalitic to trondhjemitic composition are fine- to medium-grained and have a white-grey to grey colour. The two compositions can not be differentiated in the field from granodioritic rocks. Biotite is fine-grained, ranges from 3 to 12 percent, and is often aligned. Hornblende is minor, generally 2 percent or less, and rarely aligned. While a cataclastic texture is rare the development of a subgneissic texture is more common. The quartz and plagioclase feldspar tend to form domains with aligned biotite and hornblende. Quartz and plagioclase grains are allotriomorphic. Normally zoned plagioclase grains have highly sausseritized cores and anorthite contents ranging from 21 to 44 percent (rim to core).

Muscovite-biotite pegmatite (unit 6)

Pegmatite has been observed only in map area 4. It occurs as two small irregular bodies near 63°52', 111°06' where it has intruded mafic volcanics. The texture is granophyric, with 5 to 15 percent muscovite and minor biotite in a medium to coarse-grained groundmass of plagioclase, potassic feldspar, and minor quartz. The pegmatite is probably derived from the late stage, biotite granite pluton about 2.5 km to the east.

Diabase dykes (unit 7) (Proterozoic or late Archean)

Steep diabase dykes cut all rock types in the Courageous-MacKay Lake area. Diabase dykes are plentiful in maps 1, 2, and 3 and uncommon in maps 4 and 5. The dykes are very persistent, often extending more than 20 Km along strike . Widths range from 10 m to 100 m, the widest dykes crossing the sediments. The weathered surface is rough and a rich, reddish brown.

Generally the diabase is highly magnetic which distinguishes it from gabbroic dykes. Frequently the dyke margins are fine-grained and sharp. The grain size increases from aphanitic margins to coarse-grained cores (up to 4 mm). Hematite alteration is noticeable up to 20 m from the contact. Fresh samples are a black-green colour and contain ortho- and clino-pyroxene and abundant magnetite or ilmenite. Altered samples contain clino-amphiboles, biotite, chlorite, and opaques.

Moore (1956) noted that the diabase dykes trend: a) easterly, b) north-westerly, c) north-easterly and d) northerly. The dykes belong to the MacKenzie swarm (McGlynn and Henderson, 1972). The east-west trending dykes are the oldest and they are offset by small northerly trending faults. Elsewhere in the Slave Province similar east-west dykes have been radiometrically dated as late Archean (Gates and Hurley, 1973). Within the mapped areas the predominant direction seems to be north-westerly. The dykes anastamose considerably and appear to follow structural-lithological trends for short distances. Thus the various northerly dykes of Moore (1956) may be controlled in direction by earlier structures.

CHAPTER 4

GEOCHEMISTRY

Sampling and anlaysis

Seven granitoid and thirty-eight volcanic rocks were sampled for geochemical anlaysis (Appendix 2). The granitoid rocks included granite, granodiorite, tonalite, and trondhjemite. The volcanic rocks included gabbro dykes; massive, pillowed, fragmental and feldspar phyric basalt; amygdaloidal, massive and pillowed andesite; pillowed and fragmental andesite; fragmental dacite; quartz-feldspar porphyry dykes; and massive to fragmental rhyolite (Figure 14).

The samples collected were small and from a single location within the outcrop (cf. Baragar, 1969). An attempt was made to collect the least visibly altered and deformed specimen possible.

The samples were crushed in a jaw crusher. Weathered fragments were then picked out. The remaining pieces were crushed by hand to 0.5 cm and split. About 100 gm was taken from one split and pulverized in a shatter box. Fused glass discs were made form a mixture of 1.5 grams of sample, 4.5 grams of Li_2BO_7 and 0.5 grams of $LiCO_3$. A few grains of NH_4NO_3 were also added.

All elements, major and trace, were anlayzed by X-ray fluoresence spectrography in the Ottawa University department of geology laboratory by R. Hartree. Duplicate and standard samples were run to estimate accuracy and precision. The precision for the major elements is about 2 percent while the trace elements can vary by 10 percent or more (R. Hartree, pers. comm., 1981). FeO and Fe_2O_3 are reported as FeO_T. The major elements have not been recalculated to 100 percent.

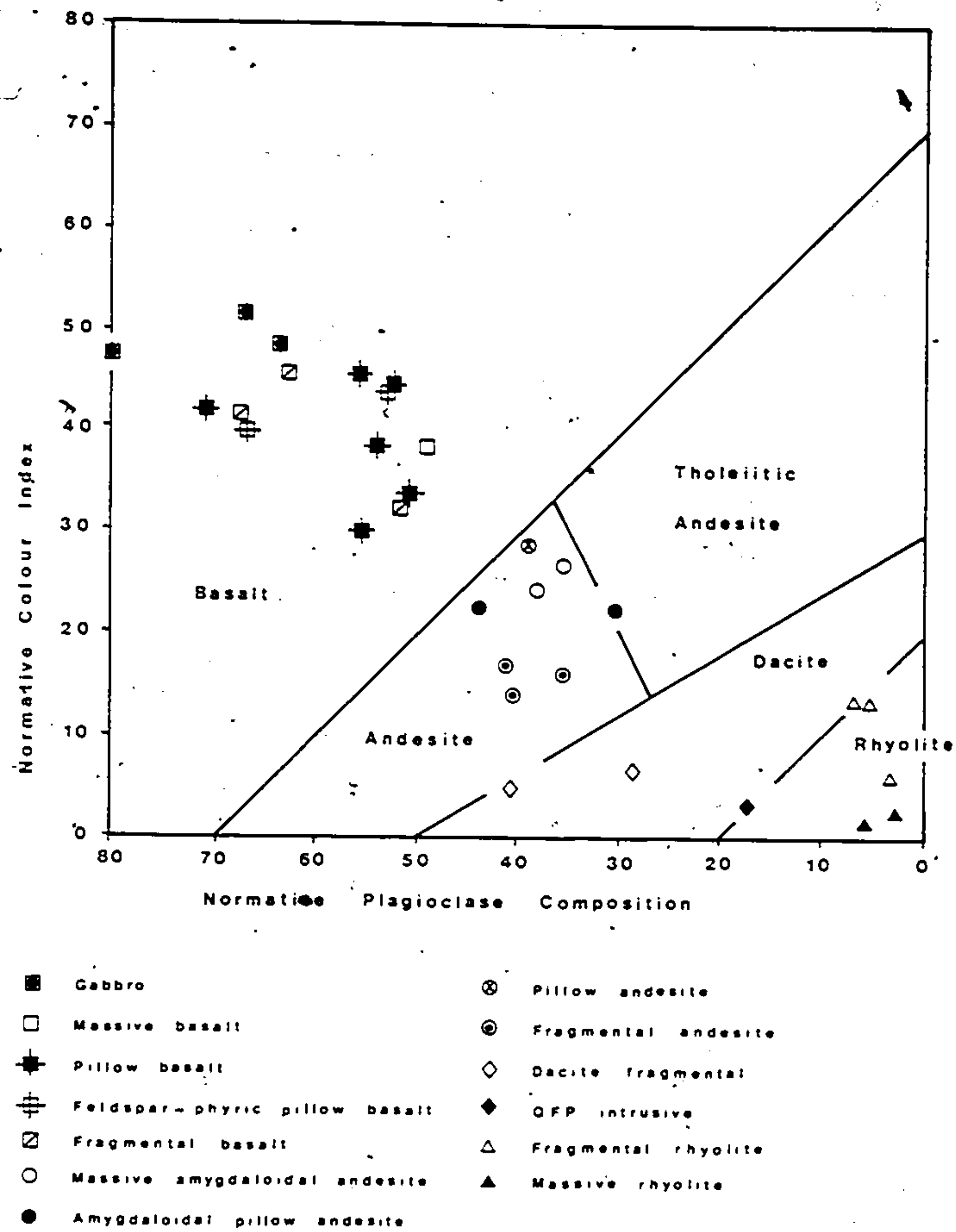
The norms were calculated by the geology department computer program. The classification scheme follows that of Irvine and Baragar (1971).

Results

Granitoid specimens 30 and 40 were identified as tonalite and trondhjemite respectively by modal analysis (Appendix 1). However, according to Barker's (1979) definition both specimens are trondhjemites as; SiO_2 is greater than 68 percent and less than 75 percent, Al_2O_3 is typical (15 percent), $FeO_T + MgO$ is close to the upper limit (3.4 percent), NaO is typical (4.5 to 5.5 percent), K_2O is less than 2 percent, and Ca_2O is between 1.5 and 3.0 percent. The anorthite content of plagioclase ranges from oligoclase to andesine (Appendix 1). This prevents the use of Barker's (1979) classification of calcic trondhjemite for andesine-bearing leucotonalites and trondhjemite for albite or oligoclase-bearing leucotonalites.

Figure 14 shows the Courageous-MacKay Lake volcanic rocks to range from basaltic through andesitic and dacitic to rhyolitic. Figure 15 plots the specimen numbers listed in Appendix 2. Figure 16 shows the location of the specimens.

The gabbroic dykes lie in the basalt field of the normative colour index versus normative plagioclase composition plot. On this plot the distinction between basalts and andesites and between andesites and dacites is effective. However, the separation between the rhyolitic and dacitic rocks is less clear. The massive rhyolites (Cycle 2) have very low colour indexes and are distinct from the Cycle 2 proclastic rocks. The Cycle 2 felsic fragmental rocks range from rhyolitic through rhyodacitic to dacitic compositions confirming field



divisions of Irvine and Baragar, 1971.

FIGURE 14.

Composition of volcanic rocks from the Courageous - MacKay Lake volcanic belt

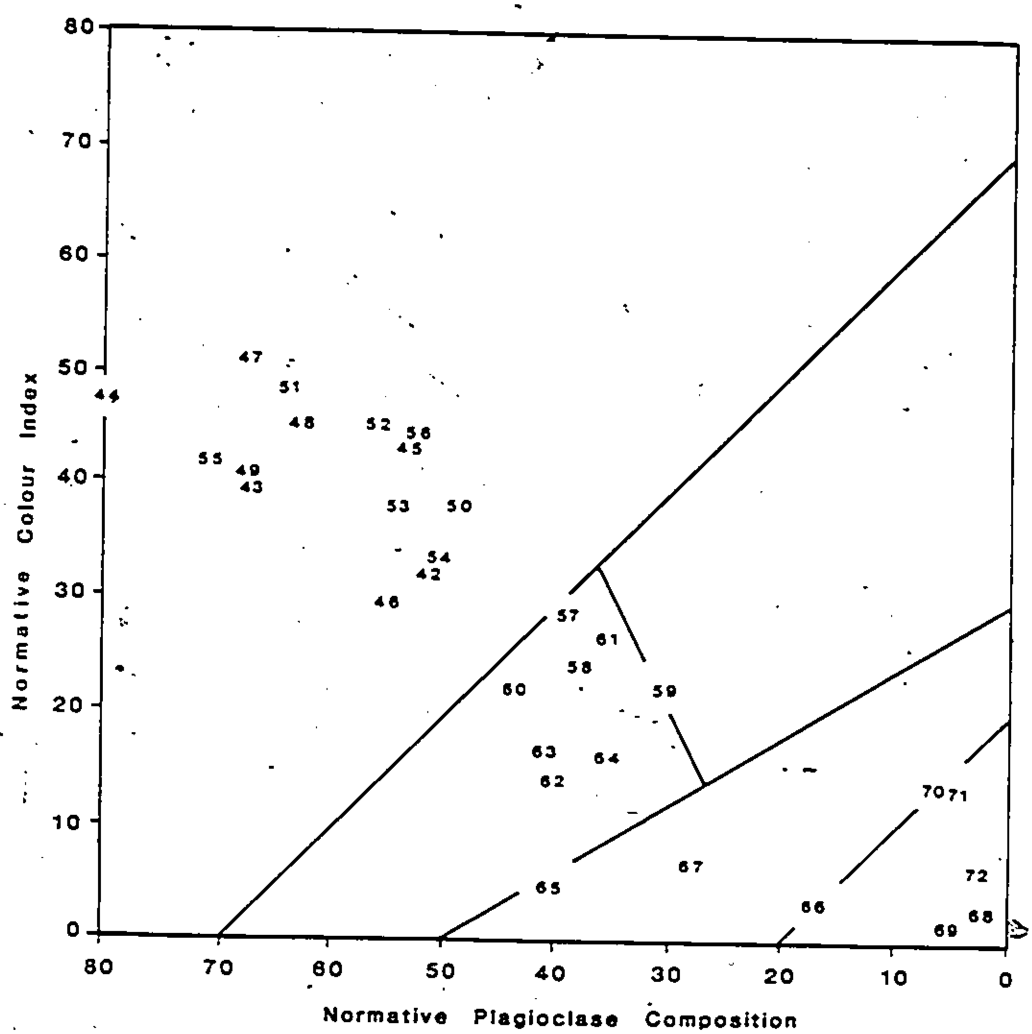


FIGURE 15. Key to Figure 14.

See Appendix 2 for chemical analyis and Figure 16 for location.

COURAGEOUS - MACKAY LAKE GREENSTONE BELT

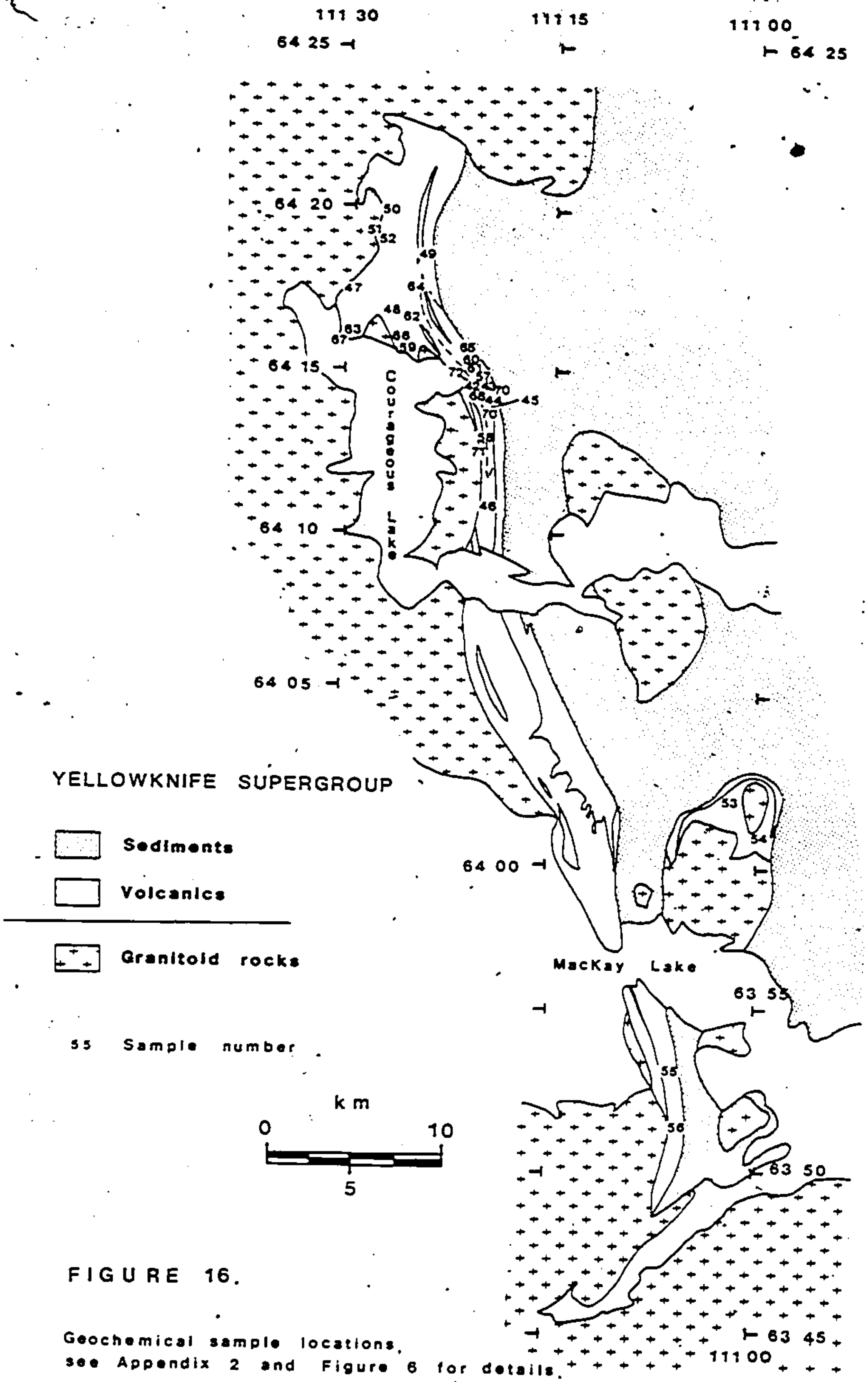


FIGURE 16.

Geochemical sample locations, see Appendix 2 and Figure 6 for details.

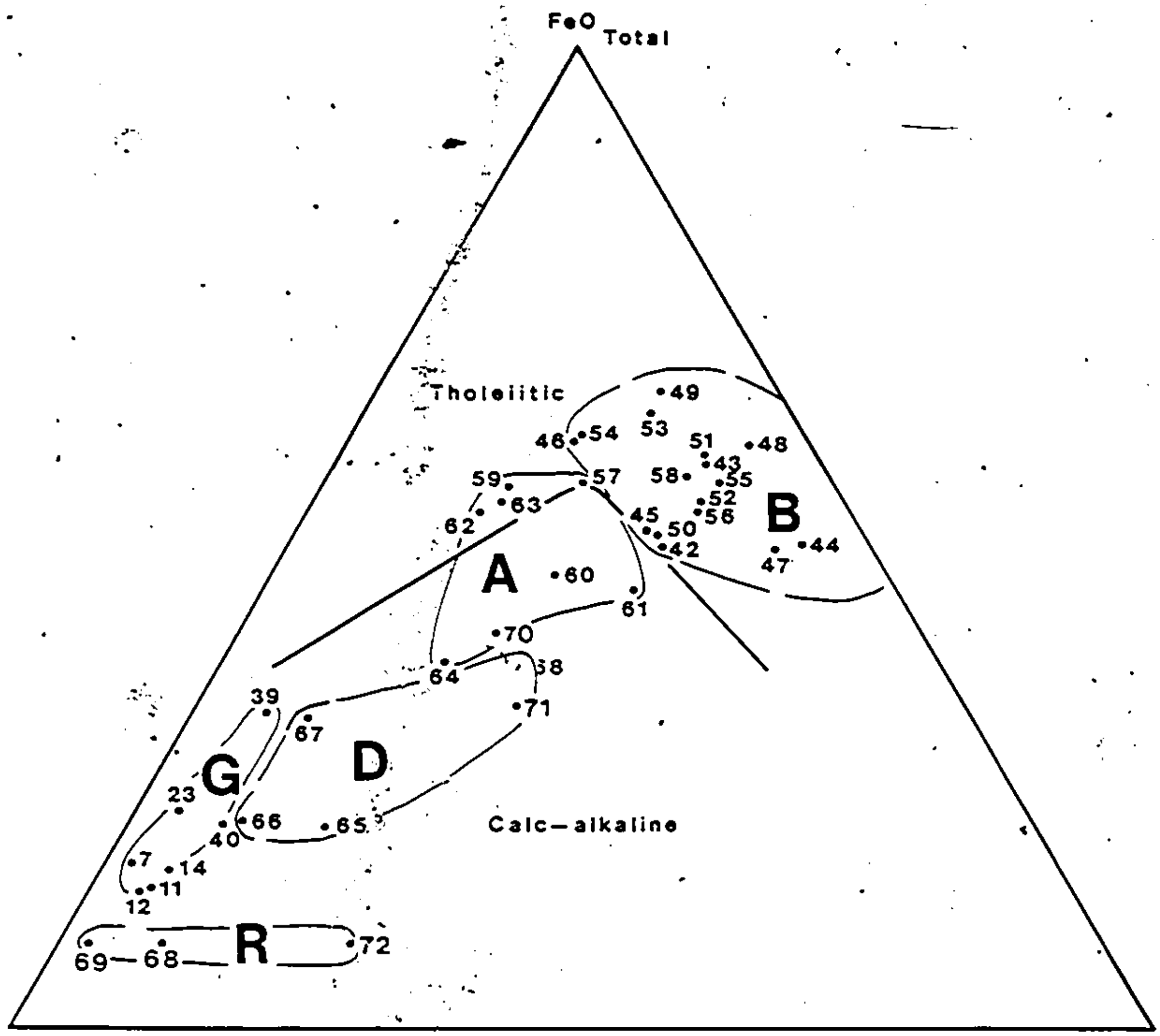
observations of an increasing specific gravity and darkening colour with increasing distance from the massive rhyolite bodies, ie. unit 2b through 2c to 2d.

A sample from a quartz-feldspar phyric intrusive body (2f) lies on the dacite-rhyolite boundary. Specimen 71 (Figure 15) a Cycle 1 block-breccia (2e) lies within the rhyolite field in Figure 14.

Figure 17, an AFM diagram, shows that the volcanic rocks trend from tholeiitic basalts and andesites to calc-alkaline andesites, dacites and rhyolites. The arbitrarily outlined fields are transitional from basaltic through andesitic to dacitic compositions. There appears to be a large gap between dacitic and rhyolitic samples. The granitoid field is plotted for comparison. Specimen 71 plots in the dacite field in Figure 17 and as a rhyolite in Figure 14, and specimen 70 which plotted as a rhyolite in Figure 14 plots as an andesite in Figure 17. This is due to the high MgO and FeO_T contents of these specimens.

According to the nomenclature of Irvine and Baragar the basalts, andesites and dacites range from K-poor, and average K to K rich. The rhyolites are K poor.

A comparison of the percentage of major oxides and traces with the SiO_2 content (Figure 18) shows for increasing SiO_2 that: FeO_T, MgO and TiO_2 decrease significantly; CaO decreases to a lesser extent; Al_2O_3, Na_2O and P_2O_5 are nearly constant; and K_2O increases. Trace element Yittrium is constant while Zirconium increases rapidly.



LEGEND

B - Basalt field
A - Andesite field
D - Dacite field
R - Rhyolite field
G - Granitoid field

FIGURE 17. A F M diagram, see Appendix 2 for details.

after Irvine and Baragar (1971).

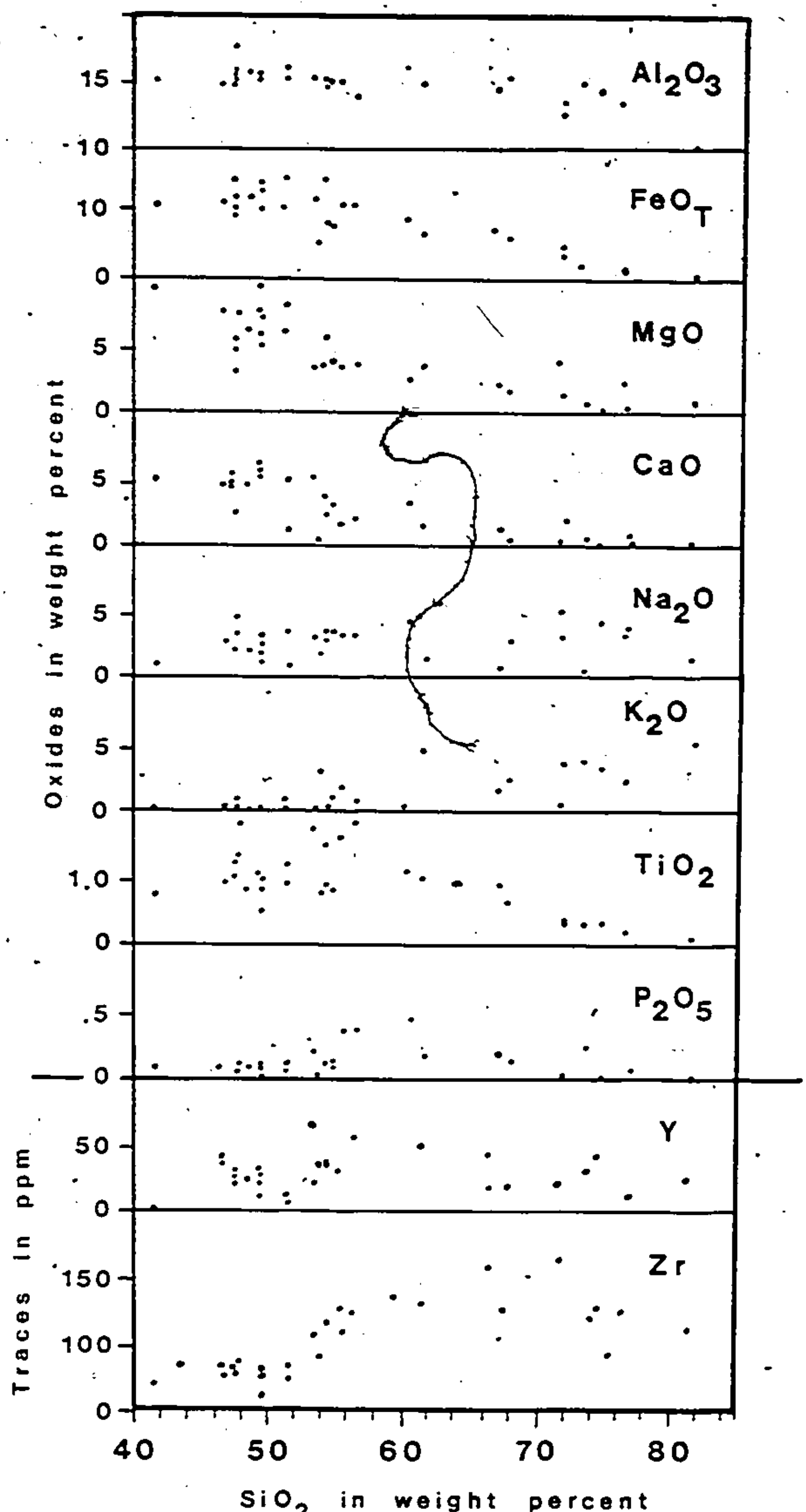


FIGURE. 18. SiO_2 variation diagram.

Intrepretation

While only a small number of samples have been analyzed the results confirm the range of compositons indicated by specific gravity measurements. The presence of a dacitic pyroclastic unit (Cycle 1) low in the volcanic pile (see Figure 6) indicates that volcanism was at least bimodal at that time. The overlying volcanics range from basalts through andesites to rhyodacites (Cycle 2). Even though the andesites appear to be localized in map areas 1 and 2 their presence in the upper 5 Km of the volcanic pile may suggest a differentiation trend.

CHAPTER 5

STRUCTURE

Introduction

Folds and cleavages formed during three major phases of deformation (D_0, D_1, and D_2) are present in the Courageous-MacKay Lake area. Weakly developed later phase structures (D_3) are scattered throughout the belt.

The east facing homocline of volcanic rocks is assumed to have been initated before the folds seen in the sedimentary rocks; this initiation is assigned to a D_{0A} subphase. The folds and foliations are shown on maps 1 to 5 and summarized on a smaller scale (Figures 20 to 23). Schematic east-west cross-sections (Figure 25) across the northern, central, and southern parts of the belt (Figure 24) show the possible structural arrangement at depth as well as general inclinations of cleavages. Figure 30 represents a structural synthesis.

The structural elements are seen to be influenced in development by rock composition and metamorphic grade. Thus sediments exhibit the bulk of the deformational features whereas volcanic and sodic granitoid rocks display early foliations only.

The distinction between structures of various phases is based on field orientations and interrelationships aided by fabric successions derived from oriented thin sections. Table 1 lists the various structural features and inferred time sequences for the phases of deformation. It is apparent that, as in the Yellowknife area (Fyson, 1981b), structures in the Courageous-MacKay Lake area repeatedly follow certain structural trends and developed over an extended time sequence (Figure 30).

Table I

Structural succession in the Courageous-MacKay Lake supracrustal rocks

Deformation phase	Structural elements	Fold description: limb length	Fold description: interlimb angle	Mineral alignment	Cleavage orientation	Fold orientation	Succession indicators	Metamorphic grade
D_{0A}	volcanic homocline							
D_{0B}	F_{0B} folds	1 km to >5 Km	tight to isoclinal			trend: northerly plunge: subvertical		
D_{1A}	S_{1A} fabric			quartz trails in biotite porphyroblasts	strike: 005 to 045 dip: steep to SE			Greenschist* facies
D_{1B}	S_{1B} cleavage			chlorite, muscovite, quartz and biotite	strike: 345 to 030 dip: E-W, steep to subvertical		generally parallel to S_0, may also be oblique	Greenschist to lower Amphibolite facies
	L_{1B} lineation				trend: N to S pitch: >85°		intersection of S_{1B} and S_0	
D_2	F_2 folds	1 cm to 1 Km	open to tight			trend: 315 to 350 plunge: moderate to subvertical	refolding of F_{0B} limbs and S_0*	
	S_2 cleavage			crenulation or segregation of biotite, chlorite and muscovite	axial planar to F_2 strike: 315 to 350 dip: NE, steep		crenulation of S_{1B}	Greenschist to upper Amphibolite facies
	L_2 lineation				pitch: >80°		intersection of S_{1B} and S_2	
D_3	S_3 cleavage			open crenulation to fractures	strike: 040 to 060 dip: E, moderate		Crenulation of S_{1B} and S_2	Greenschist facies

*except the intravolcanic sedimentary unit 4b and 4c where S_0 only is folded.

D_o Structures

D_{0A} Homocline

Pillowed rocks within the volcanic pile consistently face east for the entire length of the main belt (Figure 20). A small sodic granitoid dome to the east is surrounded by outward facing pillows (map 5).

The pillowed and other volcanic rocks throughout much of the belt range from steep to slightly overturned eastward. An exception to the steep inclination occurs in the northern part of map 1 where the volcanic layers dip as low as 30 degrees eastward. This could represent the general orientation along the belt before later steepening, or, alternatively, an area where rocks were uplifted and flattened towards the horizontal during intrusion of underlying granite plutons (cf. Fyson and Frith, 1979).

The development of the homocline (F_{0A}) in the volcanic rocks and formation of the small granitoid dome to the east may have been related to the intrusion or perhaps remobilization of the sodic granitoids. The presence of gabbro dykes, which crosscut sodic granitoid rocks (shown in map 1 and possibly map 3) and may be feeders to the volcanics, suggest that some of the sodic granitoid rocks could be syn-volcanic basement.

A marginal syncline (F_{0A}) in the sediments, trending northward between the volcanics and the eastern sodic granitoid bodies at 64°00', 111°00' (map 5) and at 64°10', 111°15' (map 3) may have been initiated as the homocline steepened and the plutons rose. A marginal syncline that curves around the sodic granitoid pluton shown in map 5 probably formed at about the same time. Mineral fabrics associated with these large scale structures have not been recognized.

F_{0B} Folds

F_{0B} folds are tight to isoclinal and near vertical structures restricted to the sedimentary rocks. Hinges are rarely seen and often inferred. The relatively constant spacing of the bedding form lines as they curve towards a hinge area in map 3 indicates a steep plunge. The plunge is interpreted as due to the folding of beds steeply inclined by D_{0A} structures. The F_{0B} folds have an wavelength of about 300 m as indicated by opposing facing directions from graded greywacke-slate beds. Maps 3 and 5 show the limb length to be much greater than the amplitude, on the order of 1 km to 5 km. Small-scale F_{0B} folds are very rare. Plate 31 shows thin quartz veins which form small tight F_{0B} folds that are refolded to form more open F_2 folds. As for F_{0A}, no cleavage foliations are associated with the F_{0B} folds.

The F_{0B} folds trend north to north-northwest along the F_{0A} homocline, except near the southeastern sodic granitoid pluton where they trend northeasterly. Later deformation has probably modified the orientations of F_{0B} folds, so that it is difficult to determine their origin.

D_1 Structures

The D_1 period of deformation can be divided into two subphases that resulted in the development of an S_{1A} foliation and an S_{1B} cleavage. Also included is an L_{1B} lineation formed by the intersection of bedding (S_0) and S_{1B}). No mesoscopic or larger folds are associated with these cleavages.

S_{1A} Inclusion trails

S_{1A} is an early fabric exhibited by "trails" (planar arrays) of quartz within biotite porphyroblasts. Fyson (1975 and 1980) notes that similar biotite porphyroblasts in the Yellowknife-Hearne Lake area (Figure 2) grew when an early foliation was already developed. The biotite porphyroblasts in this study overgrow an early fabric and preserved the direction noted here as S_{1A}, although the external foliation was rotated due to later strains. Fyson (1980) has discussed a model of porphyroblast displacement without rotation that accounts for the preservation of the S_{1A} direction.

Plate 29 shows the typical, size, distribution, and shape of biotite porphyroblasts in metasediments of upper greenschist facies grade. Biotite porphyroblasts are only located in restricted zones in maps 1 and 5 indicating metamorphic control. Plate 30 shows how the S_{1B} external cleavage is continuous with the internal quartz trails (S_{1A}). Figure 19 shows the same relationship on a smaller scale.

While a number of biotite porphyrblasts have their long axes (010 cleavage) parallel to S_2, indicating preferred mineral growth, many do not, implying that the biotite growth occurred during prograde metamorphism in a neutral strain field. The continuity between S_{1A} (internal) and S_{1B} (external) disappears when the amount of cleavage rotation is high.

The S_{1A} fabric has a north to northeasterly trend, 005 to 040, (Figure 19). In map 5 the S_{1A} fabric dips from 60 to 80 degrees southeasterly. The trend of the S_{1A} fabric has been only moderately deflected, even where later strain (D_{1B}, D_2) was high, i.e. the north side of the sodic granitoid-volcanic dome (map 5). No fold structures are recognized as associated with the S_{1A} fabric.

Plate 29. Biotite porphyroblasts partly elongated parallel to the S_2 cleavage. Faint quartz concentrations define bedding (S_0). Quartz veinlets are oblique to S_0 in an anticlockwise sense (S_{1B}) and have been crenulated by S_2. Whitish areas at the ends of the porphyroblasts are quartz-rich concentrations (quartz beards). From a pelitic greywacke of greenschist facies grade, map 5, (64°02', 111°00').

Plate 30. Biotite porphyroblast showing internal quartz trails defining the S_{1A} fabric. These trails appear to be continuous with the external S_{1B} cleavage. Note the abundance of quartz to the left of the porphyroblast indicating the development of a quartz beard. From a pelitic greywacke of greenschist facies grade, map 5 (64°04', 111°00').

Plate 29.

Plate 30.

COLOURED PICTURES

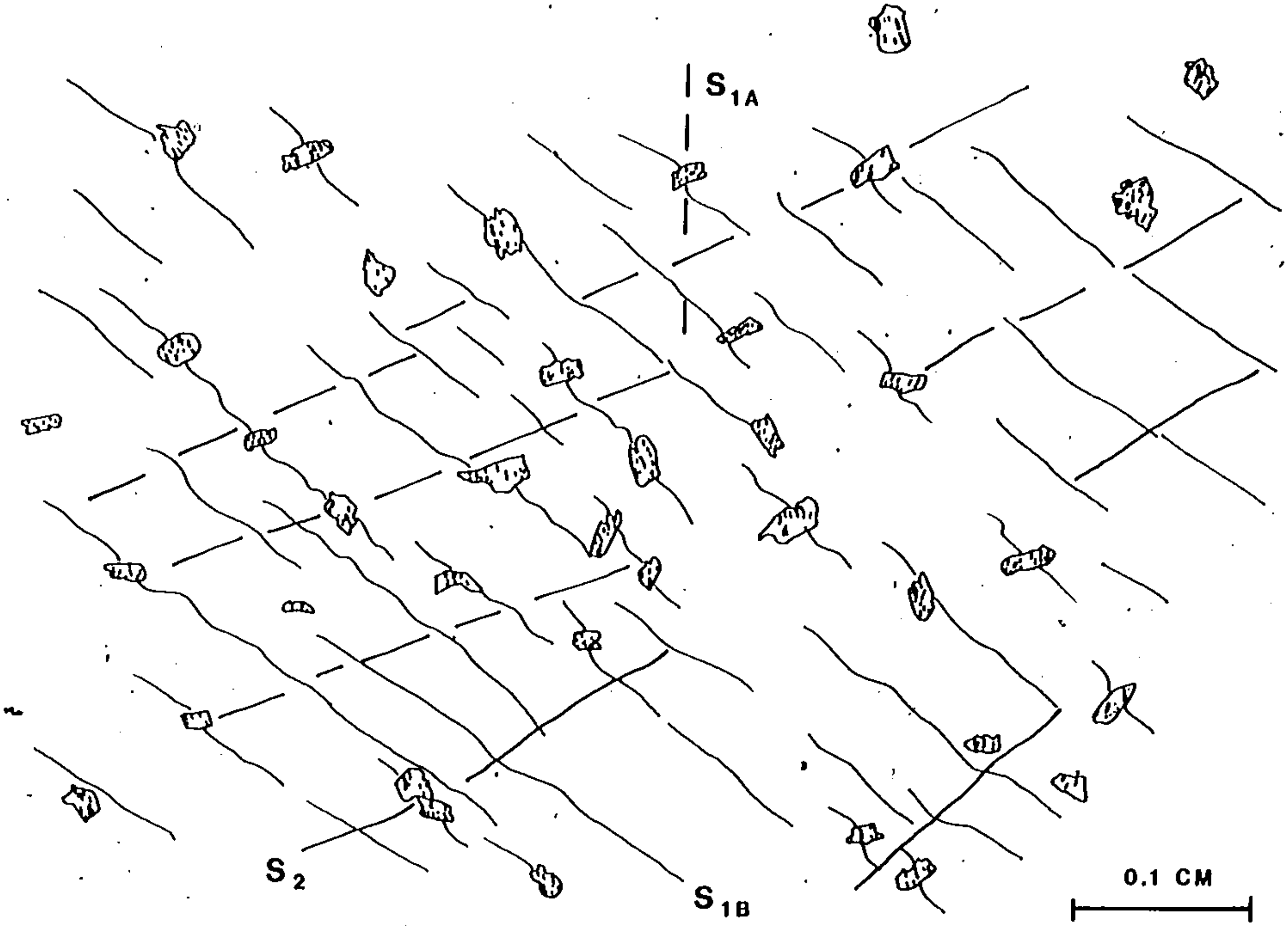


FIGURE 19. Biotite porphyroblasts with internal S_{1A} trails which are continuous with external S_{1B}. S_2 is an open crenulation of S_{1B}; Slate, map 5.

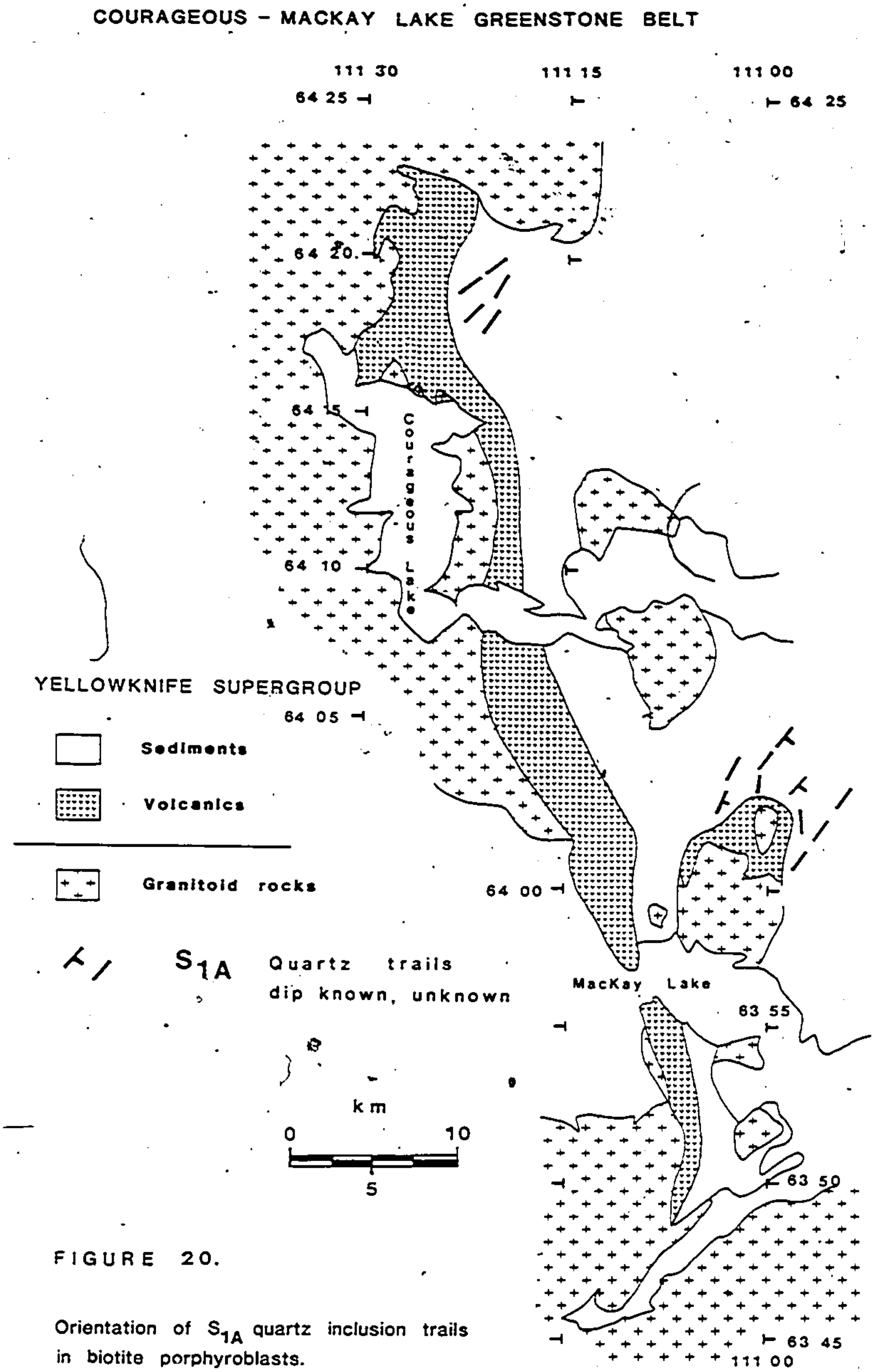


FIGURE 20.

Orientation of S_{1A} quartz inclusion trails in biotite porphyroblasts.

S_{1B} Cleavage

The S_{1B} cleavage is prominent in pelitic rocks and variably developed in rocks of greywacke and volcanic composition. Some deformed mafic ([illegible]) and felsic tuffaceous units (2c and 2d) are schistose in low grade areas where they have a high content of amphibole or mica. With increasing metamorphic grade towards the northern and southern extremities of the volcanic belt, S_{1B} becomes well developed in all units.

Within sediment in the greenschist facies S_{1B} is defined by an alignment of quartz, chlorite, muscovite, biotite, and opaques. In amphibolite facies the S_{1B} cleavage is defined by the alignment of quartz and biotite. S_{1B} is generally parallel to bedding (S_0) but may be oblique. To the east side of the sodic granitoid-volcanic dome (map 5) the S_{1B} cleavage transects the F_{0B} fold that wraps around the dome indicating that the S_{1B} cleavage formed later than the F_{0B} folds.

Figure 21 shows the form lines of S_{1B} and bedding where they are parallel, S_{1B} where oblique to S_0, the homoclinal and east-facing nature of the volcanics, and a few large F_{0B} folds. It is apparent that S_{1B} generally lies parallel to the contact of the sediments with the volcanic rocks.

The S_{1B} cleavage wraps around the sodic granitoid volcanic dome in map 5 but does not appear to follow the outline of the granite plutons in map 4 as closely. This suggests that the sodic granitoid body was present before D_1 and possibly continued to intrude during D_{1B}. On the other hand the granite plutons appear to be late or post D_{1B} as shown by mineral textures in the metamorphic aureole (see Chapter 6).

COURAGEOUS – MACKAY LAKE GREENSTONE BELT

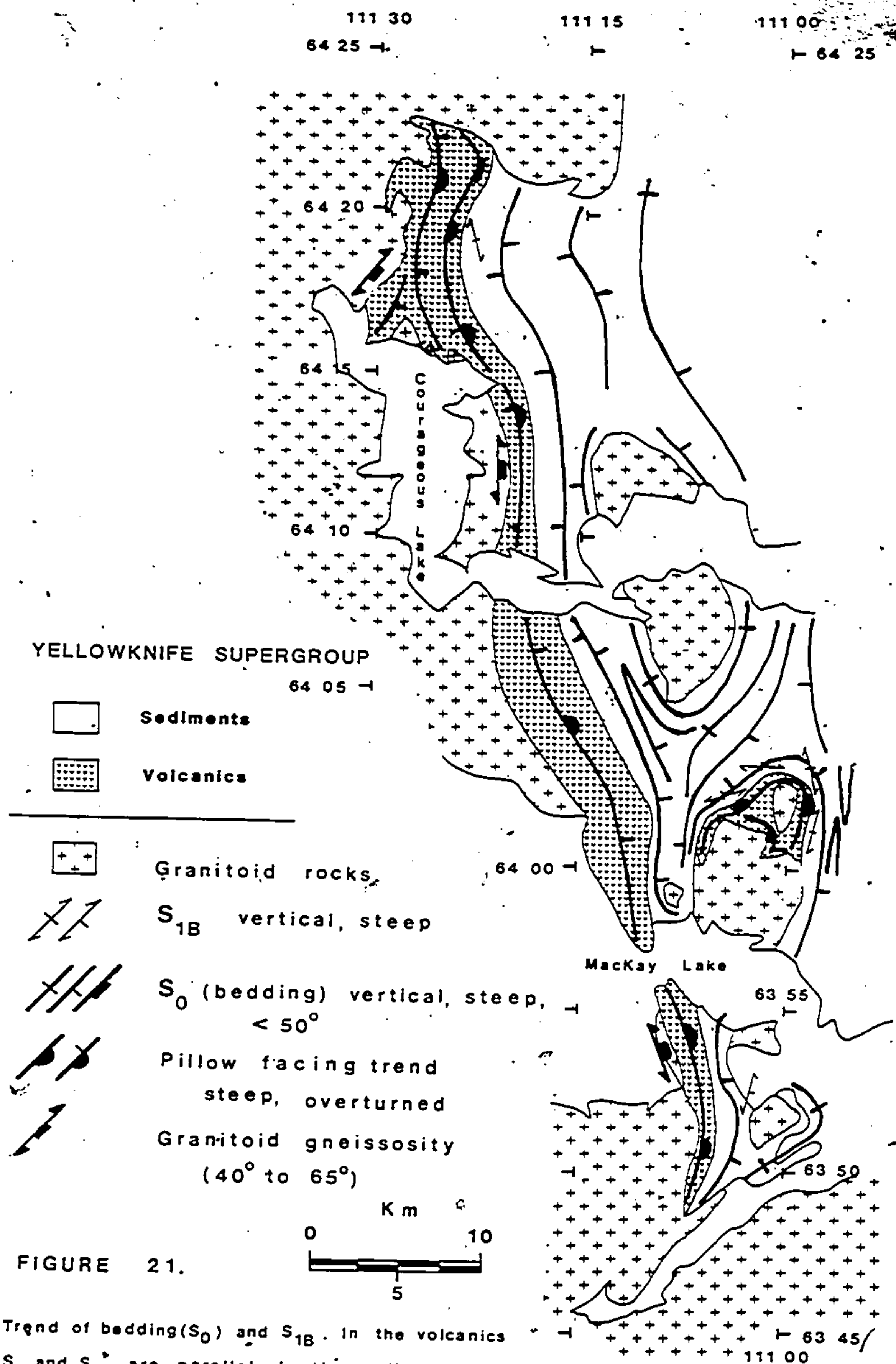


FIGURE 21.

Trend of bedding(S_0) and S_{1B}. In the volcanics S_0 and S_{1B} are parallel. In the sediments S_0 and S_{1B} are generally parallel but S_{1B} may be oblique. Folds are F_{0B} structures.

The dip of S_{1B} around these granitoid bodies is steeply outwards perhaps indicating that the intrusion of the granitoids only slightly modified the inclination of the regionally steep cleavage about steep margins or that S_{1B} was warped about steeply sided existing plutons.

Within the east-facing D_{0A} homocline of volcanic rocks (F_{0A}) cleavage and schistosity parallel to bedding is considered to be S_{1B}. The cleavage varies in dip from steep to the east in the northern portion of the belt to steeply west in the central portion and back to steeply east in the southern part of the belt (Figure 20). A similar variation in S_{1B} cleavage occurs in the sediments.

The S_{1B} cleavage is steep in the volcanic rocks except in the northern and southern extremities of the belt (maps 1 and 4). The low dip of S_{1B} in the northeastern part of map may reflect low, initial dips, or later flattening during granitoid intrusion as discussed in the D_{0A} section. The moderate dip of S_{1B} in the volcanic rocks shown in map 4 appears to reflect the moderate dip, 40 to 55 degrees, of the granitoid gneissosity along the western margin of the volcanics.

The gneissosity in the sodic granitoids is defined by a biotite alignment and domains of felsic and mafic minerals which parallel the S_{1B} cleavage in nearby volcanics. The granites (5a) are rarely foliated, exhibit cataclastic textures near the volcanic contact, and often crosscut the S_{1B} cleavage in the volcanics (map 1). This incidates that the granites are post D_{1B}. The cataclastic features are probably due to later faulting.

L_{1B} Lineation

An L_{1B} lineation, formed by the intersection of S_{1B} and bedding (S_0), pitches at a high angle across the dip of S_0. L_{1B} is only readily recognized in rocks of greenschist and lower amphibolite facies (maps 1, 2, and 5) where the sediments cleave easily.

D_2 Structures

S_2 cleavage and associated minor F_2 folds are most prominent in amphibolite facies terrains but commonly not readily prominent in lower grade rocks. Thus in maps 2 and 5 and part of map 1 much of the S_2 directional data comes from oriented thin sections, whereas in higher grade rocks (map 4 and the northern part of map 1) S_2 is readily visible, particularly where followed by quartz veins (Plate 32). L_2, an intersection lineation, is rare.

F_2 Folds

The largest F_2 folds in bedding and S_{1B}, with limbs 10 m to greater than 100 m long, generally have a "Z" asymmetry in maps 1, 3, and 4 where S_2 lies counter-clockwise to the enveloping surface. Smaller F_2 folds, with 5 cm to 100 cm long limbs (Plate 31) are present in all areas but are predominant in amphibolite grade rocks of maps 1 and 4 where quartz veins are more common.

The F_2 folds range from tight to open, with open folds generally predominating. The folds are moderately to steeply plunging and trend northwest to north-northwest. Plate 33 shows the S_{1B} fabric to be openly folded about an axial S_2 cleavage.

Plate 31. Isoclinal F_{0B} quartz veins in a cordierite-andalusite metagreywacke. F_{0B} has been refolded forming open F_2 folds. White spots are Al silicate porphyroblasts in a biotite schist; black areas on the top and bottom edges are lichen. Map 4 (63°52', 111°03').

Plate 32. S_2 cleavage defined by quartz filled veinlets which crosscut S_0 and S_{1B} in an anticlockwise sense. Folder is 30 cm long. A cordierite-andalusite, biotite, metagreywacke from map 4, (63°54', 111°04').

Plate 31.

Plate 32.

An elongate intra-volcanic sedimentary unit (4b and 4c) in the southern part of map 1 (64°16', 111°24') has been folded during D_2 deformation forming the largest F_2 folds observed. The limbs are up to 300 m long and the folds are very open. The axial trace of these F_2 folds is more northerly than in the sediments above the volcanics. As this more northerly trend can not be attributed to diffraction the signifigance is not known.

S_2 Cleavage

F_2 folds, in general, have an axial planar S_2 cleavage which ranges from an open crenulation of S_{1B} (Plate 34) to a segregation cleavage, in greenschist facies rocks, and to a biotite schistosity which has virtually eliminated S_{1B} in rocks of the middle to upper amphibolite facies. Close to the granite plutons in map 4 a biotite-sillimanite S_2 schistosity has been crenulated by S_3. S_2 is found only rarely within mafic volcanic rocks (map 1; 64°21', 111°24' and map 4; 63°50', 111°05') of upper amphibolite grade. Felsic volcanic rocks of the same grade may exhibit a weak S_2 cleavage (map 4; 63°52', 111°06').

Where S_2 is a segregation cleavage it is a pronounced colour banding associated with fine crenulations in pelitic layers, generally seen in thin section only (Plate 35). The colour banding is due to the alternation of quartz-rich zones with muscovite, chlorite, and biotite-rich zones along the hinges and limbs of the crenulations (Plate 36). Plate 37 shows the virtual obliteration of S_{1B} by S_2 in an upper amphibolite grade schist.

Figure 21 shows the S_2 cleavage orientations for the belt. The cleavage strikes north to northwesterly and dips steeply, varying from easterly to westerly inclinations along the belt in the same manner as S_{1B} (Figure 21). A slight curve

Plate 33. Small scale, open F_2 fold. Note axial planar S_2 cleavage defined by aligned biotite. S_0 and parallel S_{1B} are followed by biotite concentrations which are folded. Biotite, cordierite, andalusite, and sillimanite schist (metagreywacke) from map 4 (63°49', 111°04').

Plate 34. Broad, openly spaced S_2 crenulation of S_0 and S_{1B} (parallel). Note grading from bottom to top. Dark minerals are chlorite and biotite. Map 1, (64°17', 111°24'). Pelitic bed, greenschist facies grade (map 1; 64°17', 111°24').

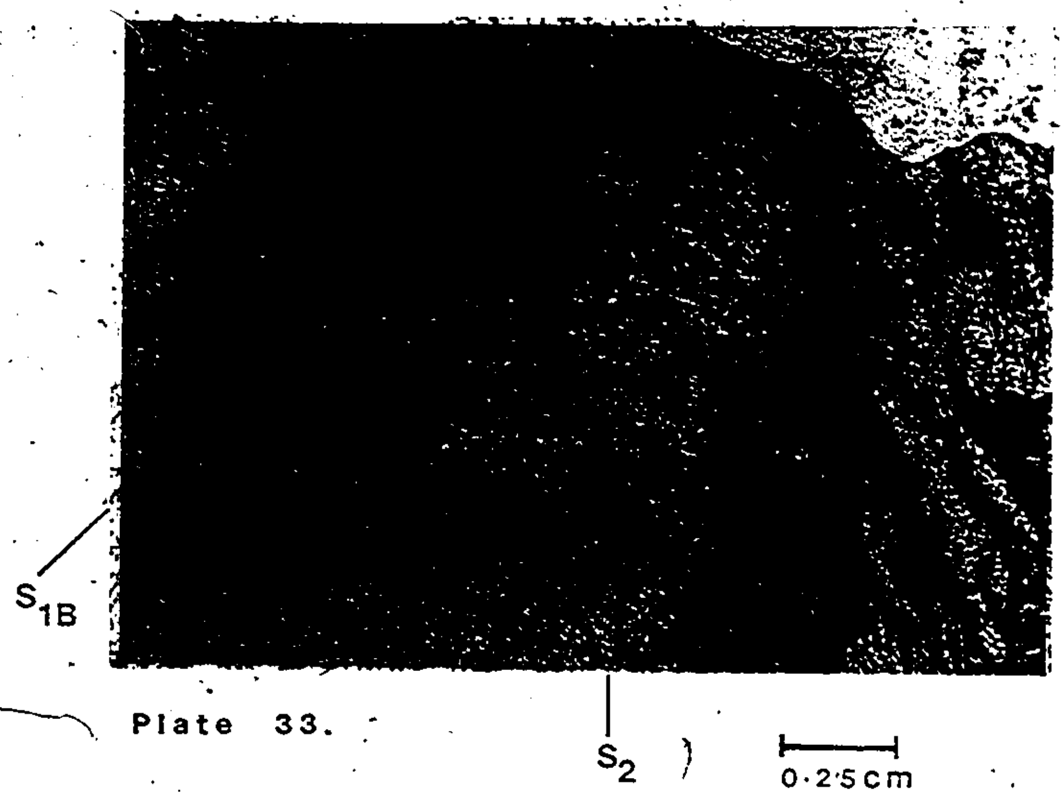


Plate 33.

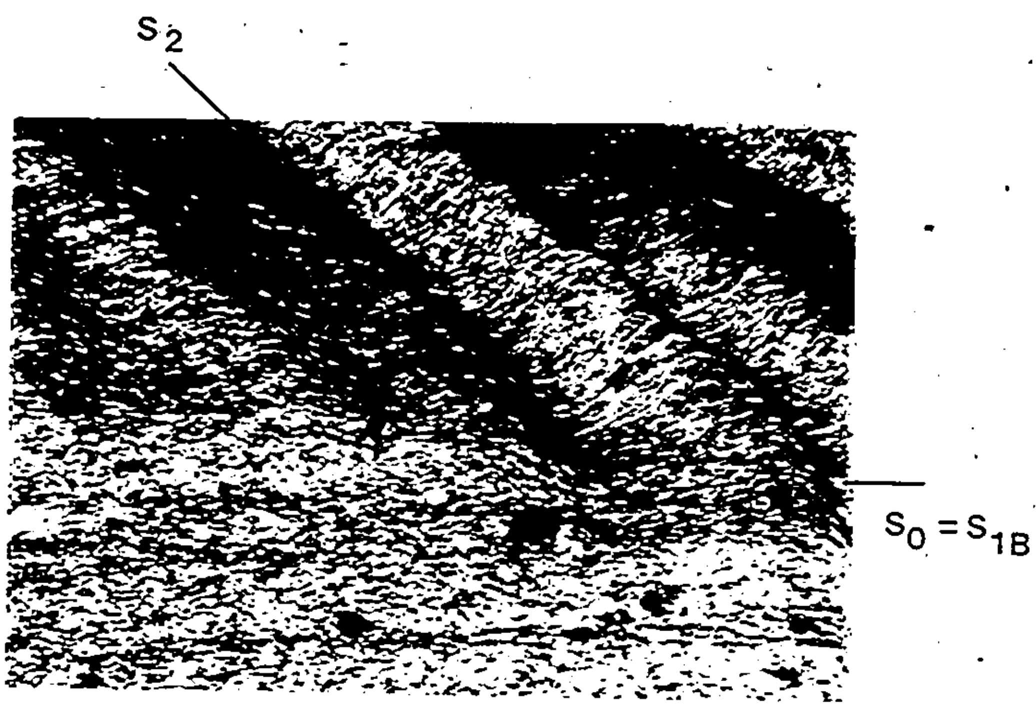


Plate 34.

COLOURED PICTURES

Plate 35. S_2 segregation and crenulation cleavage in a pelitic bed of a graded greywacke-slate sequence. Note the diffraction and dying out of S_2 into the coarse-grained greywacke. From map 2 (64°14', 111°20').

Plate 36. Detail of an S_2 segregation and crenulation cleavage. Light coloured areas are quartz-rich while dark areas are chlorite or biotite-rich. From a pelitic bed, map 1 (64°17', 111°22').

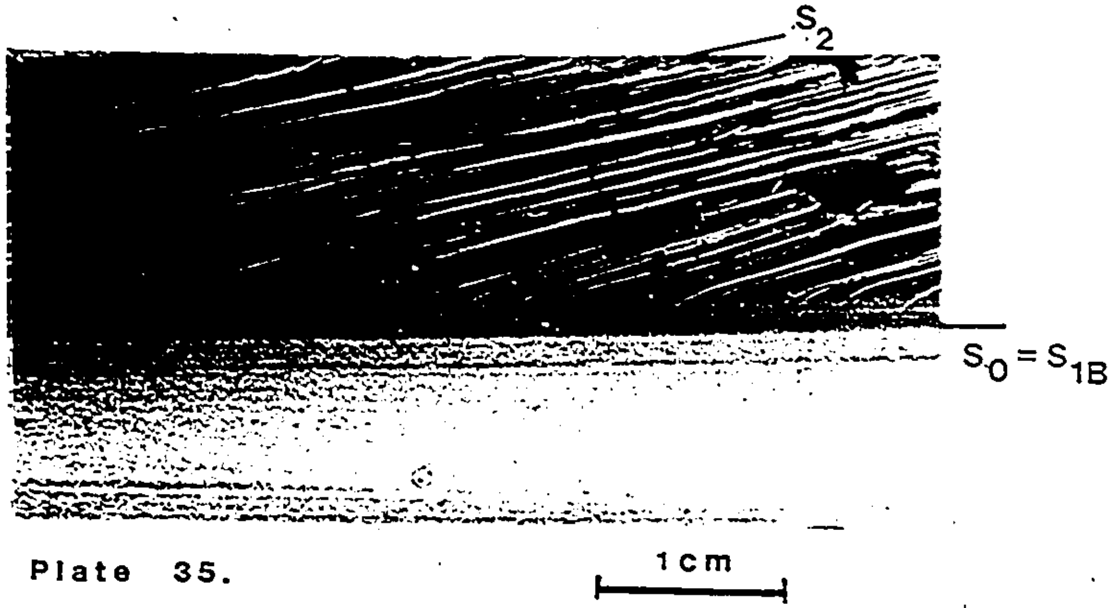


Plate 35.

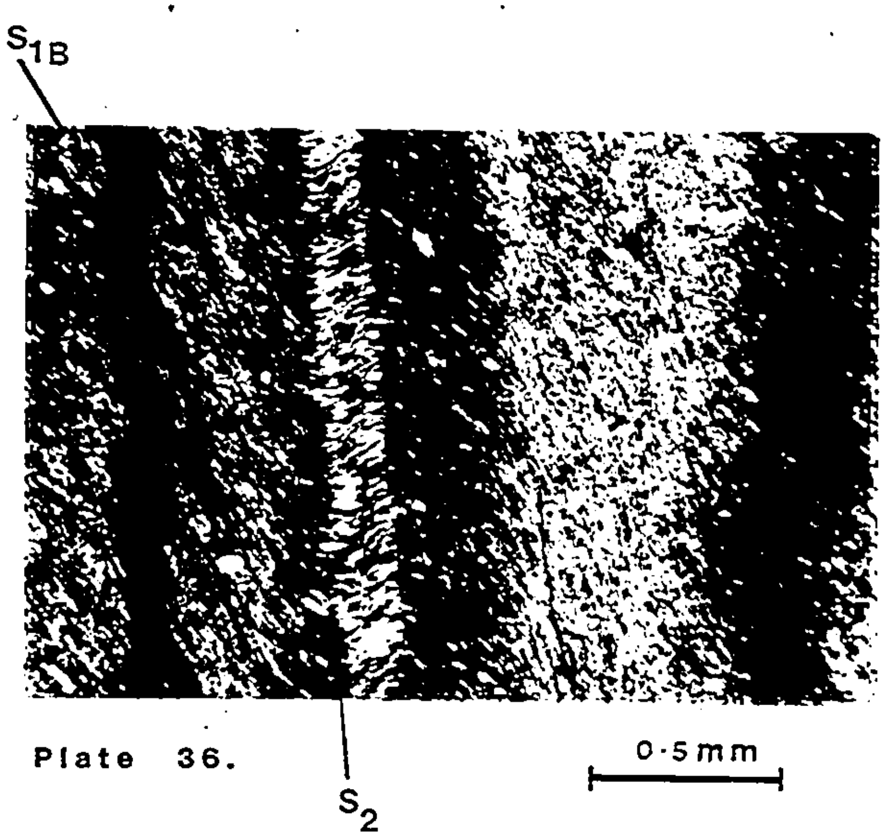


Plate 36.

COLOURED PICTURES

COURAGEOUS - MACKAY LAKE GREENSTONE BELT

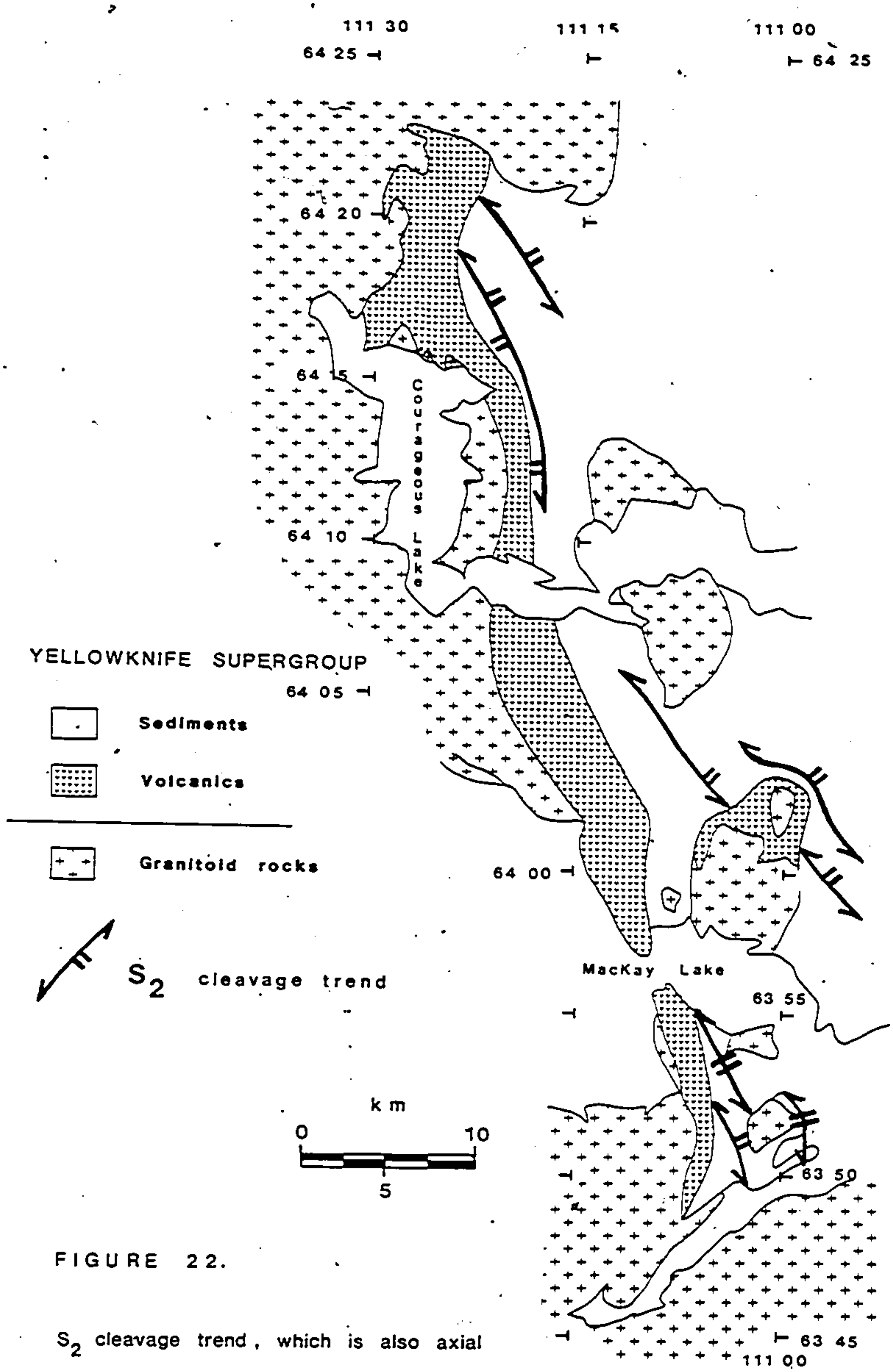


FIGURE 22.

S_2 cleavage trend, which is also axial planar to F_2 folds not shown.

in the strike of S_2 near the sodic granitoid-volcanic dome (map 5) is attributed to later (D_3) tightening.

L_2 Lineation

L_2, an intersection lineation, occurs on bedding surfaces crossed by the S_2 cleavage. L_2, is however, rarely observed due to the growth of metamorphic minerals which decrease the tendency to cleave.

D_3 Structures

No folds, other than small crenulations, were developed during D_3 deformation. S_3 is an openly spaced, discontinuous crenulation or fracture of S_{1B} and S_2 (Plate 38). This cleavage (Figure 22) strikes northeasterly, and where measured (map 1) dips to the southeast at 60 to 85 degrees. In greenschist facies terrains (map 1) S_3 is accompanied or followed by the growth of muscovite laths. In the southern part of map 4 the S_3 cleavage crenulates a biotite-sillimanite S_2 fabric.

Moore's structural trend map (Figure 1, 1956) shows two cleavages in the sediments; one northeasterly, and one northwesterly. At 64°15', 111°15' (his Figure) the northeasterly cleavage is shown to bend into the northwesterly. This has not been seen in this study and the northeasterly cleavage is here denoted as S_3 and the northwesterly cleavage S_2.

Faults

East-West to northeast trending faults are abundant in the volcanic rocks of maps 1 and 2. As marker horizons are rare the offsets are generally unknown

Plate 37. Well developed S_2 cleavage defined by aligned biotite (dark). S_0 is defined by biotite-rich bands at a high angle to S_2. S_{1B} has been obliterated. From a garnet, biotite, and cordierite schist map 1, (64°20', 111°24').

Plate 38. Graded greywacke beds. S_3 is an open, discontinuous crenulation developed in pelitic layers. S_3 is not apparent in coarse-grained layers. S_{1B} and S_2 are crenulated (S_2 is not visible at this scale). Greenschist facies map 1, (64°17', 111°24').

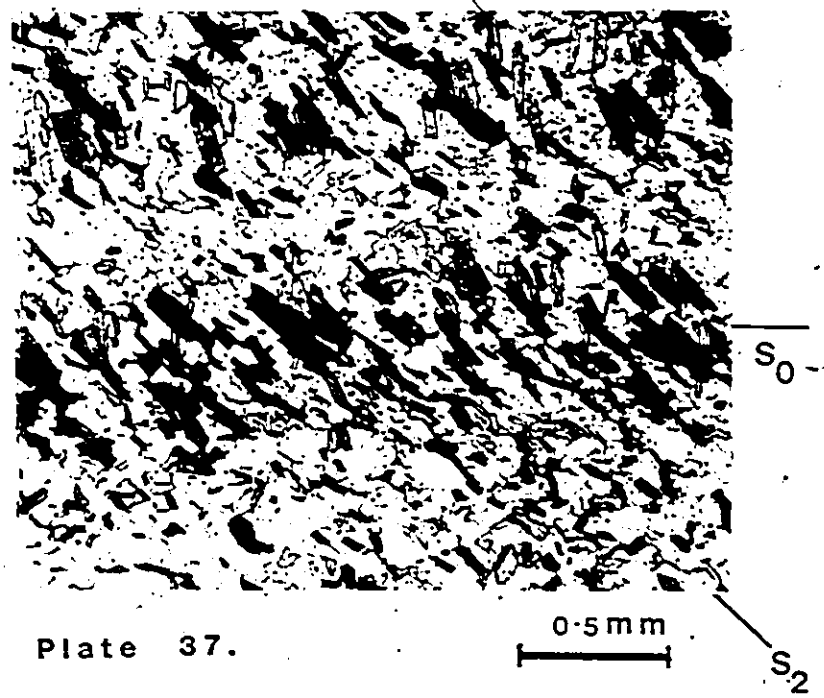


Plate 37.

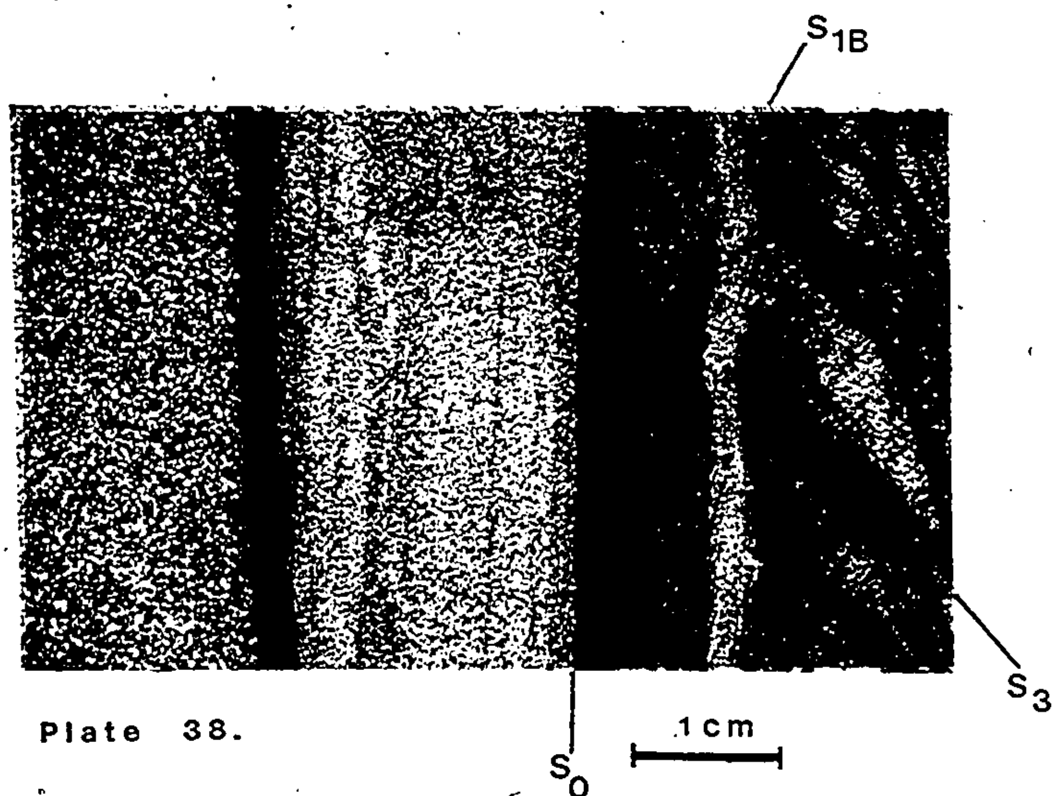


Plate 38.

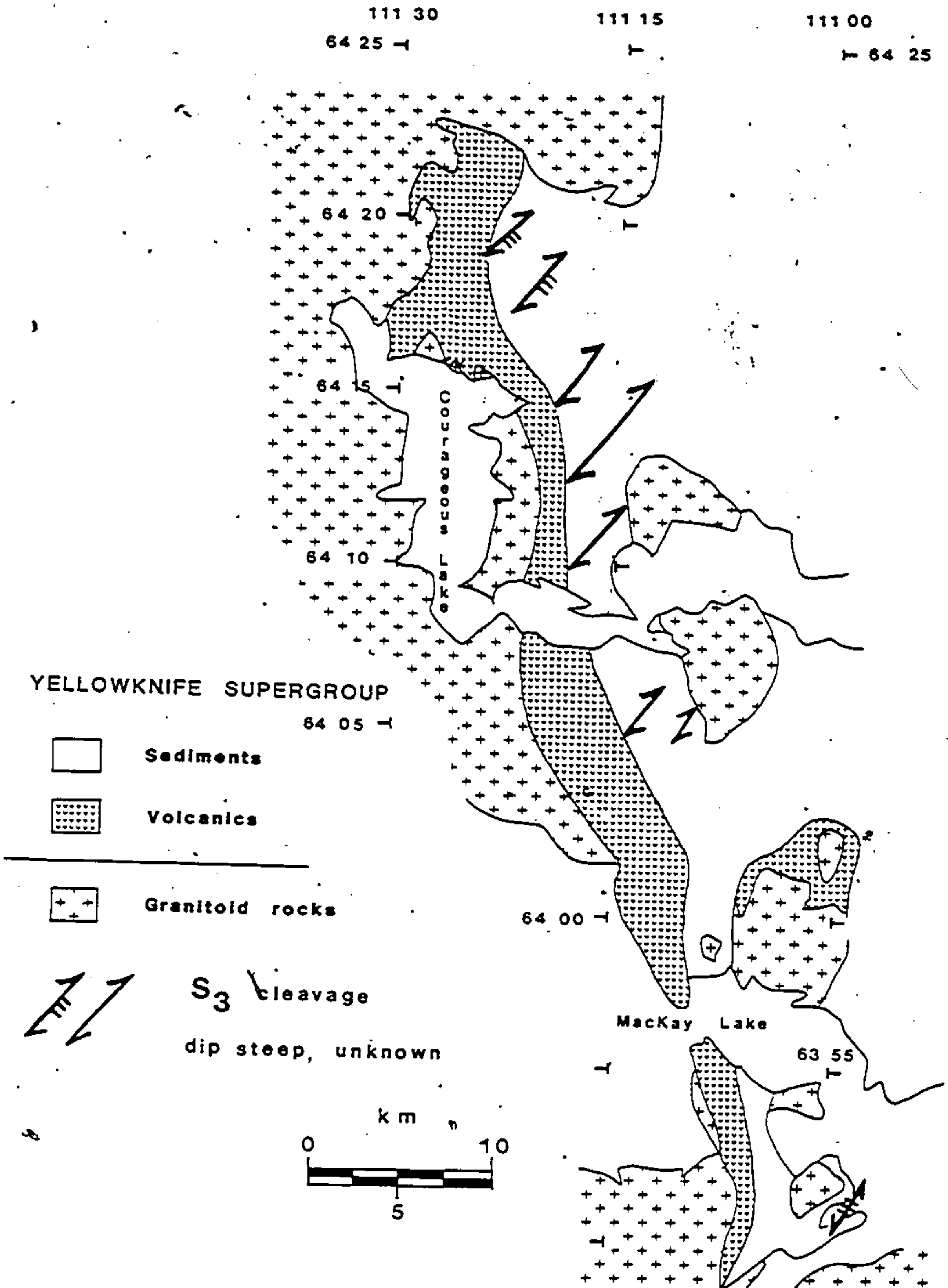


FIGURE 23.

Trend of S_3 cleavage. Data with unknown dip from Moore (1956).

or inferred. However, the feldspar phyric pillowed basalt (1f) in map 1 is offset by about 200 m in a left lateral sense. These east-west faults also offset the diabase dykes. Moore (1956) notes that the north-south faults (map 3) offset east-west diabase dykes (late Archean?) and are hence Proterozoic.

Strain

Macroscopic strain markers are found only in the volcanic rocks. Pillow cross-sections and volcaniclastic fragments range from apparently undeformed to highly deformed (see Plates 8 and 39). While it is appreciated that pillow cross-sections may vary according to their chemical composition, size and the angle of section they still may be used to indicate a general strain ellipsoid. Highly deformed pillow basalts (1h, Plate 8) have X:Y:Z ratios of 20:1:20 or more indicating a flattening field. Similarily the felsic clastic fragments in Plate 39 exhibit X:Y:Z ratios of 8 to 14:1:10. These fragments were probably never round, more likely tabular, and hence give only a general sense of strain (flattening) and not the magnitude.

The upper 1 Km of the volcanic pile of mafic and felsic rocks shows evidence of moderate to extensive shortening. The remainder of the pile exhibits little evidence of flattening except in zones of shearing or pronounced cleavage development. The thin felsic units (2c and 2d) generally exhibit a strong S_{1B} foliation indicating perhaps that the bulk of the shortening within the pile was absorbed by volcaniclastic units.

Not known is how much strain was due to D_1 deformation and how much was associated with possible tightening of the folds during D_2. The amount of shortening associated with D_2 is not clear but Wood (p. 387, 1974) suggests that a minimum of 50 percent shortening is required to develop a slaty cleavage in pelitic rocks.

Deformation and emplacement of the plutons

The gabbro dykes in the sodic granitoid rocks (maps 1 and 3) suggests that the sodic granitoids, along the western volcanic margin, may be in part basement to the volcanics. However, the sodic granitoid dome to the east of the volcanic belt (map 5) indicates post volcanic remobilizaiton or intrusion. The sodic granitoid rocks along the western volcanic margin often contain a mineral alignment parallel to the S_{1B} fabric in the volcanics. This suggests that these rocks were near present levels relative to the volcanics before D_{1B} deformation.

Granite bodies along the western margin of the volcanics intrude the volcanic and sodic granitoid rocks, and crosscut the S_{1B} fabric in the volcanics indicating that emplacement was post D_{1B}.

S_2 cleavage warps about cordierite-andalusite porphyroblasts apparently within thermal aureoles of the granites (Plate 40). Therefore the granite plutons, though at least partly post D_{1B}, seem to have been in the vicinity before D_2 deformation.

The linear, north-northwest array of granitoid plutons east of the volcanics parallels the general alignment of the belt (Figure 23). This alignment could reflect fault controlled emplacement of the plutons.

Summary and Conclusions

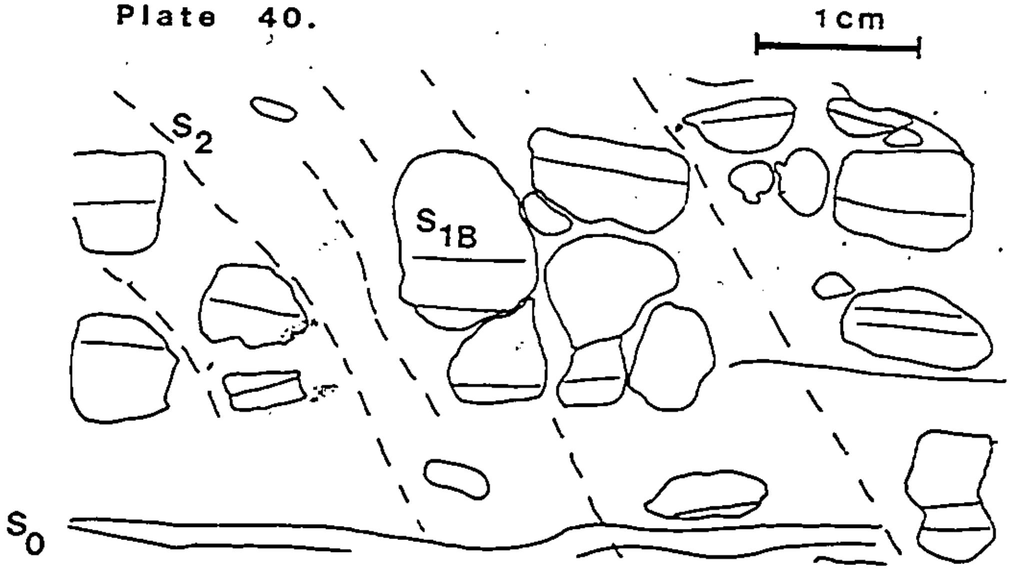
It has been shown that the deformational history of rocks in the Courageous-MacKay Lake area began (D_{0A}) with the development of a major

Plate 39. Flattened felsic pyroclastic rock (2b). A horizontal surface, X:Y=8 to 14:1. Vertical surface not shown X = Z. From map 1, (64°20', 111°26').

Plate 40. Cordierite porphyroblasts which have overgrown the S_{1B} cleavage fabric. S_{1B} is defined by the thin white streaks in the porphyroblasts. S_2 cross S_{1B} at a high angle and warps around the prophyroblasts. This relationship suggests that the growth of the porphyroblasts was post D_1 and pre D_2. Cordierite and biotite schist (metagreywacke) from map 1, (64°20', 111°24').

Plate 39.

Plate 40.



COURAGEOUS - MACKAY LAKE GREENSTONE BELT

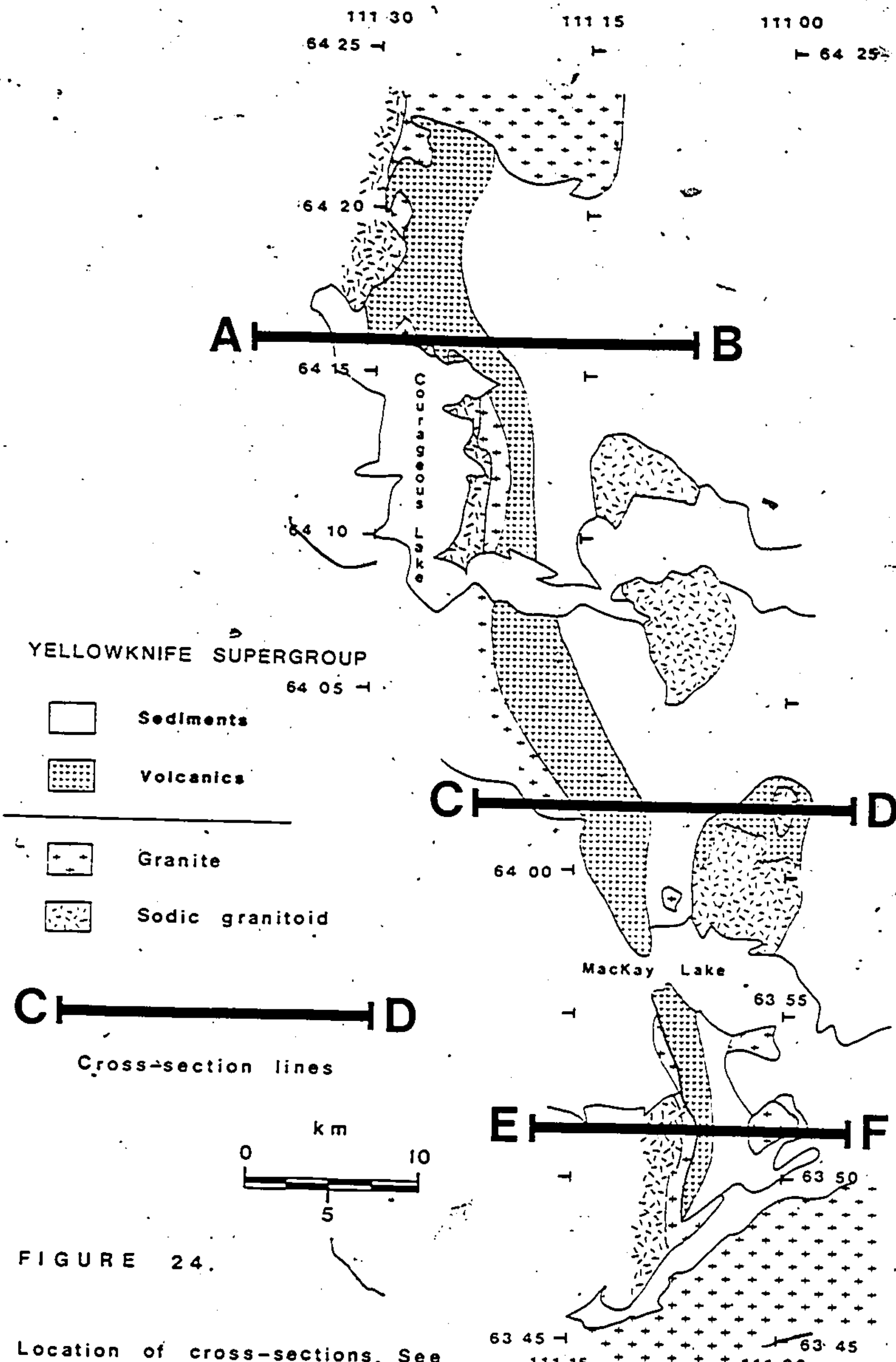


FIGURE 24.

Location of cross-sections. See figure 25.

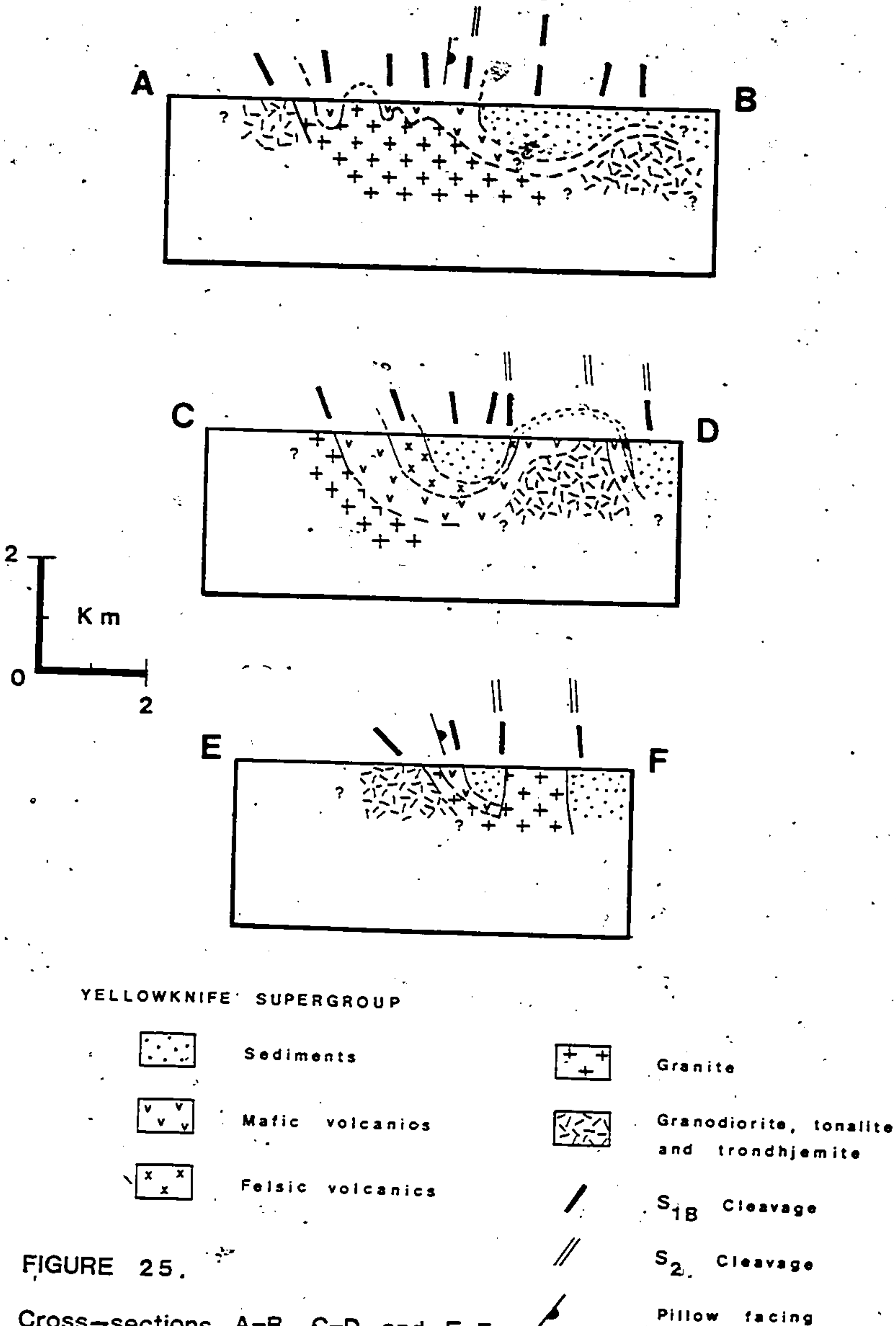


FIGURE 25.

Cross-sections A-B, C-D and E-F. See Figure 24 for locations.

east facing homocline in the volcanics (Figure 30). A marginal syncline (F_{0A}) formed during the intrusion or perhaps remobilizaiton of sodic granitoid bodies east of the volcanics and a syncline may have formed between these bodies.

Later movements (D_{0B}) formed large scale F_{0B} folds. These dominantly trend north-northwest along the belt but the initial orientation before later deformation is not clear. No cleavage foliations are associated with D_0 structures.

An northeasterly striking fabric, S_{1A}, preserved soley in biotite porphyroblasts, may indicate northwest-southeast compression (D_{1A}) oblique to the early structures. This was followed by D_{1B} deformation during which the pervasive, north-northwest striking, steep foliation (S_{1B}) was developed generally parallel to bedding in both the volcanics and sediments, but noteably oblique where F_{0B} structures curve around plutons. Compression approximately east-west across the belt is suggested. D_{1B} probably tightened and steepened existing F_{0B} folds.

Structures of a later D_2 deformation appear confined to the sedimentary rocks. An S_2 crenulation and segregation cleavage strikes northwesterly and is axial planar to minor folds, particualrly in higher grade rocks, where the earlier deformed foliation, S_{1B}, is a well developed schistosity. The D_2 structures suggest an northeast-southwest compression oblique to the belt.

A late stage, discontinuous crenulation cleavage, S_3, is scattered throughout much of the sedimentary rocks. S_3 strikes northwest in a similar direction to the earliest foliation S_{1A}. A return to northwest-southeast compression is envisaged.

The structures described decrease in size from large F_{0B} folds, through small F_2 folds, to S_3 crenulations. Local strain as shown by the foliations and minor folds was weak during D_0, moderate during D_1, the highest during D_2, and weak during D_3.

Sodic granitoid plutons may range from syn-volcanic to pre or syn D_{1B}. The granite plutons range from post D_{1B} to pre D_2.

CHAPTER 6

METAMORPHISM

Introduction

The Courageous-MacKay Lake area supracrustal rocks have undergone a three stage metamorphic history similar to that reported by Ramsay and Kamineni (1977) for the Yellowknife area. This includes: 1) regional metamorphism of greenschist facies grade; 2) thermal metamorphic aureoles of low to high amphibolite facies grade associated with post D_{1B} to pre or syn D_2 granitic intrusions; and 3) late, hydrothermal retrogression. All stages took place under low to moderate confining pressures.

The metasediments exhibit the greatest variety of metamorphic assemblages. Assemblages in the volcanic rocks do not allow cordierite and other isograds defined in the metasediments to be continued into the volcanics. Also, metamorphic reactions in the mafic volcanics appear to have been continuous; for example the colour of hornblende and the anorthite content of plagioclase change gradationally along the belt. Hence it is difficult to correlate the metamorphic reactions in pelitic rocks with those in the volcanic pile. Nevertheless, metamorphic assemblages from pelitic and felsic volcanic rocks within the volcanic sequence have been useful. The scarcity of those rocks within the volcanic pile in maps 4 and 5 make correlation with metamorphic isograds in the metasediments tenuous at best.

Prograde metamorphism

Pelitic rocks

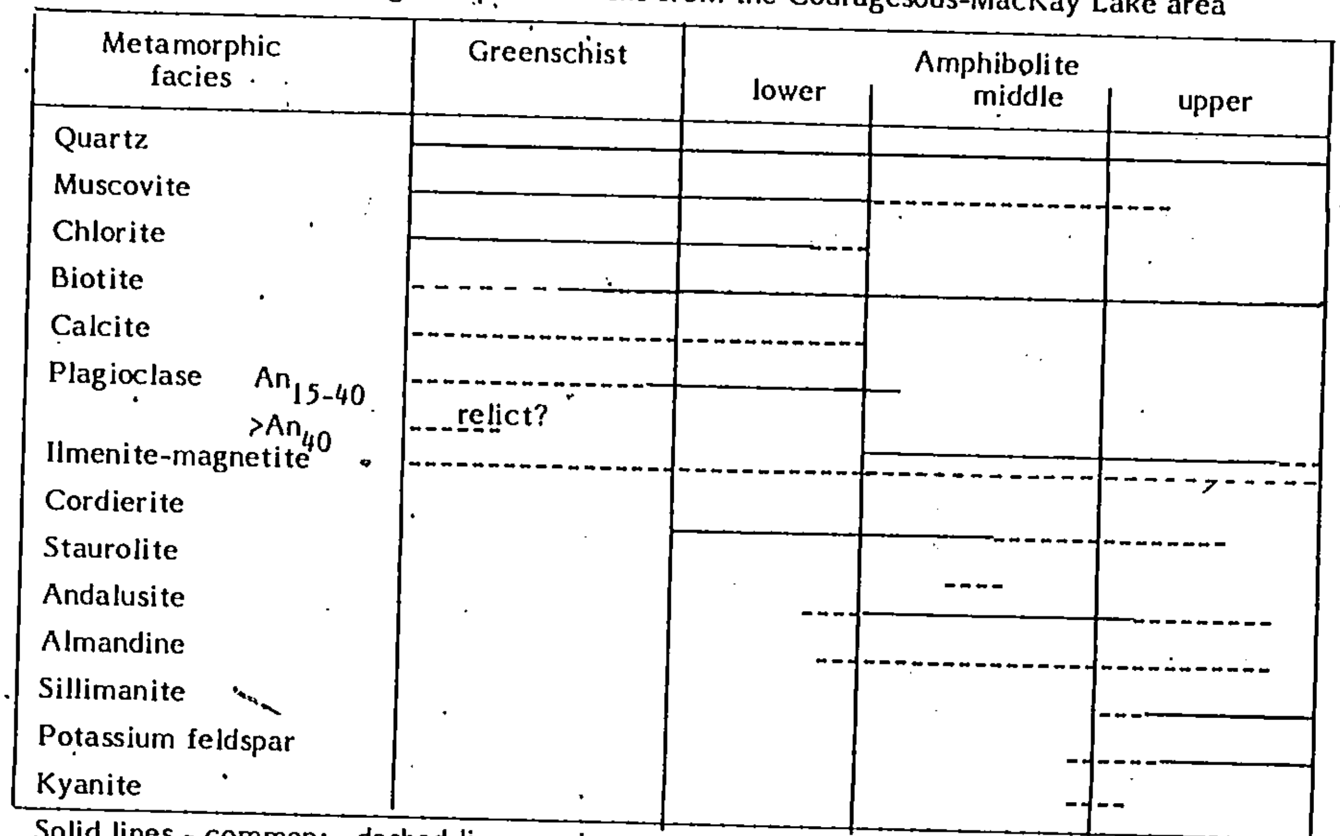
All the greenschist to upper amphibolite facies mineral assemblages in pelitic rocks contain quartz, plagioclase, biotite, and minor ilmenite or magnetite. Fine-grained tourmaline is very common in high-grade pelitic rocks.

The greenschist facies assemblages contain muscovite, chlorite, and biotite (see Table 2). The amphibolite facies is divided into lower, middle, and upper subfacies (Bourne, 1978). The lower amphibolite facies is characterized by the cordierite, biotite, chlorite and muscovite assemblage. The middle amphibolite facies contains cordierite, andalusite, (staurolite), biotite, and almandine with minor chlorite and muscovite. The main distinction in the mineral assemblage from the lower amphibolite facies is the presence of andalusite and the minor amount of muscovite. Additionally the plagioclase changes composition from $An_{<40}$ to $An_{>40}$ in the middle (and upper) amphibolite facies. The upper amphibolite facies is marked by the presence of sillimanite in addition to andalusite, cordierite, biotite, minor potassium fledspar, and rare almandine. In one location (map 4) kyanite but no garnet was observed. These assemblages indicate low pressure conditions similar to Miyashiro's (1973) Abukauma Plateau area. However, Thompson (1978, and pers. comm. 1981) suggests slightly higher pressure (Pyreneean) conditions.

Cordierite-andalusite porphroblast schists are the most common amphibolite facies metasediments in the Courageous-MacKay Lake area. Their distribution about the northern and southern ends of the mapped area, maps 1 and 4, indicates an association with granite intrusions.

Table 2

Metamorphic assemblages in pelitic rocks from the Couragesous-MacKay Lake area



Solid lines - common; dashed lines - minor

Staurolite is very rare and is enclosed by andalusite or cordierite (see Plate 41). The paucity of staurolite in the Yellowknife metasediments has been attributed to the low iron content of the sediments (Thompson, 1978). However, the rimming of staurolite by cordierite or andalusite suggests that it is unstable in prograde metamorphism (Ramsay and Kamineni, 1977) and may be consumed during the production of andalusite.

Andalusite appears in the middle amphibolite facies and becomes more abundant at the expense of cordierite as the grade increases. Frequently andalusite occurs with fibrolitic sillimanite and biotite.

Plate 42 shows kyanite with sillimanite and biotite. Cordierite is also present but not illustrated. This specimen came from the southernmost part of map 4, within 300 m of the granite contact, and suggests a local increase in pressure or a decrease in temperature (see Thompson, 1978, Fig. 11a).

The isograds in Figure 26 reflect the appearance or disappearance of a metamorphic mineral or assemblage (Thompson, 1978). No biotite-in isograde is shown because all the pelitic rocks throughout the Courageous-MacKay Lake area exhibit biotite. However, coarser-grained greywacke beds in the greenschist facies between latitudes 64°15' and 64°10' do not contain biotite except within 1 mm to 3 mm of ilmenite grains. This suggests compositional control of the development of biotite as noted by Ramsay (1973a and b). Kretz (1968) has suggested the reaction:

chlorite (1) + muscovite = biotite + chlorite (2)
+ quartz + $4H_2O$

where chlorite (2) differs from chlorite (1). Within the greenschist facies

Plate 41. Staurolite (ST) surrounded by andalusite (A) in a cordierite, andalusite, and biotite schist. B-biotite, Q-quartz. From an intervolcanic felsic (2d?) horizon in map 4 (63° 52', 111° 10').

Plate 42. Kyanite (K) and sillimanite (S) in a sillimanite, cordierite, and biotite schist. M-muscovite, B-biotite. Note retrograde muscovite along the Kyanite margins indicating unstable conditions. From a metasediment in map 4 (63°49', 111°09').

Plate 41.

0·5mm

Plate 42.

0·5 mm

assemblage the associated plagioclase is oligoclase with some fragments exhibiting primary? andesine compositions.

The lower boundary of the amphibolite facies is defined by the cordierite-in reaction. Just preceding this isograd is a thin zone of biotite porphyroblasts, notably those which preserve the S_{1A} fabric trails in maps 1 and 5. The cordierite may have been formed by the following reaction:

chlorite + biotite (1) + muscovite + quartz + albite + ilmenite =

cordierite + biotite (2) + H_2O (Ramsay, 1974).

Ramsay (ibid) notes that some biotite is consumed and some may be produced during this reaction.

The cordierite prophyroblasts range from 0.2 cm to 3.0 cm across and have a subrounded form in both horizontal and vertical sections (see Plates 43 and 44). Plates 40 and 44 show the cordierite prophyroblasts to overgrow an S_{1B} foliation defined by aligned quartz and biotite. The deflection of S_{1B} around the porphyroblasts to form augen structures is well shown in plates 43 and 44. The overgrowth and deflection of S_{1B} indicate that the cordierite crystals grew after S_{1B} had developed but before the end of D_{1B} deformation; that is the cordierite growth was syn D_{1B}. However, plate 40 shows the cordierite to overgrow S_{1B}, which is undeflected, and to deflect an S_2 cleavage. Evidently the growth of cordierite ranges from syn to post D_{1B} to pre D_2.

Almandine occurs above the cordierite-in reaction (Table 2) but the distribution is discontinuous (see maps 1 and 5). The garnets are small, fresh, and continue up-grade into andalusite and sillimanite bearing rocks. This patchy distribution may indicate a compostional control for garnet growth, for example high Fe and Mn concentrations as suggested by Thompson (1978).

Plate 43. Rounded cordierite porphyroblasts in a lower amphibolite facies metagreywacke. Biotite fabric which warps around the prophyroblasts is parallel to the S_{1B} cleavage. S_2 is not visible at this scale. A horizontal section from map 1 (64°18', 111°28').

Plate 44. Vertical section showing rounded shape of cordierite porphyroblast. Note the fabric within the porphyroblast (S_{1B}) which is parallel to the external biotite fabric which warps around the prophryoblast. S_2 is an open crenulation not readily apparent. From a lower amphibolite facies metagreywacke in map 1 (64°20', 111°24').

Plate 43.

Plate 44.

Cordierite and andalusite porphyroblasts with biotite and minor muscovite appears to be a middle amphibolite facies assemblage (Table 2) possibly forming from the reaction:

chlorite + muscovite + quartz = andalusite + cordierite + biotite + H_2O (Thompson, 1978, R 5).

Above this grade cordierite decreases, andalusite increases and fibrolitic sillimanite appears. This suggests the reaction:

cordierite + muscovite = biotite + andalusite/sillimanite of (Thompson, 1978).

Minor potassium feldspar (microcline) is sporadically distributed within biotite, andalusite, sillimanite ± cordierite bearing assemblages. The reaction to produce potassium feldspar is not understood. Muscovite appears to have been completely consumed during the production of cordierite and andalusite preventing the reaction:

quartz + muscovite = potassium feldspar + andalusite/sillimanite.

The metamorphic assemblages in map 4 indicate a relatively broad amphibolite zone of biotite, cordierite, andalusite and sillimanite bearing rocks. A few samples near 63°55', 111°05' (map 4) contain cordierite, andalusite and biotite, indicative of middle amphibolite facies grade. The remainder of metasediments in map 4 contain sillimanite indicating upper amphibolite facies conditions. The sillimanite isograd (Figure 26) appears to parallel the granite pluton at 63°54', 111°02'.

Sediments near the southeastern sodic granitoid-volcanic dome (map 5) have predominantly greenschist facies assemblages. Moore (1956) shows the cordierite isograde to extend eastward from map 3 to just south of the domal area. Two samples containing cordierite from the southeast side of the dome indicate that the isograd continues eastward. Apparently the lower amphibolite isograd reflects the thermal doming associated with the granite plutons to the south rather than the sodic granitoid body.

Felsic volcanic rocks

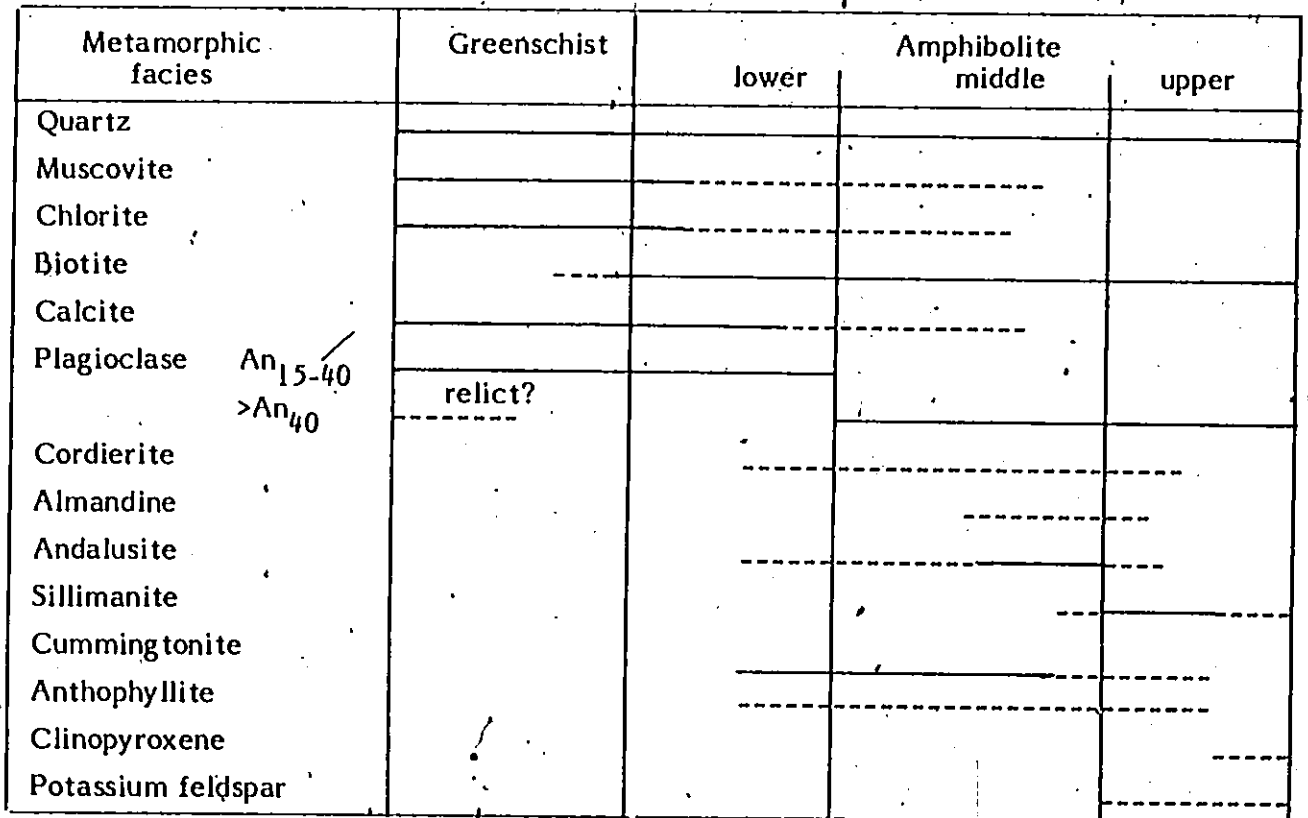
Diagnostic metamorphic mineral assemblages are not develped in massive rhyolite bodies (2a) or in rhyodacitic quartz – feldspar phyric intrusions (2f). These rocks develop minor biotite and exhibit a general grain coarsening with increasing metamorphic grade. The oclastic units, especially the thin, fine-grained 2c and 2d units, have developed chlorite-biotite greenschist facies to upper amphibolite facies assemblages.

The lowest grade (greenschist) assemblage in the felsic volcanics (Table 3) contains chlorite, muscovite, calcite, and ilmenite-magnetite in a quartz-feldspar matrix. Between 64°10' and 64°15' (map 1) muscovite and chlorite are abundant while the rare biotite is located in close association to sparsely distributed ilmenite. Biotite becomes common in felsic rocks just below the cordierite-in isograd (located in the metasediments).

Cordierite, cummingtonite, and rare anthophyllite with minor almandine and andalusite (a middle amphibolite assemblage, Table 3) occur in felsic volcanic units in the northern part of map 1. The cummingtonite appears to occur up-grade from the cordierite-in isograde in the metasediments. This is similar to the isograd distribution in the Benjamin Lake area (Heywood and Davidson, 1969). Davidson (1967) and Miyashiro (1973) suggest the following

Table 3

Metamorphic assemblages in felsic volcanic rocks from the Courageous-MacKay Lake area



Solid lines - common; dashed lines - minor

reaction for the development of cummingtonite:

calcic amphibole + quartz = cummingtonite + anorthite.

Hornblende is rarely observed in the felsic volcanic rocks. This may be the reason for the minor development and erratic distribution of cummingtonite. The muscovite, chlorite, and biotite appear to have reacted to form cordierite and andalusite by the same reaction as described earlier for the pelitic rocks.

Sillimanite and potassium feldspar occur with cummingtonite, cordierite, andalusite and biotite in upper amphibolite faices assemblages (see Table 3) in the northernmost protion of map 1. This may suggest the phase transition andalusite = sillimanite and the reaction:

muscovite + quartz = potassium feldspar + sillimanite (Miyashiro 1973).

However, the earlier cummingtonite forming reaction could have formed the potassium feldspar if all the muscovite had been consumed during the development of cordierite and andalusite. Potassium feldspar also occurs with biotite-cummingtonite assemblages. Rare clinopyroxene has been observed in cordierite, cummingtonite, and biotite assemblages. Table 3 shows the plagioclase to range from andesine to labradorite in these middle to upper amphibolite facies rocks.

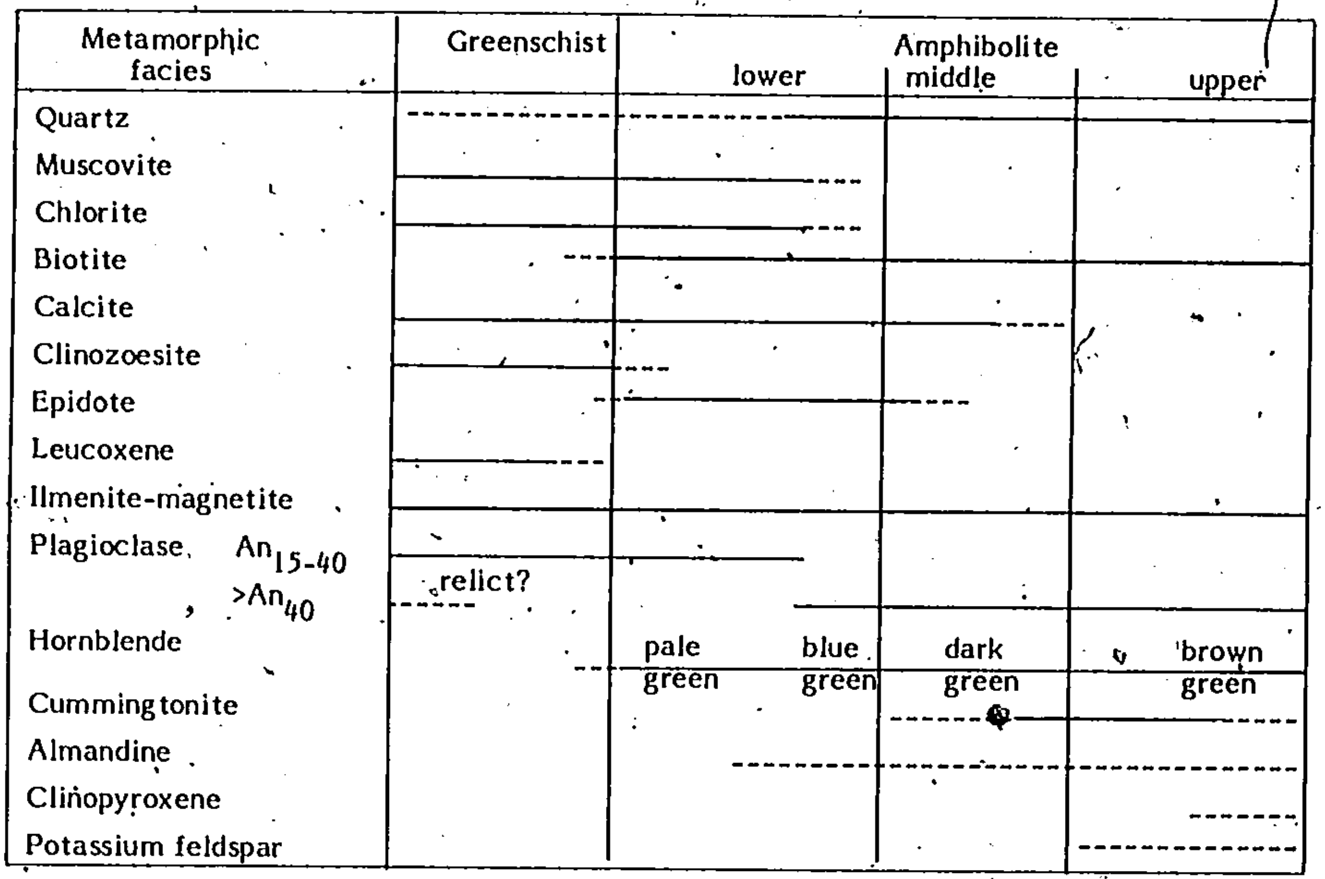
Mafic and intermediate volcanic rocks

Metamorphic assemblages in the mafic and intermediate volanics range from the greenschist facies, through the epidote amphibolite facies to the upper amphibolite facies.

Greenschist facies assemblages contain chlorite, muscovite, calcite, clinozoesite, leucoxene, ilmenite, magnetite, plagioclase, and rare quartz (see Table 4). Biotite occurs rarely and is associated with ilmenite or magnetite.

Table 4

Metamorphic assemblages in mafic to intermediate volcanic rocks from the Courageous-MacKay Lake area



Solid lines - common; dashed lines - minor

Plagioclase is uaually oligoclase but some phenocrysts of andesine compositon have been observed. Rare relict clino- and ortho-pyroxene have also been observed.

The development of biotite increases near the greenschist to lower amphibolite facies boundary. The boundary is defined by the development of actinolitic-hornblende and epidote, denoting Miyashiro's (1973) epidote-amphibolite facies. This boundary is vague due to the sparsity of samples. It would appear to occur in map 1 just south of the cordierite-in isograd in the metasediments. The mafic and intermediate rocks in maps 4 and 5 are above this epidote – amphibolite facies grade.

Middle amphibolite facies assemblages contain hornblende, calcite, quartz, ilmenite-magnetie, and andesine. Biotite and almandine and cummingtonite are irregularity distributed in map 1. Biotite is minor in the amphibolites in maps 4 and 5. Cummingtonite was observed only once in map 4 and has not been seen in map area 5. Garnet has not been observed in the amphibolites of either map 4 or 5.

The upper amphibolite facies mafic volcanic rocks contain abundant biotite and hornblende, minor potassium feldspar, and rare cummingtonite and clinopyroxene. Andesine and quartz are common and almandine is irregularily distributed (see Table 4).

With increasing metamorphic grade the pleochroism of the hornblende changes (Miyashiro, 1973 and Thurston and Breaks, 1978) from a pale-green to a blue-green, through a dark-green to a brown-green (see Table 4). This may indicate increasing oxidation or the addition of titanium (Miyashiro, 1973).

Distribution of isograds

The isograds, indicating an increase in grade towards the northern and southern ends of the belt where it terminates against granitoid plutons (Figure 26), suggest a rise of regional isotherms related to granitic intrusions. The mapped traces of the isograds are broadly spaced, possibly indicating a shallow dip to the isograd surfaces. It can be seen from Figure 26 that the cordierite-in isograd extends about 15 km to the north of the granite plutons in the southern part of the belt. Similarily in the northern part of the belt the cordierite-in isograd is located about 10 km south of the nearest granite bodies. If the metamorphism is related to the granite plutons it would appear that they underlie the northern and southern ends of the Courageous-MacKay Lake belt.

Due to the lack of samples no attempt has been made to delineate in maps 2 and 3 an amphibolite facies isograd parallel to the western granitoid margin. The lack of diagnostic mineral assemblages in the mafic and intermediate rocks of maps 4 and 5 combined with the sparse sample distribution prevent the mapped subdividison of these amphibolites into the three facies suggested for map 1.

A sillimanite isograd has been drawn in the volcanic rocks in the northern part of map 1. While it is felt that numerous granite apophyses have locally influenced the development of sillimanite this isograd reflects the general increase in metamorphic grade towards the north.

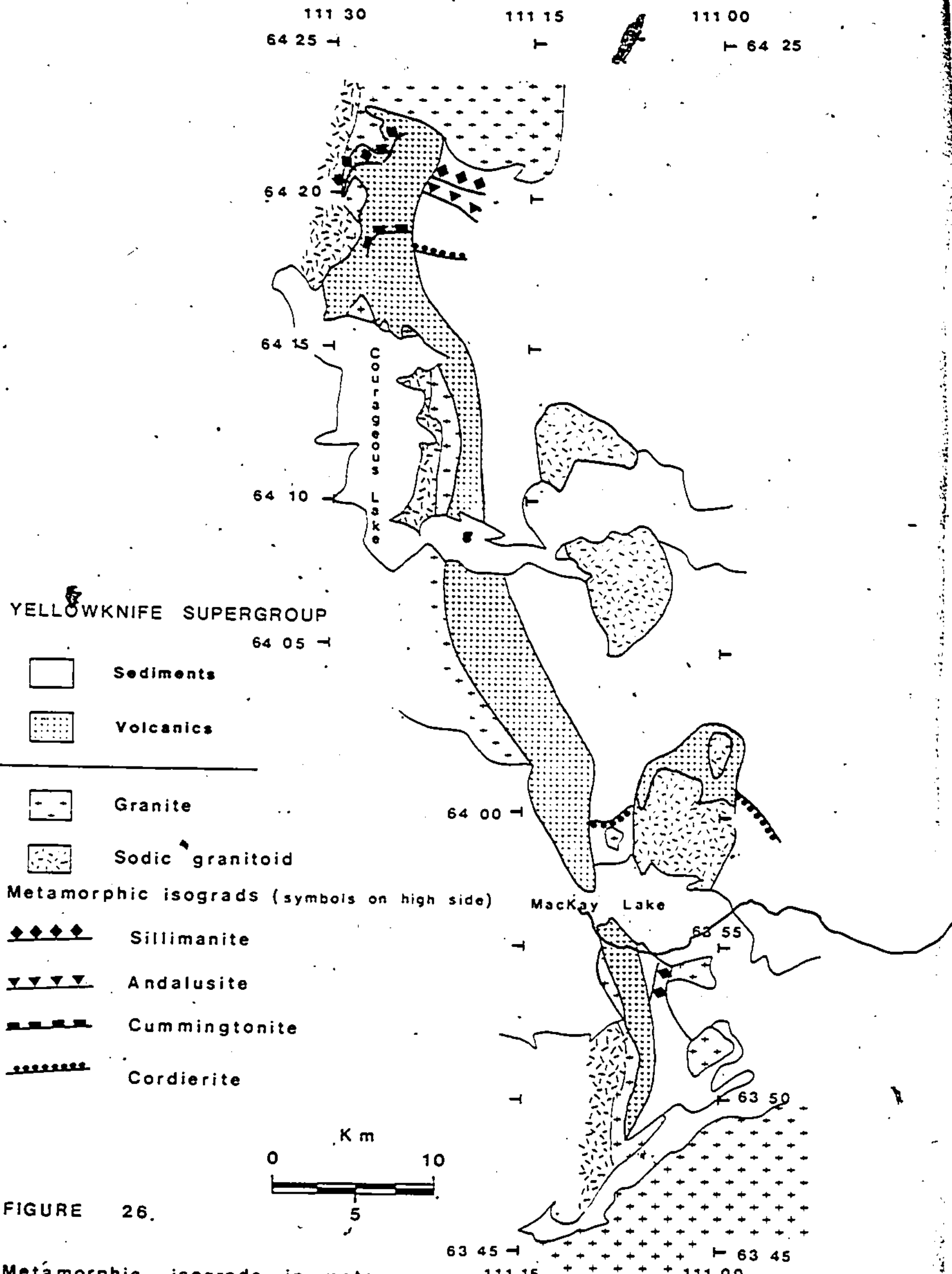


FIGURE 26.

Metamorphic isograds in meta-volcanic and metasedimentary rocks.

Retrograde metamorphism

Retrograde reactions in amphibolite facies sedimentary rocks are ubiquitous and it is often difficult to distinguish prograde from retrograde minerals. The retrograde assemblages are somewhat similar in compositon to the reactants of the prograde reactions discussed earlier.

Andalusite retrogresses to muscovite and biotite. Cordierite is often pinitized and alters to muscovite and chlorite. Sillimanite is often rimmed by fine muscovite. Biotite retrogresses to muscovite and chlorite (penninite) along the 010 cleavage.

Cummingtonite in the volcanic rocks alters to tremolite. Retrograde reactions for cordierite and andalusite in the volcanics are the same as those for the sedimentary rocks. Clinopyroxene in both the felsic and the mafic to intermediate volcanics alters to green hornblende. Hornblende is often rimmed by biotite, penninite and opaques. Almandine in the mafic volcanic rocks is rimmed by fine muscovite, chlorite and magnetite.

As there appears to have been some muscovite growth during D_3 the retrograde phase may have been post D_3, but how much later is indetermineable.

Pressure and temperature conditions during metamorphism

The P-T diagram, Figure 27, shows the range of metamorphic reactions in the Courageous-MacKay Lake area. The zone enclosed by the dashed lines represents the level of erosion and the increasing temperature towards the ends of the belt.

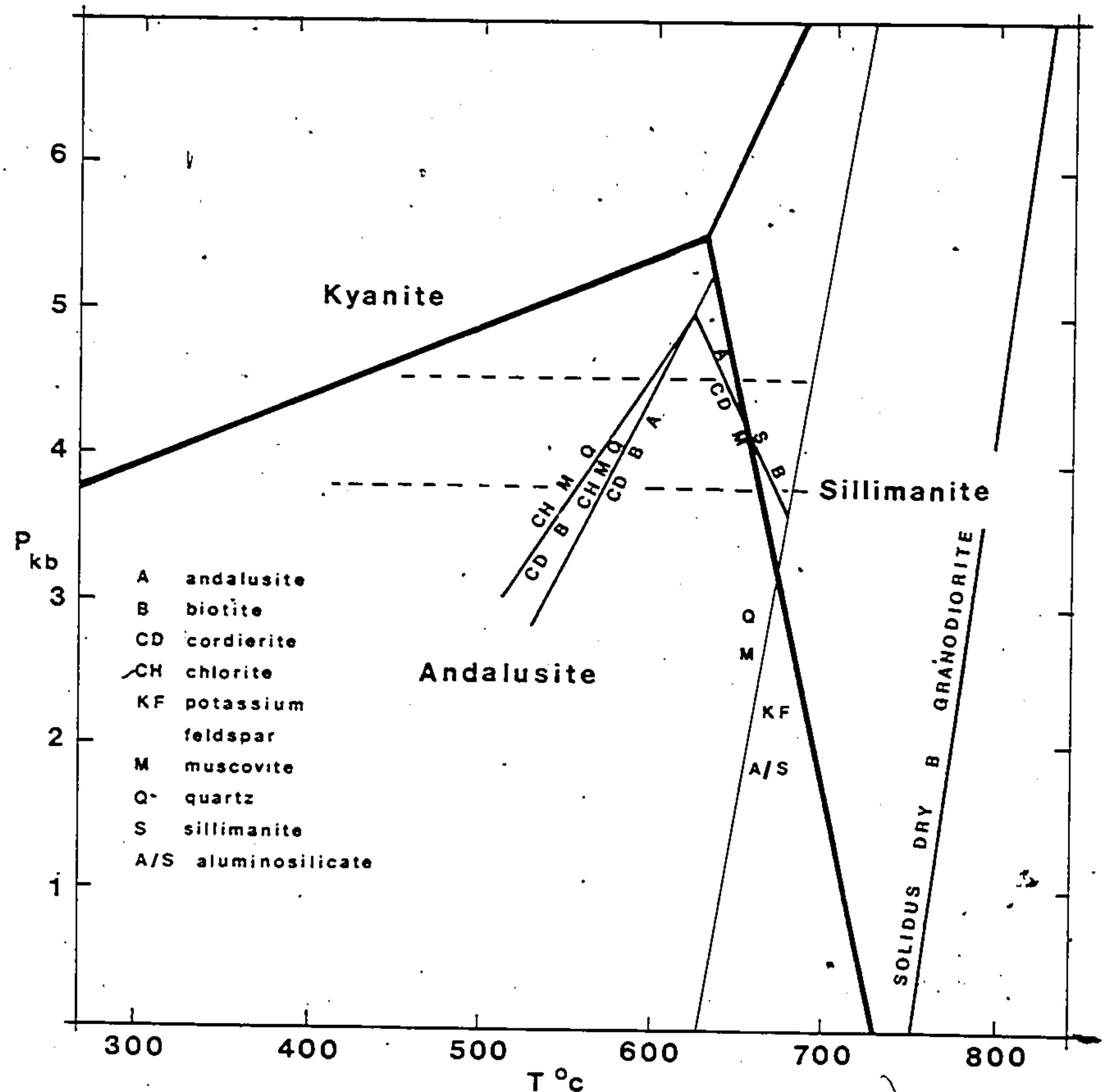


FIGURE 27. P-T phase diagram for the Courageous-MacKay Lake area supracrustal rocks. After Thompson (1978). Dashed lines indicate possible levels of exposure.

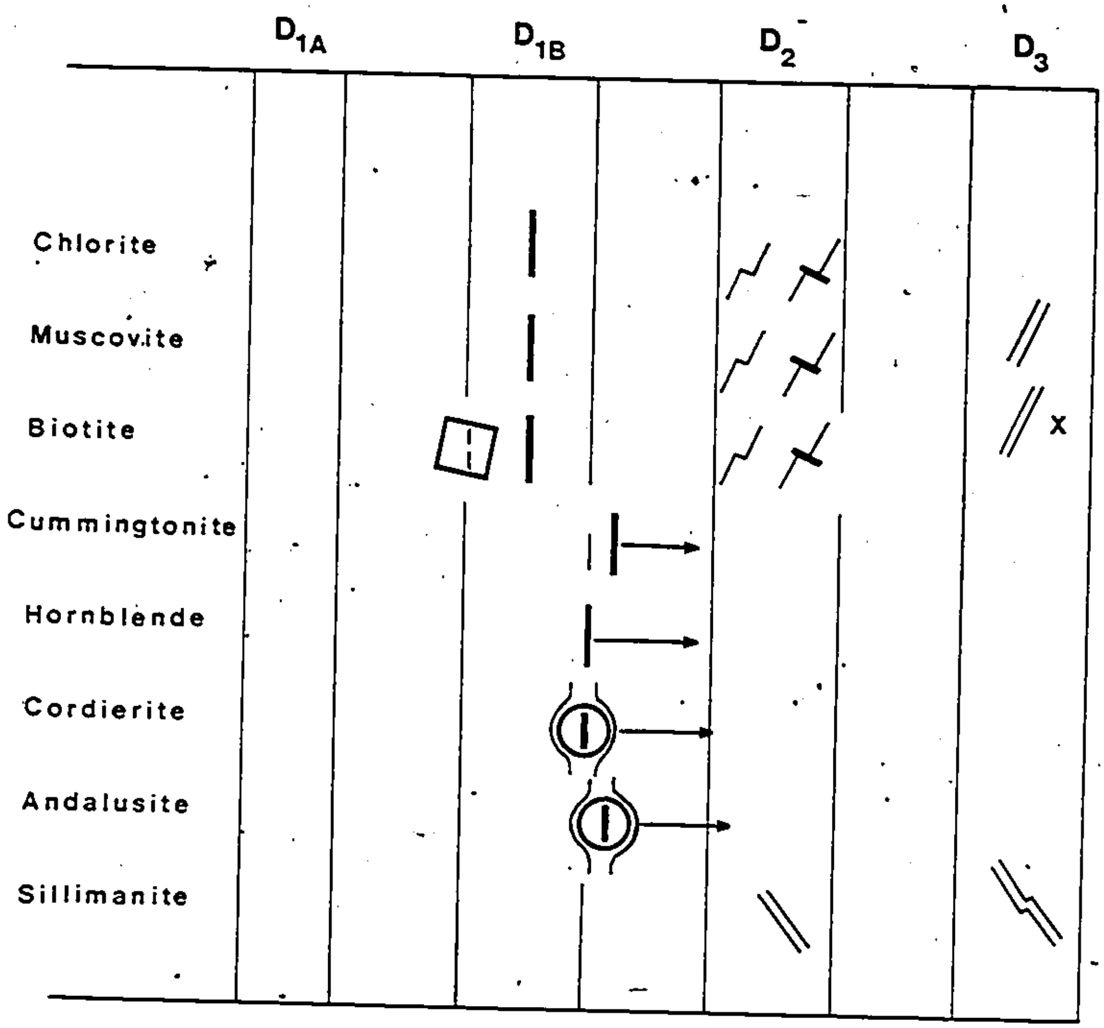
The temperatures during prograde metamorphism ranged from below 500°C to less than 700°C. Ramsay and Kamineni (1977, Fig. 8) report the chlorite-biotite greenschist subfacies boundary at about 400°C. It is thought that the temperature associated with the regional greenschist facies metamorphism in the Courageous-MacKay Lake area was higher, but less than 500°C as the development of biotite was hindered by the lack of ilemnite in most rocks.

The indicated pressures are between 3 Kb and 4 Kb. As noted by Thompson (1978) the use of the Richardson et al. (1969) aluminosilicate triple point is controversial. The use of Holdaways (1971) triple point would lower the pressures by at least 1 Kb. The temperature range would remain similar.

Deformation and mineral growth

The growth of chlorite, muscovite, and biotite parallel to the S_{1B} cleavage occurred under greenschist facies regional metamorphic conditions. The subsequent prograde mineral growth may be a result of the thermal doming of isograds related to the emplacement of the granite plutons. Figure 28 shows the relationship between mineral growth and deformation.

After D_{1A}, possibly during early D_{1B} deformation the rising isotherms formed the biotite porpyroblasts which overgrew and preserved the S_{1A} orientation. Later near the extremities of the belt, cordierite porphyroblasts overgrew the S_{1B} cleavage. As S_{1B} partly warps about these porphyroblasts syn to post D_{1B} growth is indicated. Within the mafic volcanics hornblende grew parallel to S_{1B}, possibly late D_{1B}.



LEGEND

S_{1A} in biotite porphyroblasts

S_{1B} cleavage

Al silicate porphyroblasts with internal S_{1B}, external S_{1B} or S_2

S_2 crenulation cleavage

S_2 segregation cleavage

S_2 cleavage

S_3 crenulation cleavage

S_3 cleavage

X Random

FIGURE 28. Deformation and mineral growth.

During D_2, in greenschist facies terrains, the S_{1B} cleavage was crenulated and in some places new chlorite, muscovite, and biotite grew forming a segregation cleavage. Andalusite porphyroblasts rarely contain an internal S_{1B} fabric and S_2 warps about them suggesting a late D_{1B} to early D_2 period of growth. Sillimanite is often parallel to S_2 indicating syn D_2 growth.

The S_3 cleavage crenulates the D_2 fabric. Minor muscovite and biotite occurs parallel to the S_3 cleavage. Retrograde biotite, muscovite, and chlorite tend to be random, i.e. post D_3.

Discussion

The widespread development of the chlorite-biotite greenschist facies assemblages in the Courageous-MacKay Lake area represent a pre to syn D_{1B} regional grade of metamorphism. The development of biotite was controlled by the lack of ilmenite in most rock types. It is possible that relatively cool, sodic granitoid basement bodies located in maps 3 and 5 have no metamorphic aureole, indicating intrusion temperatures of less than 500°C.

The regional metamorphism continued during D_2 deformation. The isograds at the northern and southern ends of the belt reflect the thermal doming of the regional isotherms during the intrusion of granite plutons. Mineral growth and fabric relationships indicate that the thermal doming began during D_{1B} and lasted until D_2. Mineral assemblages indicate that regional greenschist facies conditions prevailed during D_3. The large distances between the isograds suggests shallow dips of the isotherm surfaces over unexposed granite bodies.

The metamorphic assemblages associated with the thermal doming suggest low confining pressures and range from greenschist to upper amphibolite faices. The discontinuous distribution of garnet in all rock types may indicate compositional control rather than increasing pressure conditions. The rare occurrences of staurolite enclosed by andalusite or cordierite may indicate that staurolite was formed during prograde metamorphism associated with the thermal doming. However, continued staurolite growth appears to have been prevented by the rapid development of cordierite and andalusite which consumed the available chlorite and muscovite (Thompson, 1978). A late stage of retrograde hydrothermal metamorphism altered the prograde minerals developing low grade greenschist facies minerals.

CHAPTER 7

SUMMARY AND CONCLUSIONS

Yellowknife Supergroup rocks of basaltic, andesitic, and dacitic to rhyolitic composition in the Courageous-MacKay Lake volcanic belt form a composite pile, up to 7 Km wide and 100 Km long, which thins rapidly to the east.

Initial volcanism (Figure 29a) formed a subaqueous, predominantly basaltic pile with minor rhyodacitic rocks on a sodic granitoid basement. The topography was flat to shallowly dipping away from extrusive centres. The belt had a linear, north-south configuration which thinned to the north, south, and east. Massive flows were more common than pillowed flows in the north and central portions of the belt perhaps suggesting close proximity to eruptive centres.

A series of eruptions produced Cycle 1 rhyodacitic block-sized breccia (Figure 29b) which extends along much of the belt.

This was followed by a continuation of the extrusion of massive and pillowed basaltic lavas over the entire length of the belt. Highly amygdaloidal (vesicles up to 0.8 cm across), massive and pillowed andesites were extruded in the north central portion of the belt indicating a shallow, less than 200 m deep, subaqueous environment (Figure 29c). Intercalated are feldspar phyric basalts and Cycle 2 rhyolitic volcaniclastic rocks. This suggests that the gabbroic sills and dykes which are feldspar phyric intruded aobut this time and that a second cycle of volcanism had begun.

A 2 Km succession of Cycle 2 felsic volcanic rocks in the centre of the belt was fed by numerous quartz-feldspar phyric dykes which crosscut thick mafic massive and pillowed lavas (Figure 29d).

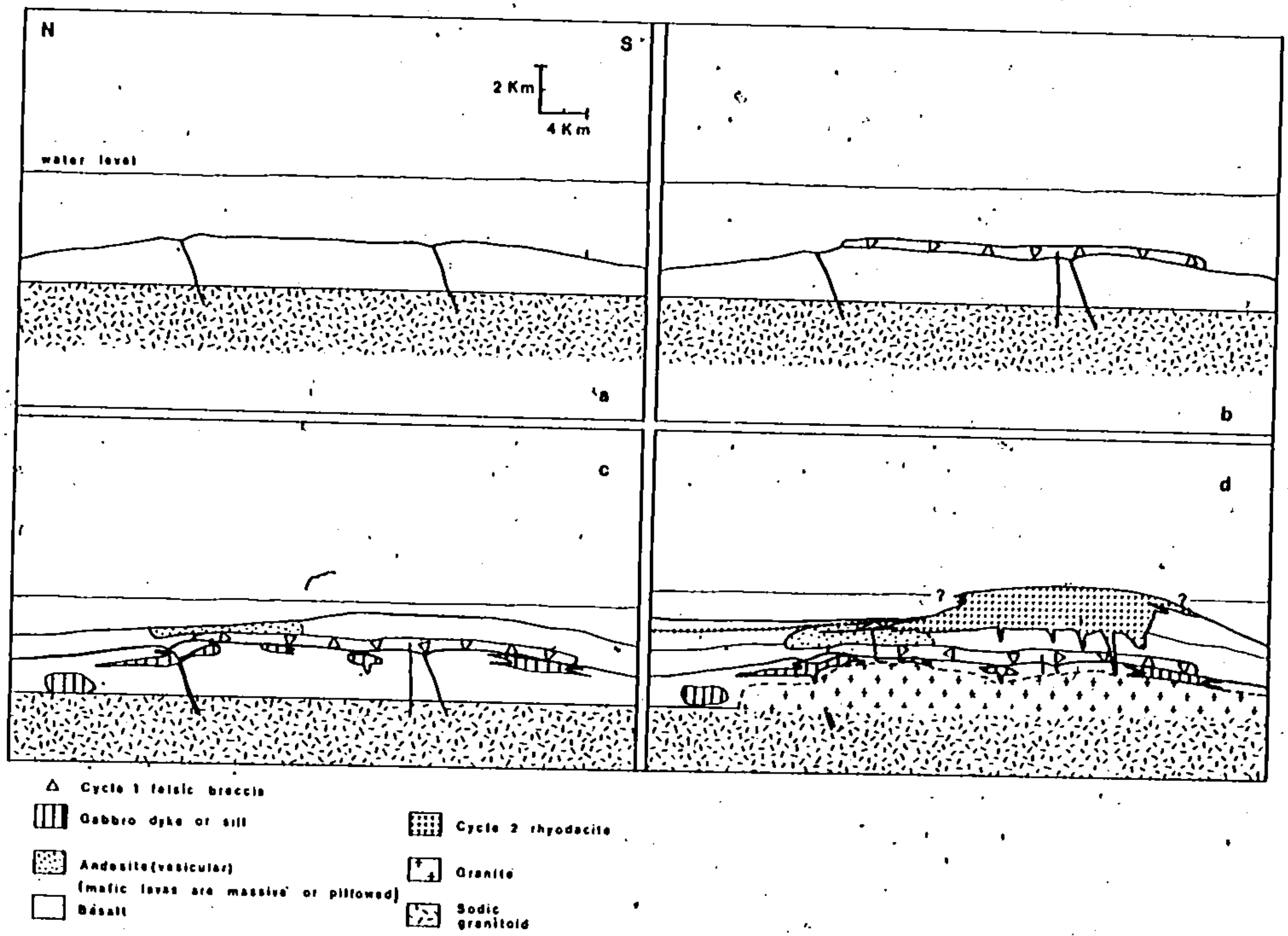


FIGURE 29.

Evolution of the Courageous-MacKay Lake volcanic pile. See text for discussion.

The major volcanic edifice had a shallow dipping, subaqueous, northern flank. A small dome and massive bodies of rhyolitic composition formed on this flank. Associated with the dome are vent facies clastic rocks which grade laterally and vertically from unstratified rhyolitic blocks, and lapilli-sized to poorly bedded dacitic volcaniclastics. Thin units of this dacitic clastic are overlain by basaltic and andesitic rocks to the north indicating penecontemporaneous mafic to intermediate and felsic volcanism.

Turbiditic sediments of unknown thickness overly the volcanic rocks. A granitoid-volcanic clast conglomerate that outcrops close to the volcanic-sedimentary contact suggests either the elevation and subaerial erosion of granitoid rocks soon after volcanism or the erosion of previously exposed granitoids.

Intrusion or perhaps remobilization of the sodic granitoid basement along major north-south faults may have initiated deformation (D_0) which began with the formation of the F_{0A} homocline in the volcanics and marginal synclines in the sediments between the volcanics and the sodic granitoid bodies to the east (Figure 30). Continued tilting and east-west movements developed the major, isoclinal and steeply plunging F_{0B} folds in the sediments which parallel the main volcanic belt and wrap around the eastern sodic granitoid plutons.

D_{1A} deformation began, under greenschist facies regional metamorphic conditions, in response to northwest-southeast subhorizontal compression which formed the S_{1A} fabric. During D_{1B}, rising isotherms produced biotite porphyroblasts which overgrew and preserved the S_{1A} fabric in its initial orientation during the formation of the S_{1B} cleavage. S_{1B} is a north to north-northwesterly striking subvertical cleavage which transects F_{0B} folds

D_{0A} Homocline formation in the volcanic pile with marginal syncline developing in the sediments as sodic granitoids rise or remobilize along fault zones. Small sodic granitoid domes and marginal synclines to the east.

D_{0B} Continued movements to form steeply plunging N–S F_{0B} folds in the sediments close to the volcanic belt. ENE folds (F_{0B}) near the southeast pluton. No cleavage developed.

D_{1A} NW–SE horizontal compression with the formation of the S_{1A} cleavage fabric.

D_{1B} E–W compression. Formation of a N–S S_{1B} cleavage oblique to F_{0B}. S_{1A} rotates towards S_{1B} except in biotite porphyroblasts.

D_2 Metamorphism peaks, granites intrude along the western volcanic margin and as small plutons to the SE in the sediments. NE–SW compression forms NW–SE S_2 cleavage and minor F_2 folds. Deflection of structures around granite plutons.

D_3 NW–SE compression forms a weak NE–SW fabric (S_3).

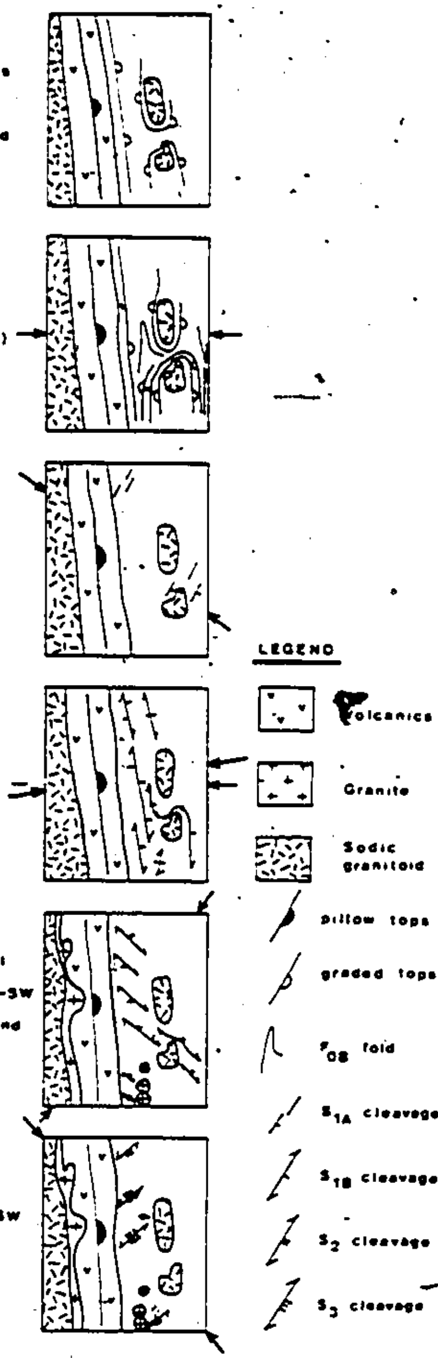


FIGURE 30.

Structural synthesis of the Courageous–MacKay Lake area.

With further increase in temperature during and after D_{1B} deformation, cordierite and andalusite overgrew the S_{1B} cleavage and may have continued until D_2. Hornblende and cummingtonite also crystallized during D_{1B}. The range of metamorphic reactions from greenschist through lower and middle amphibolite to upper amphibolite facies is attributed to the syn D_{1B} to early D_2 thermal doming of regional isograds associated with the intrusion of granite plutons (Figure 31).

F_2 minor folds and a subvertical, axial planar S_2 crenulation to segregation cleavage developed during northeast-southwest subhorizontal compression (D_2). S_2 is ubiquitous in amphibolite facies terrains. The dominance of the S_2 fabric and associated tight folds suggest high strain in the metasediments during D_2 deformation. This coincided with the peak of metamorphism as indicated by the growth of sillimanite (with biotite) parallel to S_2.

Later (D_3), a weak northwest-southeast subhorizontal compression crenulated the S_2 cleavage. The minor growth of oriented biotite and muscovite indicates the return to greenschist facies metamorphic conditions.

A noteable feature in the proposed sequence of events is that compression appears to have east-west and northwest-southeast directions, that is east-west during D_{0B} and D_{1B}, and northwest-southeast during D_{1A} and D_3, although there is an additional direction (northeast-southwest during D_2) before the last event (D_3). The reactivation of compression in preferred directions could be related to repeated movements of crustal blocks in a regional shear system (Fyson, 1981b).

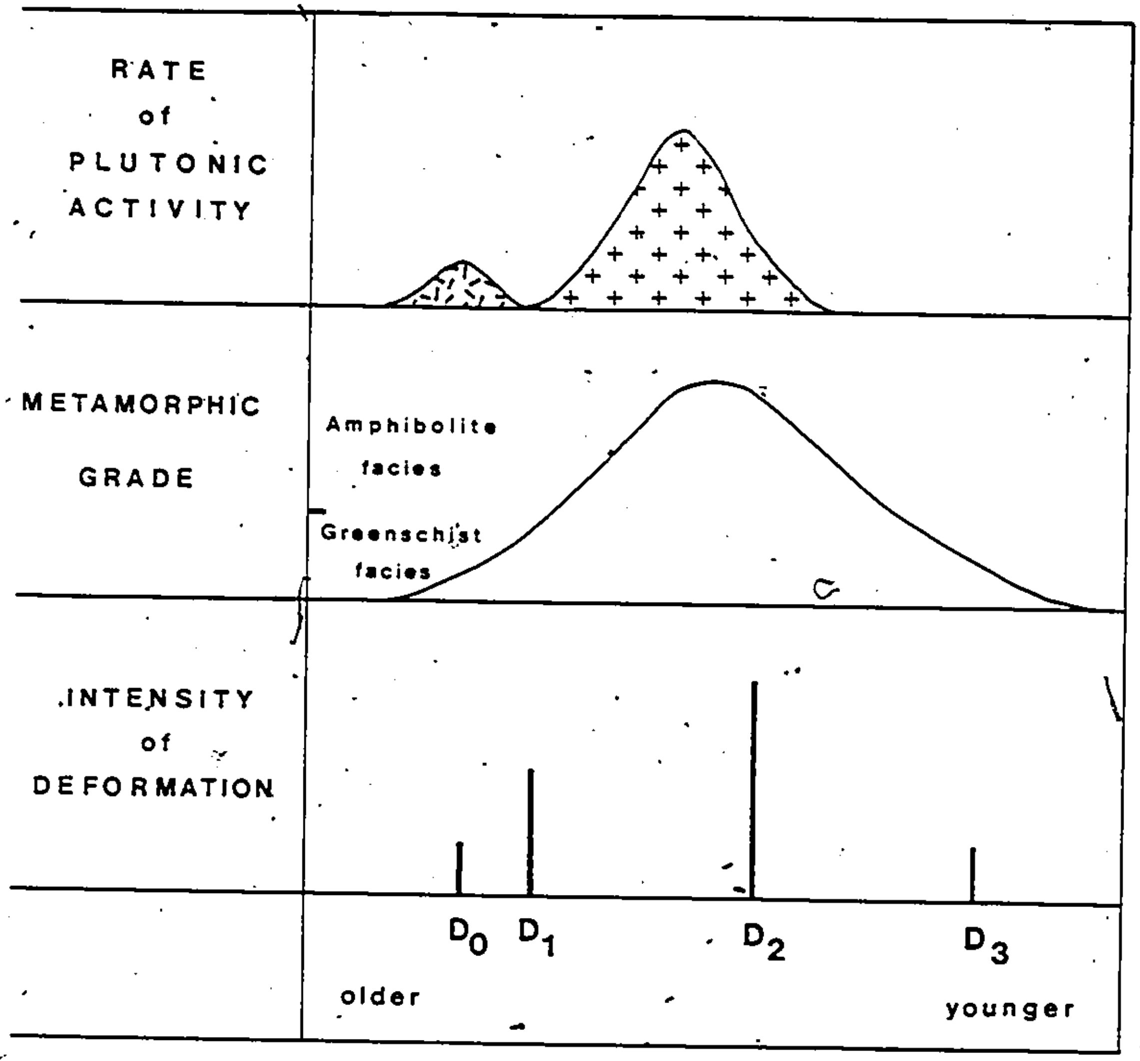
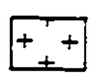


FIGURE 31. Time sequence of igneous, metamorphic, and tectonic activity in the Courageous–MacKay Lake area.



Granite

Sodic granitoid.

While most of the cleavage orientations appear to be regional in nature the abrupt change in the trend of the bedding and S_{1B} from north-south to northeast-southwest at the south end of the belt may reflect a change in the direction of the margin of the granitoid plutonic complex which follows several fracture sets (cf. Lambert, 1977a).

In brief, the structural succession appears to have begun with diapiric uplift of sodic granitoids and consequent formation of the east-facing homocline in the volcanic rocks. This was followed by successive periods when regional subhorizontal compression varied in orientation and intensity, but was reactivated in specific directions. The peak of metamorphism concided with the highest local strain and with thermal doming of regional isotherms during granite intrusion.

Suggestions for further work

Detailed mapping and sampling of the central portion of the volcanic belt (map 3) is required to identify the geochemical nature of this part of the section, the lithology of the felsic rocks, and the nature of the minor structures not fully identified by previous work (Moore, 1956). The chemical composition of the granitoid rocks to the west of the belt and especially the pluton at 64°10', 111°08' needs to be examined.

A detailed structural analysis of the greenschist facies sediments to the east of the study area should be investigated to see if the structures identified in this study have the same characteristics over a broader area, including localities adjacent to and far removed from granitoid bodies.

REFERENCES

Baragar, W.R.A.

1966: Geochemistry of the Yellowknife volcanic rocks. Can. J. Earth Sci., 3, p. 9-30

Baragar, W.R.A. and McGlynn, J.C.

1976: Early Archean basement in the Canadian Shield: A review of the evidence. Geol. Surv. Can., Paper 76-14, p. 21.

Barker, F.

1979: Trondhjemite: definition, environment and hypotheses of origin in; Trondhjemites, dacites, and related rocks. F. Barker editor. Elsevier Scientific Publ. Co., Holland, p. 1-12.

Bostock, H.H.

1976: Geology of the Itchen Lake area, District of Mackenzie, 76E (W/2) and part of 86H. Geol. Surv. Can., Open File 338.

Bouma, A.H.

1962: Sedimentology of some flysch deposits. Elsevier Publ. Co., Amsterdam. 168 p.

Bourne, J.H.

1978: Metamorphism in the eastern and southwestern portions of the Grenville Province, in Metamorphism in the Canadian Shield, Geol. Surv. Can., Paper 78-10, p. 315-328.

Davidson, A.

1967: Metamorphism and intrusion in the Benjamin Lake map-area, Northwest Territories. Unpublished Ph.d. thesis, U.B.C., 204 p.

Dimroth, E., Cousineau, P., Leduc, M., and Sanschangrin, Y.

1975: Structure and organization of Archean subaqueous basalt flows, Rouyn-Noranda area, Quebec, Canada. Can. J. Earth Sci., 15, p. 902-918.

Fisher, R.V.

1966: Rocks composed of volcanic fragments and their classification. Earth Sci. Rev., 1, p. 287-298.

Folinsbee, R.E.

1949: Lac de Gras, District of Mackenzie, Northwest Territories. Geol. Surv. Can., Map 977A. 1:253, 440 scale.

Folinsbee, R.E. and Moore, J.C.

1950: Matthews Lake, Northwest Territories. Geol. Surv. Can., Paper 50-2, p. 11.

Frith, R.A.

1981: Preliminary account of the geology of the Beechey Lake-Duggan Lake map areas, District of Mackenzie; in Geol. Surv. Can., Paper 81-1A, p. 333-339.

Fyson, W.K.

1975: Fabrics and deformation of Archean metasedimentary rocks, Ross Lake-Gordon Lake area, Slave Province, Northwest Territories. Can. J. Earth Sci., 12, p. 765-776.

1980: Fold fabrics and emplacement of an Archean granitoid pluton, Cleft Lake, Northwest Territories. Can. J. Earth Sci., 17, p. 325-332.

Fyson, W.K. (cont.)

1981a: Divergent fold overturning and regional tectonics, southern Slave Province, Northwest Territories. Precambrian Research, 14, p. 107-118.

1981b: A complex succession of folds and cleavages in Archean rocks, Yellowknife, N.W.T. (in press).

Fyson, W.K. and Frith, R.A.

1979: Regional deformations and emplacement of granitoid plutons in the Hackett River greenstone belt, Slave Province, Northwest Territories. Can. J. Earth Sci., 16, p. 1187-1195.

Gates, T.M. and Hurley, P.M.

1973: Evaluation of Rb-Sr dating methods applied to Matachewan, Abitibi, Mackenzie, and Sudbury dike swarms in Canada, Can. J. Earth Sci., 10, p. 900-919.

Henderson, J.B.

1970: Stratigraphy of the Archean Yellowknife Supergroup, Yellowknife Bay-Prosperous Lake area, District of Mackenzie. Geol. Surv. Can., Paper 70-26, p. 12.

1975: Sedimentology of the Archean Yellowknife Supergroup at Yellowknife, District of Mackenzie. Geol. Surv. Can. Bull., 246, p. 62

1981: Archean basin evolution in the Slave Province, Canada in; Precambrian plate tectonics, A. Kroner, ed., Elsevier Sci. Pub. Co., Amsterdam, in press.

Henderson, J.B. and Easton, R.M.

1977: Archean supracrustal-basement rock relationships in the Keskarrah Bay map-area, Slave Structural Province, District of Mackenzie. Geol. Surv. Can., Paper 77-1A, p. 217-220.

Henderson, J.F.

1944: MacKay Lake, District of Mackenzie, Northwest Territories. Geol. Surv. Can., Map 738A, 1:253,440 scale.

Henderson, J.F. and Brown, I.C.

1966: Geology and structure of the Yellowknife greenstone belt, District of Mackenzie. Geol. Surv. Can., Bull., 141, p. 87.

Heywood, W.W. and Davidson, A.

1969: Geology of Benjamin Lake map-area, District of Mackenzie. Geol. Surv. Can., Memoir 361, p. 35.

Holdaway, M.J.

1971: Stability of andalusite and the aluminum silicate phase diagram. Am. J. Sci., 271, p. 97-131.

Irvine, T.N. and Baragar, W.R.A.

1971: A guide to chemical classification of the common volcanic rocks. Can. J. Earth Sci., 8, p. 523-548.

Jones, J.G.

1969: Pillow lavas as depth indicators. Am. J. Sci., 267, p. 181-195.

Kretz, R.

1968: Study of pegmatite bodies and enclosing rocks, Yellowknife-Beaulieu region, District of MacKenzie. Geol. Surv. Can., Bull. 159, p. 109.

Lajoie, J.

1979: Facies models 17. Volcaniclastic rocks; in Facies Models, editor R.G. Walker, Geol. Assoc. Can., Reprint series 1, p. 191-200.

Lambert, M.B.

1977a: Anatomy of a greenstone belt-Slave Province, N.W.T.; in Spec. Paper 16, Geol. Assoc. Can., p. 331-340.

1977b: The southwestern margin of the Back River Volcanic Complex, District of Mackenzie. Geol. Surv. Can., Paper 77-1A, p. 179-180.

1978: The Back River Volcanic Complex – a cauldron subsidence structure of Archean age. Geol. Surv. Can., Paper 78-1A, p. 153-157.

1980: A uranium-lead age of zircons from volcanics and sediments of the Back River Volcanic Complex, eastern Slave Province, District of Mackenzie. Geol. Surv. Can., Paper 80-1C, p. 239-242.

MacDonald, G.A.

1972: Volcanoes. Prentice Hall Inc., New Jersey, p. 510.

McGlynn, J.C. and Henderson, J.B.

1970: Archean volcanism and sedimentation in the Slave Structural Province; in Symposium on Basins and Geosynclines of the Canadian Shield; ed. Baer, A.J., Geol. Surv. Can., Paper 70-40, p. 31-44.

1972: The Slave Province; in Variations in tectonic styles in Canada; Geol. Assoc. Can., Spec. Paper 11, p. 506-526.

Miyashiro, A.

1973: Metamorphism and metamorphic belts. George Allen and Unwin Ltd., London, p. 492.

Moore, J.C.G.

1951: Courageous Lake, Northwest Territories, Geol. Surv. Can., Paper 51-14, p. 8.

1956: Courageous-Matthews Lakes area, District of Mackenzie, Northwest Territories. Geol. Surv. Can., Memoir 283, p. 52.

1965: Petrology of deep-sea basalt near Hawaii. Am. J. Sci., 263, p. 40-52.

Parsons, W.H.

1969: Criteria for the recognition of volcanic breccias, review. Geol. Soc. Am. Bull. 115, p. 263-304.

Ramsay, C.R.

1973a: Controls of biotite zone chemistry in Archean metasediments near Yellowknife, N.W.T., Canada. J. Petrol., 14, p. 467-488.

1973b: The origin of biotite in Archean metasediments near Yellowknife, N.W.T., Canada. Contrib. Min. Petrol., 42, p. 43-54.

1974: The cordierite isograd in Archean metasediments near Yellowknife, N.W.T. Canada – varations on an experimentally established reaction. Contrib. Min. Petrol., 47, p. 27-40.

Ramsay, C.R. and Kamineni, D.C.

1977: Petrology and evolution of an Archean metamorphic aureole in the Salve Craton, Canada J. Petrol., 18, p. 460-486.

Richardson, S.W., Bell., P.M., and Gilbert, M.C.

1969: Experimental determination of kyanite-andalusite and andalusite-sillimanite equilibria; the aluminum silicate triple point; Am. J. Sci., 266, p. 513-541.

Streckeisen, A.

1976: To each plutonic rock its proper name. Earth Sci. Rev., 12, p. 1-33.

Thompson, P.H.

1978: Archean regional metamorphism in the Slave Structural Province – a new perspective on some old rocks; in Metamorphism in the Canadian Shield, Geol. Surv. Can., Paper 78-10, p. 85-102.

Tirrul, R. and Bell, I.

1980: Geology of the Anialik River greenstone belt, Hepburn Island map area, District of Mackenzie. Geol. Surv. Can., Paper 80-1A, p. 157-164.

Thurston, P.C. and Breaks, F.W.

1978: Metamorphic and tectonic evolution of the Uchi-English River subprovince; in Metamorphism in the Canadian Shield, Geol. Surv. Can., Paper 78-10, p. 49-62.

Walker, R.G.

1979: Facies models 8. Turbidites and associated coarse clastic deposits; in Facies Models, editor R.G. Walker, Geol. Assoc. Can., Reprint series 1, p. 91-103.

Wood, D.S.

1974: Current views of the development of slaty cleavage. Ann. Rev. Earth Plan. Sci. Letters, 2, p. 369-401.

APPENDIX I

Modes, igneous- and deformation-textures of granitoid rocks in the Courageous-MacKay Lake area. Data from stained slabs and thin sections

Name and sample number	Texture	Quartz	Plagioclase	Potassic Feldspar	Biotite	Hornblende	Opaque minerals	Accessory minerals	An content
	f fine-grained m medium-grained hy hypidiomorphic granular al allotriomorphic granular ph porphyritic ct cataclastic	p phenocryst s sutured-contact	p phenocryst sa saussuritized cores nz normal zoning oz oscillatory zoning my myrmekite gr graphic intergrowth	p phenocryst mi microcline apt anti-perthitic	a aligned n non-aligned mu muscovite alteration cl chlorite alteration	a aligned n non-aligned bt biotite-alteration	mt magnetite il ilmenite py pyrite lu leucoxene he hematite	al allanite ap apatite ca calcite ep epidote gt garnet to tourmaline sp sphene zr zircon	rim to core
GRANITE									
Δ 16-L2 1	m,al	35.7	28.8 sa,my	33.6 mi	1.9 n			Tr-ap	27
19-L1 2	m,al,ph	38.9	32.2 p,sa,nz	25.0 p,mi	3.9 n,cl	Tr-n		Tr-ep	25
32-L3 3	m,al,ph	36.4 s	35.3 sa,nz	25.3 p,mi	3.0 n			Tr-ca,ep,zr	23-31
36-L2 4	m,al,ph	34.5 s	37.9	23.9 p,mi	3.9 n,mu,cl			Tr-ep	
40-L2 5	m,al,ph	33.5	29.5 sa	33.4 p,mi	3.6 n,cl		Tr-py,he	Tr-ep,zr	30
47-L3 6	f-m,al	36.4	27.8	30.6	5.2 n				
48-L1 7	m,al	41.0 s	34.8	21.6	2.6 n				
70-L2 8	f-m,al	29.4	38.9	28.8	2.9 a				
85-L1 9	m,al	35.9	26.0 sa,nz,my	37.2 mi,apt	0.9 a,mu		Tr-mt	Tr-gt,to,sp,zr	23
125-L1 10	m,al,ph	31.7	36.5 p	28.3 p,mi	3.5 a				
133-L4 11	m,al,ph	24.7	44.0 p,sa,nz,my	25.9 p,apt	5.4 n,mu			Tr-zr	21-23
133-L5 12	m,al,ph	24.1 s	39.7 sa,nz	31.2 p,mi,apt	5.0 n,mu			Tr-ap,zr	21-25
133-L6 13	m,al,ph	28.3	40.1 p	22.1 p,mi,apt	8.8 n				
142-L1 14	m,al,ph	26.2	39.0 sa,nz	29.6 p,mi,apt	5.2 n,mu				
142-L2 15	m,al,ph	30.5	34.1 sa,nz	29.9 p,mi,apt	5.5 n,mu		Tr-mt	Tr-ap,zr	24-28
GRANODIORITE									
Δ 18-L1 16	f,al,ph	27.2 p	43.4	22.7 mi	9.2 n				
18-L3 17	m,al,ph	38.6	37.6 p,sa,nz	16.3 mi	7.5 n		Tr-il,lu	Tr-ep,zr	22-25
26-L1 18	m,al,ph	30.0	52.0 p,sa,nz	7.3 mi	10.7 n		Tr-mt	Tr-ep,sp,zr	22-35
29-L4 19	f-m,al,ph	30.3	41.0 sa,my	15.0 mi	13.6 n,cl		Tr-mt	Tr-ap,ep,zr	26-34
35-L5 20	f,al	25.1	51.0 sa,nz	12.9 mi	8.8 n		L.3il,lu	Tr-ap,ep	30
40-L1 21	m,al	35.1	44.5 p,sa,nz	10.9 mi	9.5 a,cl		Tr-mt	Tr-al,ep,zr	24-35
42-L1 22	m,hy,ph	36.5	45.6 p,sa,nz	9.9 mi	8.0 n			Tr-ep,zr	25
51-L5 23	m,al,ph	43.2 p	41.4	11.3 mi	4.1 a				
80-L2 24	m,al,ph	23.8 s	54.7 p	17.6 p,mi,apt	3.9 a,mu			Tr-ap,zr	28
101-L3 25	m,al,ph	21.0 p	60.5 sa,nz	14.1 mi	4.4 n,cl		Tr-mt	Tr-al,ap,ca	21-28
106-L2 26	m,al,ph	33.3 s	53.3 p,nz,oz	8.9 mi	4.5 n,mu			Tr-ap,zr	
109-L1 27	m,al-hy	27.4 s	54.9	11.3	6.4 a		Tr-he		
114-L3 28	m,al	23.8	55.5	12.0	8.4 a				
TONALITE									
Δ 40-Lb 29	m,al	30.2	56.7 sa,gr	3.9 mi	7.0 a	2.2 a	Tr-mt	Tr-sp,zr	27
100-L1 30	f-m,al,ph	25.0 p	64.9	5.8	4.3 a				
101-L2 31	m,al,ph	25.1	63.3 nz	6.7 mi	2.9 n,cl	2.0 n,bt	Tr-mt	Tr-ap,ep,zr	22-30
108-L2 32	m,al,ph	21.6	69.4 p,sa,oz	4.0 mi	4.0 a,cl	1.0 n,bt	Tr-mt	Tr-ap,ep	22-31
114-L2 33	m,al,ph	29.8	58.8 p,nz	5.6	5.8 a				
TRONDHJEMITE									
Δ 26-L2 34	m,ct	33.6 s	52.0 p,sa,nz		7.0 n,cl		Tr-mt	Tr-ca,ep,zr	
31-L2 35	f,al,ph	26.0	61.2 p,sa,nz		12.8 n	2.0 n,bt	Tr-mt	Tr-ca,ep,zr	21-44
34-L2 36	m,al,ph	27.9 p,s	62.9 sa,nz		9.2 a,cl		Tr-mt	Tr-ca,ep,zr	23-38
34-L3 37	m,al	46.2	47.3 sa,nz		3.8 n,cl		Tr-mt	Tr-ca,ep,zr	21-33
43-L2 38	m,al	27.7	55.1 sa,nz		4.5 n	10.8 n,bt	Tr-mt	Tr-ap,ca,ep	24-45
45-L3 39	m,ct	29.3 s	62.4		8.3 a			Tr-ep,sp,zr	22-30
114-L1 40	m,al	22.9	71.1 p,nz	Tr-mi	6.0 n		Tr-mt	Tr-zr	22-29
118-L1 41	m,al,ph	31.6 p	63.2 p	Tr-mi	5.2 a				

location of samples in Figure 13.

APPENDIX 2

Chemical composition of the volcanic and granitoid rocks from the Courageous-MacKay Lake area

Rock type	Granitoids						Basalts			
Specimen no.	7	11	14	23	30	40	42	43	44	45
Major oxides (weight per cent)										
SiO_2	76.44	72.35	72.62	78.39	74.60	70.04	48.25	48.89	41.89	47.01
Al_2O_3	12.63	14.41	15.31	12.53	14.20	16.66	16.36	15.99	14.7	14.49
FeO_T	1.62	1.45	1.81	1.82	3.05	2.20	9.40	12.64	10.91	11.75
MgO	.21	.54	.65	.32	.57	.84	5.67	6.42	9.03	7.51
CaO	.95	1.21	.55	1.80	2.68	3.08	8.08	9.31	9.55	8.48
Na_2O	4.14	4.10	4.14	4.02	4.26	5.45	3.16	2.00	.97	2.42
K_2O	3.52	4.15	4.59	1.96	1.22	1.85	.10	.04	.3	.07
TiO_2	.13	.21	.22	.16	.27	.27	1.12	.84	.68	.95
P_2O_5		.08	.10		.05	.08	.09	.07	.04	.07
MnO	.01	.01	.01	.03	.07	.03	.20	.18	.15	.17
S				.01	.04		.08	.01	.01	.04
NiO							.02	.01	.03	.02
Cr_2O_3							.05	.04	.05	.04
TOTAL	99.65	98.51	100.00	101.04	101.01	100.50	92.58	96.44	88.31	93.02
Trace elements (ppm)										
Ba	564.	537.	60.7	351.	282.	659.	80.	18.	408.	19.
Cr		4.			5.	20.	351.	250.	25.	297.
Zr	125.	130.	124.	147.	159.	176.	64.	66.	176.	63.
Sr	53.	131.	103.	85.	113.	163.	98.	126.	53.	78.
Rb	113.	173.	182.	112.	172.	107.			17.	
Y	48.	6.		31.	12.	39.	31.	30.	56.	35.
Ce	118.	104.	100.	135.	78.	111.	42.	49.	49.	53.
Zn	4.	20.	15.	10.	40.		93.	72.	114.	76.
Ni	4.	6.	15.	7.	8.	19.	144.	85.	12.	133.
Ratios										
K/Rb	258.13	199.6	209.7	144.93	58.64	296.88	-		416.63	
Ce/Y	2.46	18.7	1.76	4.36	6.61	2.82	1.33	1.63	.88	1.51
Normative composition (cation equivalents)[a]										
Quartz	34.289	27.763	27.002	40.193	35.921	21.636	2.783	3.861		.998
Corundum	.309	1.292	3.028	.573	1.226	.306				
Orthoclase	21.101	24.998	27.207	11.654	7.224	10.828	.644	.252	2.037	.452
Albite	37.673	34.490	37.250	36.285	38.399	48.42	30.877	19.094	9.996	23.706
Anorthite	4.778	5.582	2.079	8.98	13.023	14.606	32.835	36.733	40.034	31.071
Diopside							5.879	5.749	8.077	7.763
Hedenbergite							2.248	3.778	3.169	3.71
Enstatite	.588	1.518	1.798	.888	1.58	2.295	14.096	15.972	20.462	18.74
Ferrosilite					.127		5.390	10.485	8.028	8.958
Fosterite									3.085	
Fayalite									1.210	
Rutile	.101	.141	.082							
Magnetite				.017	1.858	.393	2.981	2.601	2.616	2.795
Ilmenite		.017	.143	.224	.378	.372	1.698	1.244	1.087	1.444
Chromite		.001			.001		.061	.043	.062	.052
Apatite			.210		.105	.166	.205	.156	.096	1.60
Pyrrhotite	.035			.035	.139		.302	.037	.04	1.52
Hematite	1.144	1.029	1.201	1.152		.959				
Normative Colour Index	1.71	2.56	3.14	2.28	3.94	4.02	32.3	39.83	47.7	43.41
Normative Plagioclase	11.86	58.01	57.79	20.79	25.32	23.17	51.5	67.12	80.	58.17

[a] Norms calculated by the Ottawa University computer program according to the Irvine and Baragar (1971) classification

APPENDIX 2 (cont.)

Rock type	Basalts									
Specimen No.	46	47	48	49	50	51	52	53	53	55
Major oxides	(weight percent)									
SiO_2	48.23	50.54	52.76	50.16	52.18	47.95	50.08	54.61	53.89	50.56
Al_2O_3	15.84	14.55	14.59	15.51	16.58	14.5	15.20	14.18	15.03	15.00
FeO_T	10.40	11.71	15.23	14.03	11.41	14.91	13.50	15.26	11.98	10.66
MgO	3.15	9.30	8.39	5.02	6.57	7.40	7.76	5.57	3.66	6.10
CaO	9.18	11.83	2.04	10.88	9.50	10.29	10.53	7.36	10.02	12.11
Na_2O	2.78	1.79	.67	1.8	3.55	1.99	2.71	2.65	2.96	1.61
K_2O	.33	.13	.38	.18	.2	.33	.17	.14	.60	.18
TiO_2	1.29	.56	1.22	1.01	.88	.09	.95	1.48	1.74	.83
P_2O_5	.09	.03	.09	.08	.05	.07	.07	.12	.16	.05
MnO	.36	.19	.17	.38	.22	.25	.20	.28	.31	.17
S	.08		.02	.08	.03			.01	.02	.02
NiO	.01	.01		.01	.01	.01	.02		.01	.01
Cr_2O_3	.04	.03		.05	.01	.03	.04	.01	.02	.05
TOTAL	91.98	100168	95.56	99.19	101.19	98.72	101.23	101.67	100.40	97.35
Trace elements	(ppm)									
Ba	137.	39.	72.	76.	15.	25.	40.	81.	98.	41.
Cr	290.	202.	26.	324.	91.	205.	272.	76.	112.	311.
Zr	71.	29.	71.	57.	50.	52.	52.	90.	113.	52.
Sr	99.	90.	32.	94.	84.	79.	127.	197.	180.	109.
Rb	11.		6.	3.	3.	16.	2.		10.	7.
Y	26.	10.	6.	24.	9.	39.	18.	33.	64.	33.
Ce	45.	64.	43.	46.	41.	29.	35.	40.	46.	36.
Zn	104.	56.	120.	90.	60.	134.	81.	98.	109.	51.
Ni	103.	114.	34.	93.	52.	78.	159.	35.	41.	113.
Ratios										
K/Rb	398.07		500.76	581.92	550.99	167.63	649.04		511.75	222.66
Ce/Y	1.75	6.15	7.12	1.90	4.79	.75	1.97	1.20	.71	1.08
Normative composition	(cation equivalents)*									
Quartz	5.17	2.19	23.552	5.492				9.294	8.196	6.387
Corundum			11.413							
Orthoclase	3.496	.774	2.452	1.115	1.179	2.035	1.011	.846	3.649	1.121
Albite	26.837	16.181	6.562	16.922	31.773	18.631	24.466	24.305	27.325	15.225
Anorthite	32.55	31.505	10.4	35.308	28.634	30.935	28.977	26.96	26.692	34.947
Diopside	7.788	15.186		8.527	9.365	10.248	11.667	4.11	10.557	14.662
Hedenbergite	6.29	6.734		8.014	5.062	7.219	6.816	3.526	8.127	7.739
Enstatite	5.805	18.256	25.268	10.248	11.892	13.872	10.861	13.653	5.111	10.406
Ferrosilite	4.689	8.095	15.11	9.632	6.428	9.771	6.346	11.713	3.934	5.492
Fosterite					1.13	1.731	3.635			
Fayalite					.611	1.219	2.124			
Rutile										
Magnetite	3.253	2.168	3.102	2.748	2.481	2.715	2.576	3.183	3.43	2.566
Ilmenite	2.004	.785	1.854	1.473	1.222	1.438	1.331	2.106	2.492	1.218
Chromite	.052	.033	.003	.054	.015	.034	.044	.012	.018	.053
Apatite	.21	.063	2.06	.175	.104	.153	.147	.257	.344	.11
Pyrrhotite	.31		.076	.291	.104			.035	.071	.073
Hematite										
Normative Colour Index	29.8	51.23	45.57	40.64	38.12	48.21	45.36	38.29	33.70	42.08
Normative Plagioclase	55.36	67.38	62.70	67.6	48.88	63.79	55.68	54.06	50.89	70.89

*Norms calculated by the Ottawa University computer program according to the Irvine and Baragar (1971) classification

APPENDIX 2 (cont.)

Rock type	Basalt	Andesite								Dacite
Specimen no.	56	57	58	59	60	61	62	63	64	65
Major oxides	(weight percent)									
SiO_2	50.16	48.50	57.09	56.22	56.13	55.62	67.84	60.91	62.56	74.16
Al_2O_3	15.19	17.21	13.79	14.39	14.74	14.81	13.69	15.90	14.77	14.75
FeO_T	13.31	12.78	11.03	11.46	7.60	8.44	7.28	8.41	6.34	1.55
MgO	7.75	4.49	3.85	3.09	3.71	3.63	1.95	2.38	3.20	1.28
CaO	10.51	4.76	3.90	3.44	5.73	3.77	2.20	5.98	2.50	1.03
Na_2O	2.95	4.25	3.27	3.74	3.17	3.60	1.71	4.13	2.45	.88
K_2O	.12	.20	.86	1.77	1.25	.43	2.53	.25	4.59	3.79
TiO_2	.98	1.18	1.86	1.53	.80	.87	.93	1.08	.96	.21
P_2O_5	.07	.10	.35	.35	.13	.13	.17	.43	.15	.02
MnO	.18	.19	.17	.14	.13	.13	.11	.10	.13	.03
S	.02	.14	.03	.17	.01	.01	.01	.03	.01	.01
NiO	.01	.02			.01	.01				
Cr_2O_3	.03	.03			.01	.01				
CO_2								.01		
H_2O										
TOTAL	101.30	93.27	96.22	96.32	93.42	93.46	98.42	99.61	97.86	97.73
Trace elements	(ppm)									
Ba	696.	87.	408.	207.	215.	98.	331.	92.	223.	463.
Cr	38.	319.	25.	15.	63.	54.		35.	2.	2.
Zr	176.	64.	176.	153.	120.	130.	217.	184.	184.	167.
Sr	381.	49.	53.	50.	73.	51.	36.	168.	45.	68.
Rb	53.	9.	17.	58.	31.	6.	60.	13.	15.	133.
Y	42.	21.	56.	29.	23.	35.	38.	33.	72.	31.
Ce	60.	51.	49.	54.	68.	74.	95.	70.	89.	126.
Zn	115.	91.	114.	67.	88.	81.	84.	73.	15.	17.
Ni	3.	145.	12.	12.	49.	65.	5.	30.	12.	7.
Ratios										
K/Rb	271.72	187.22	416.63	250.86	330.61	382.82	348.88	164.14	366.94	206.37
Ce/Y	1.41	2.39	.88	1.85	2.92	2.14	2.52	2.10	1.23	4.11
Normative composition	(cation equivalent)*									
Quartz		1.267	18.367	12.735	14.112	13.835	38.139	17.807	18.809	49.184
Corundum		1.879	1.436	1.033		2.211	5.242		1.794	8.434
Orthoclase	.711	1.281	5.446	11.144	8.027	2.739	15.811	1.313	28.211	23.609
Albite	26.549	41.330	31.431	35.745	30.901	34.813	16.222	37.934	22.858	8.321
Anorthite	27.927	24.874	18.265	15.732	24.215	19.233	10.359	24.672	11.871	5.350
Diopside	12.234				3.131			1.298		
Hedenbergite	6.879				1.455			.946		
Enstatite	8.959	13.426	11.379	9.081	9.555	16.7414	5.688	6.073	9.180	3.722
Ferrosilite	5.037	10.319	6.241	7.460	4.441	6.113	4.052	4.426	2.849	
Forsterite	4.778									
Fayalite	2.686									
Rutile	-									.147
Magnetite	2.599	3.035	3.761	3.372	2.611	2.669	2.684	2.760	2.673	
Ilmenite	1.369	1.781	2.774	2.269	1.210	1.305	1.369	1.539	1.390	.014
Chromite	.055	.055	.004	.003	.011	.009		.006	.002	
Apatite	147.	.227	.785	.780	.296	.293	.376	.921	.326	.044
Pyrrhotite	.7	.526	.112	.628	.038	.037	.057	.107	.036	.037
Hematite										1.138
Normative Colour Index	48.54	28.6	24.16	22.20	43.93	26.83	13.79	17.04	16.09	4.87
Normative Plagioclase	52.74	38.96	38.14	30.56	22.40	35.59	40.39	40.83	35.52	40.54

*Norms calculated by the Ottawa University computer program according to the Irvine and Baragar (1971) classification

APPENDIX 2 (cont.)

Rock type	Dacite			Rhyolite			
Specimen no.	66	67	68	69	70	71	72
Major oxides (weight percent)							
SiO_2	76.96	72.59	81.51	74.99	68.54	72.17	76.67
Al_2O_3	12.74	13.12	9.86	14.36	15.50	12.76	12.77
FeO_2	4.59	3.70	.70	.79	5.59	4.28	.71
MgO	.73	1.13	.72	.24	2.92	3.42	2.04
CaO	1.20	1.85	.07	.49	.47	.45	.20
Na_2O	3.37	2.70	1.56	4.17	2.60	4.49	3.14
K_2O	1.80	3.66	5.04	3.84	2.24	.28	2.04
TiO_2	.08	.27	.08	.27	.59	.30	.17
P_2O_5		.02		.04	.11	.03	.02
MnO	.04	.04			.03	.05	.01
S	.01	.01	.01	.01	.11		.01
NiO					.01		
Cr_2O_3					.03		
CO_2							
H_2O							
TOTAL	98.52	99.09	99.55	99.20	98.74	98.23	97.78
Trace elements (ppm)							
Ba	[illegible]	512.	528.	659.	439.	85.	377.
Cr		3.	16.	20.	175.	18.	20.
Zr	151.	235.	118.	176.	133.	257.	85.
Sr	40.	71.	40.	163.	189.	38.	26.
Rb	44.	124.	59.	107.	61.	3.	48.
Y	94.	34.	24.	39.	15.	86.	10.
Ce	140.	117.	104.	111.	99.	111.	103.
Zn	3.	31.			64.	11.	5.
Ni	17.	14.	6.	19.	74.	11.	9.
Ratios							
K/Rb	338.39	244.66	715.42	296.88	307.19	800.97	353.95
Ce/Y	1.49	3.48	4.34	2.82	6.54	1.29	10.74
Normative composition (cation equivalents)*							
Quartz	44.791	35.050					
Corundum	3.457	1.574	49.740	32.566	36.920	36.091	45.200
Orthoclase	11.000	22.329	1.927	2.814	9.252	4.839	5.736
Albite	31.262	25.004	30.843	22.994	13.683	1.697	12.480
Anorthite	6.153	9.334	14.492	37.904	24.109	41.314	29.161
Diopside			.359	2.197	1.665	2.087	.891
Hedenbergite							
Enstatite	2.082	3.218	2.057	.671	8.326	9.676	5.825
Ferrosilite		1.115			2.279	1.870	
Fosterite							
Fayalite							
Rutile	.034		.076	.207			.133
Magnetite		1.909		[illegible]	2.257	1.929	
Ilmenite	.047	.388		[illegible]	.849	.428	
Chromite			.003	.003	.029	.003	.003
Apatite		.043		.557	.238	.064	.312
Pyrrhotite	.036	.036	.036	.085	.394		.043
Hematite	.138		.505	.035			.036
Normative Colour Index	3.27	6.63	2.52	1.19	13.70	13.90	6.32
Normative Plagioclase	17.27	28.37	2.36	5.79	6.83	5.09	3.14

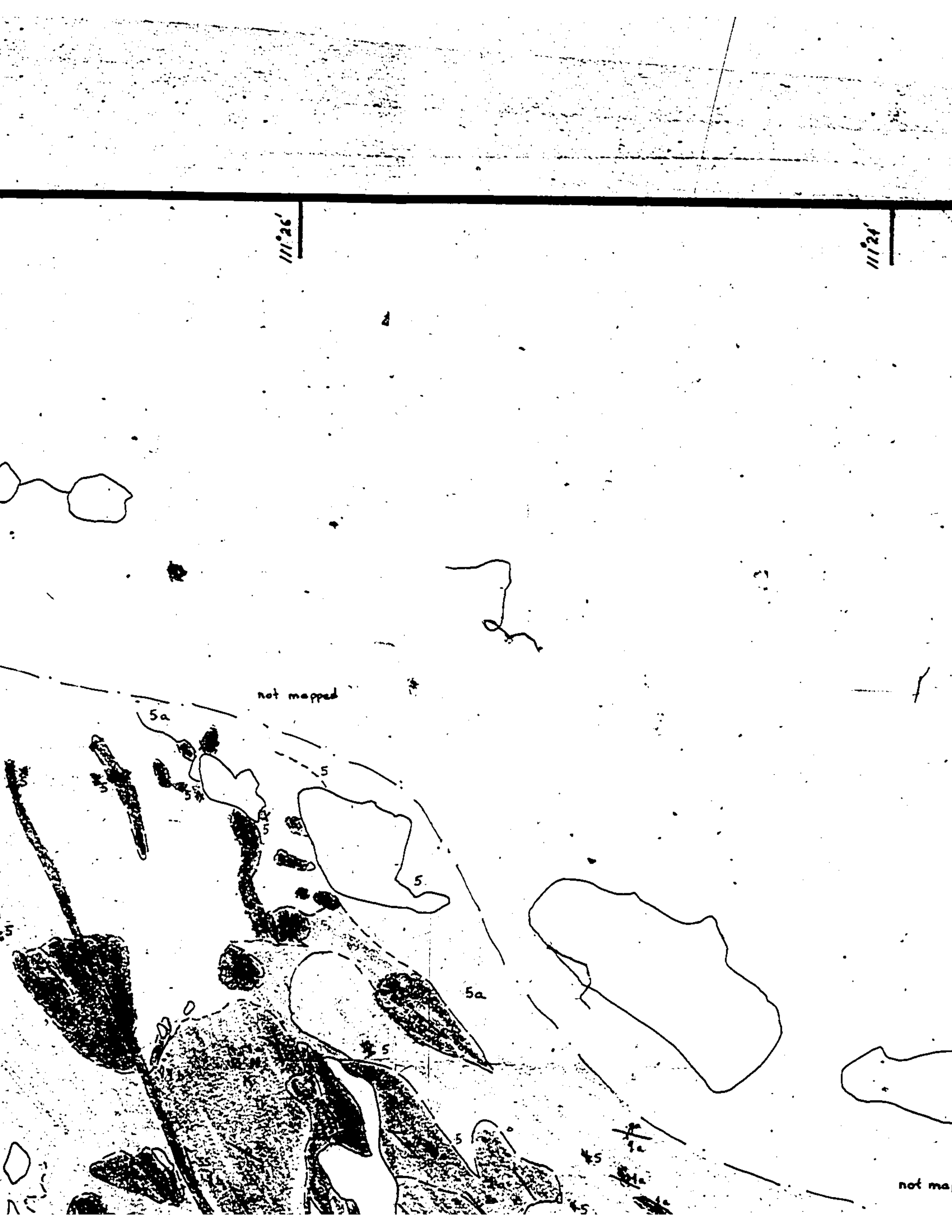
*Norms calculated by the Ottawa University computer program according to the Irvine and Baragar (1971) classification

MAP 1

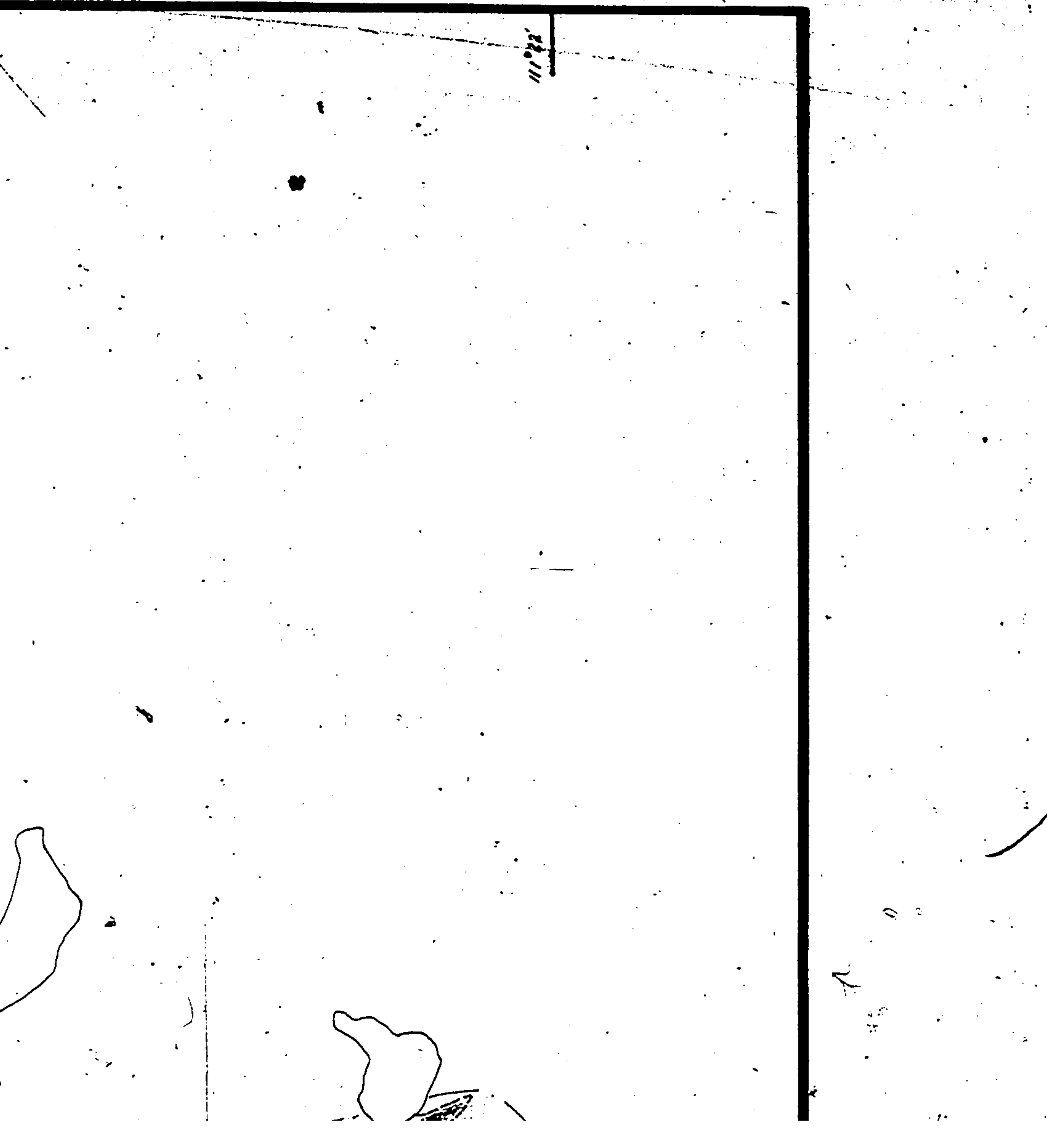
2 OF

111°30'


111°28'



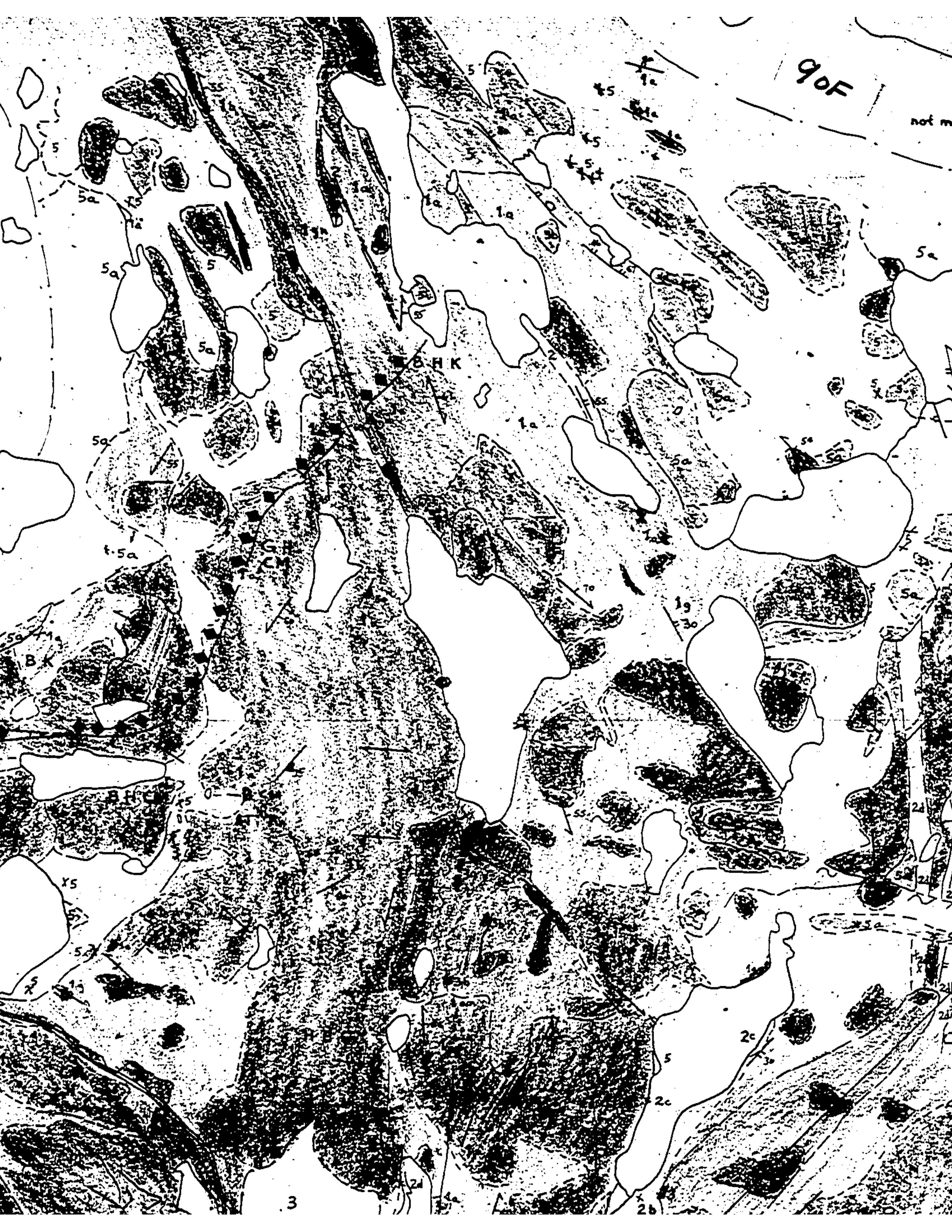
111°26'
111°24'
not mapped
5a
5
5a
not map

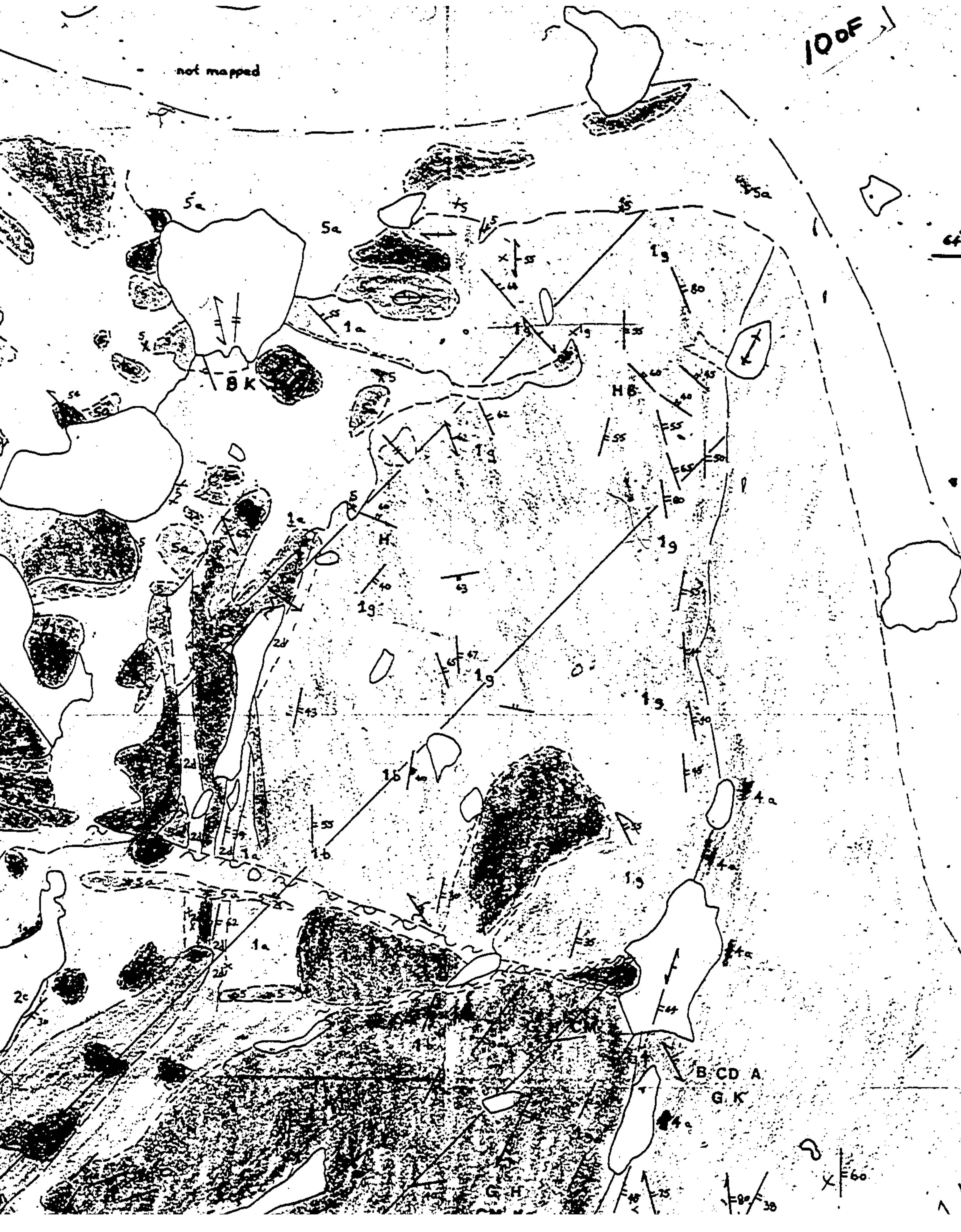

111°22'

64°22′

6 OF

80F
not mapped
mapped
5
5a
5b
1a
BCD
AS
K
BCM
CDK
BCDA
SK
CMA
CDS
BK

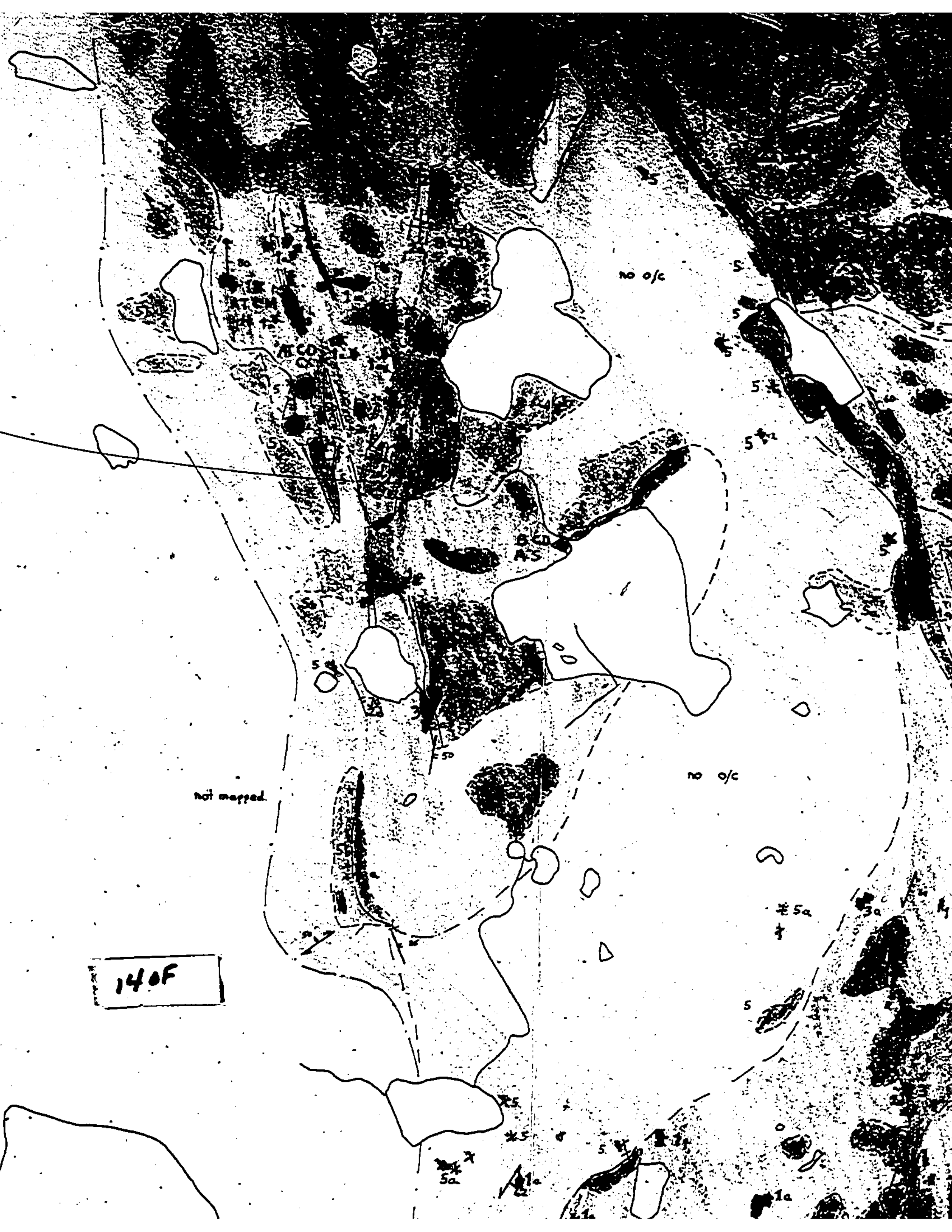

90F
GHK
GH
CM
BK
BHC
1a
1g
2c
2d
2b
5
5a
3

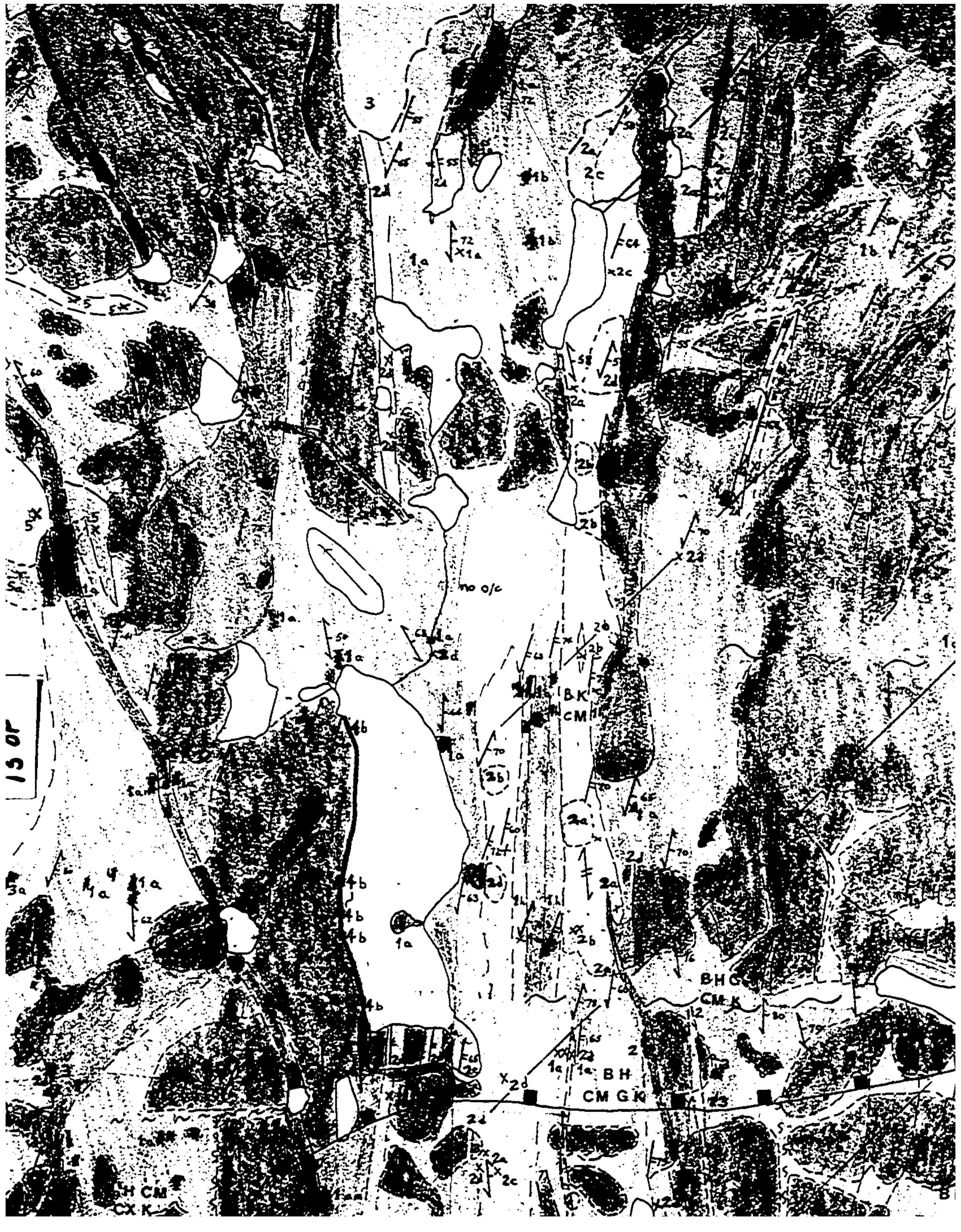


10oF
not mapped
5a
1a
1g
BK
HB
H
2d
2c
1b
4a
GH CM
B CD A
G K
G H

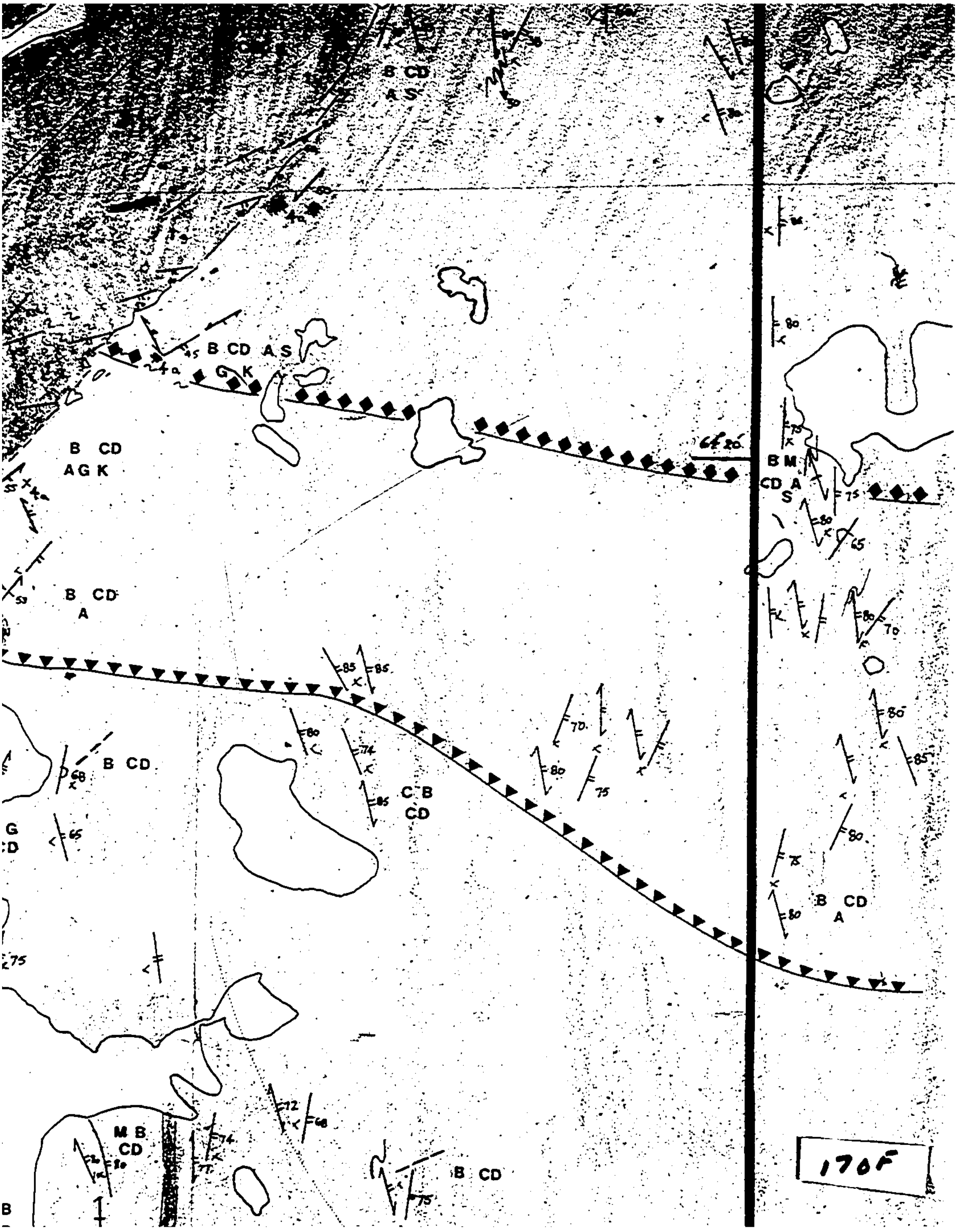
Sa
1a
1g
HB
H
1b
4a
B CD A
G K
G H
64°22'
110F

12 of


no o/c
no o/c
not mapped
14 F

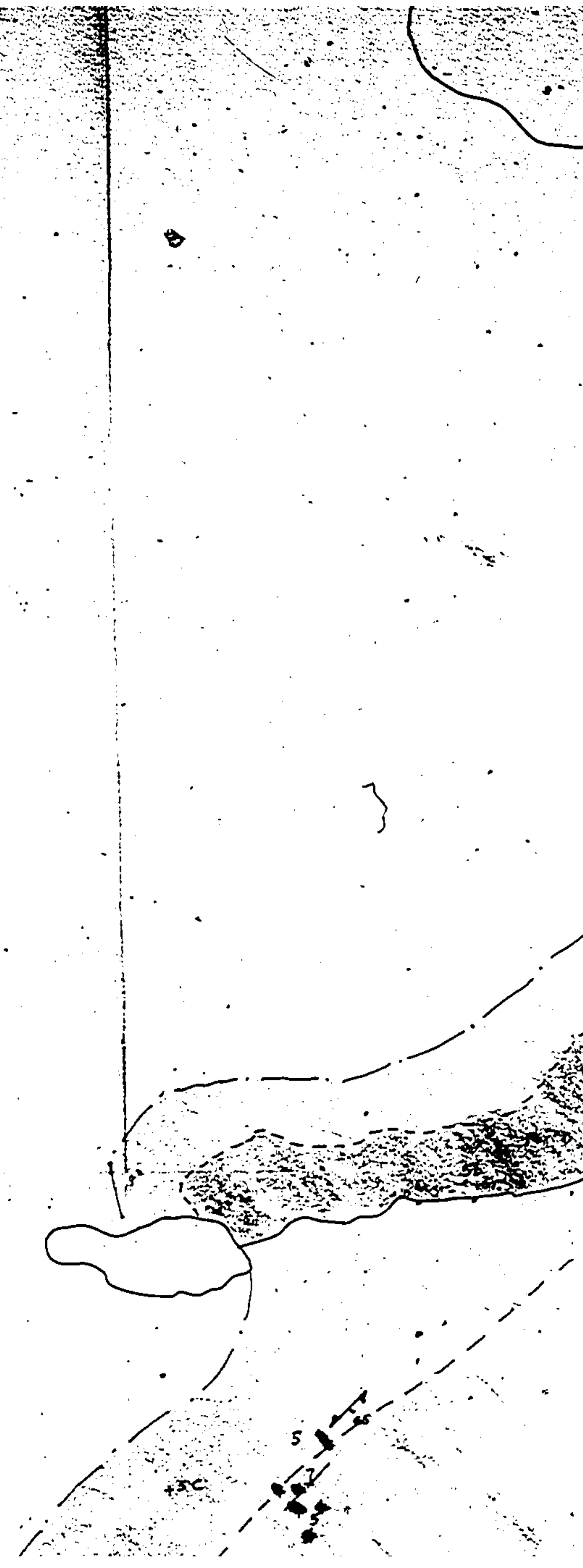

no o/c
BK
CM
BH
CM GK
BH CM
CX K

B CD
A S
B CD A S
G K
B CD
A G K
B CD
A
B CD
C B
CD
B G
CD
M B
CD
B CD
M B
CD
4a
B M
CD A
S
160F


B CD
A S
B CD A S
G K
B CD
A G K
B CD
A
B CD
C B
CD
G
CD
B M
CD A
S
B CD
A
M B
CD
B CD
B
170F

180F

190F




20 OF
not mapped
no O/c


21OF
No O/C


C M B
CD
C M B
CD
C M
B
C M
B
C M
B
C M
B
C M
B
C M B
CD
22 OF

23OF

LEGEND

INTRUSIVE ROCKS

PROTEROZOIC

Diabase: highly magnetic, steeply dipping dykes.

ARCHEAN

Pegmatite: biotite-muscovite pegmatite.

Granitoid rocks: 5a) biotite granite (synkinem granodiorite; 5c) biotite-hornblende tonalite; 5d) trondhjemite (synvolcanic to earlier?).

Metagabbro: feeder sills and dykes to the volcan subunit 4a and unit 6, crosscuts 5b. 3a, massive 3b, massive, feldspar-porphyritic.

SUPRACRUSTAL ROCKS

YELLOWKNIFE SUPERGROUP

Metasediments: 4a) greywacke, arkose, and 4b) intervolcanic argillite or phyllite; conglomerate; 4d) pyritic banded chert; 4e) granit conglomerate.

Cycle 2

2

Metarhyolite to metadacite: 2a) massive rhy block-breccia; 2c) rhyodacitic quartz-feldsp volcaniclastic; 2d) dacitic ash to lapilli-size 2f) massive quartz-feldspar phyric intrusive rock.

Intermediate metavolcanics: 1c) massive, amyd flow; 1d) pillowed, amygdaloidal andesite 1h) andesitic fragmental rock.

Mafic metavolcanics: 1a) massive basalt flow; 1 flow; 1e) massive feldspar phyric basalt flow; 1f) phyric basalt; 1g) "banded" basalt (highly flattened)

Note: volcanic units without inclined ruling have to a specific cycle.

Cycle 1

tic); 5b) biotite
otite-hornblende

pile, older than
non-porphyritic;

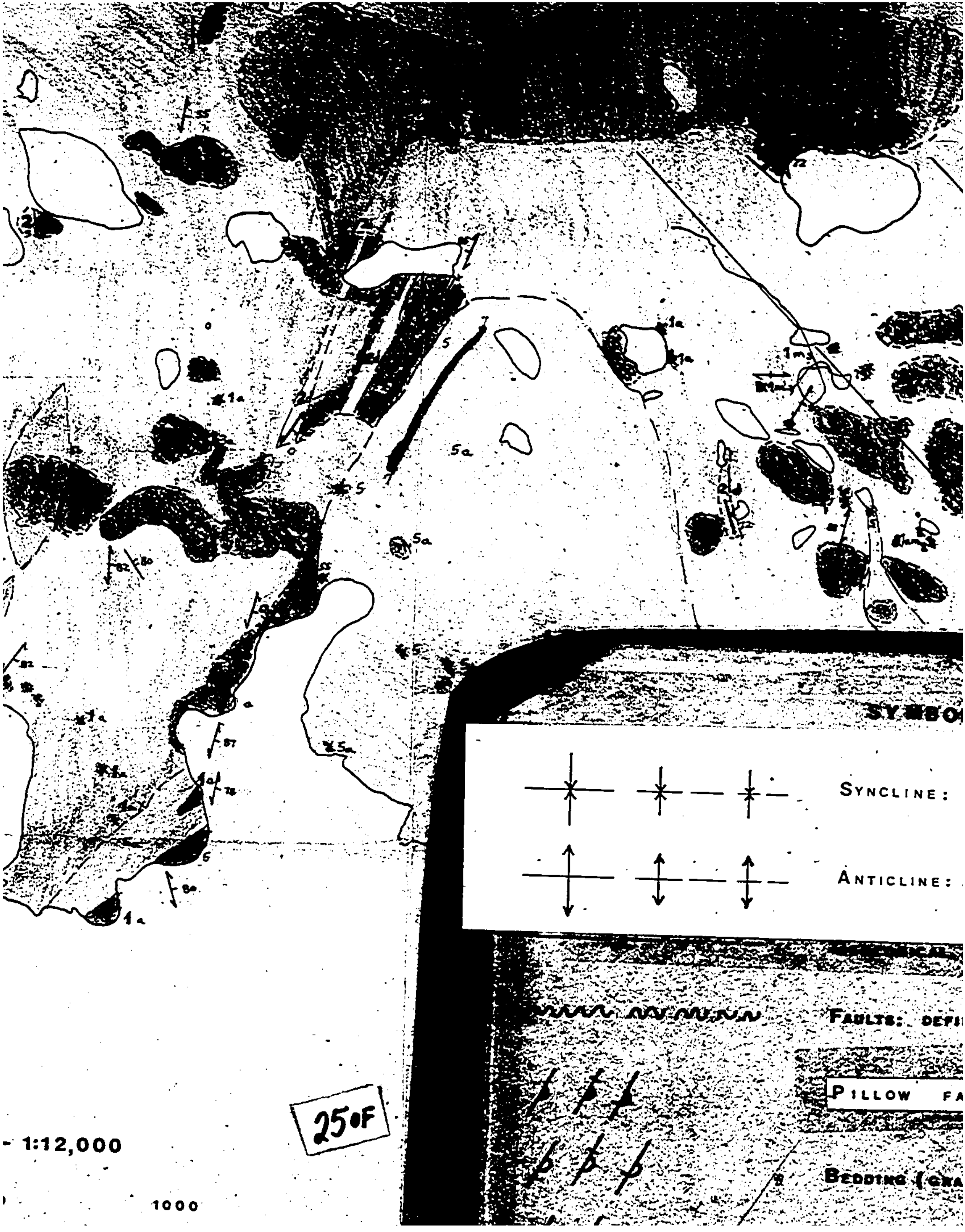
ate turbidites;
c) intervolcanic
l-volcanic clast

e; 2b) rhyolite
lapilli-sized
volcaniclastic;

loidal andesite
low:

pillowed basalt
lowed feldspar

t been related


SYNCLINE:
ANTICLINE:
FAULTS: DEFI
PILLOW FA
BEDDING (GRA
- 1:12,000
1000
25 OF

S

DEFINED, APPROXIMATE, ASSUMED

DEFINED, APPROXIMATE, ASSUMED

, ASS

NED, APPROXIMATE, ASSUMED

ACING — INCLINED, VERTICAL, OVERTUR

ADED TOPS) — INCLINED, VERTICAL, OVERTUR

S UNKNOWN) — INCLINED, VERTICAL

26OF

MAP 1

270R

2

Metarhyolite to metadacite: 2c) rhyodacitic quartz-
sized volcaniclastic; 2d) dacitic ash to lapilli-sized
2e) rhyodacitic block-breccia (highly chloritic).

Mafic metavolcanics: 1a) massive basalt flow; 1b)
flow.

Metamorphic assemblages: A - andalusite; AT
B - biotite; C - chlorite; CD - cordierite; CM -
CX - clinopyroxene; E - epidote; G - garnet;
K - potassium feldspar; M - muscovite; S - sillimanite

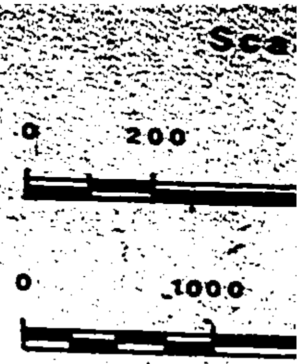
m = carbonatized; s = sheared; n = silicified.

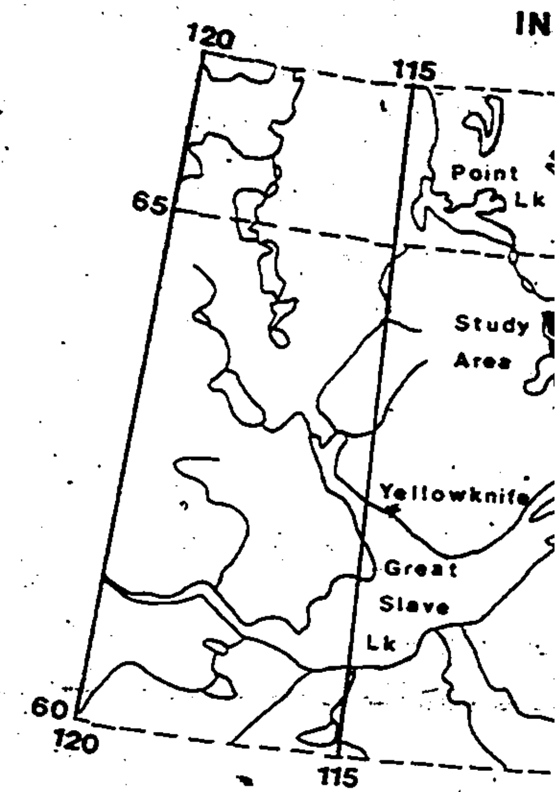
280F

-feldspar lapilli-
| volcaniclastic;

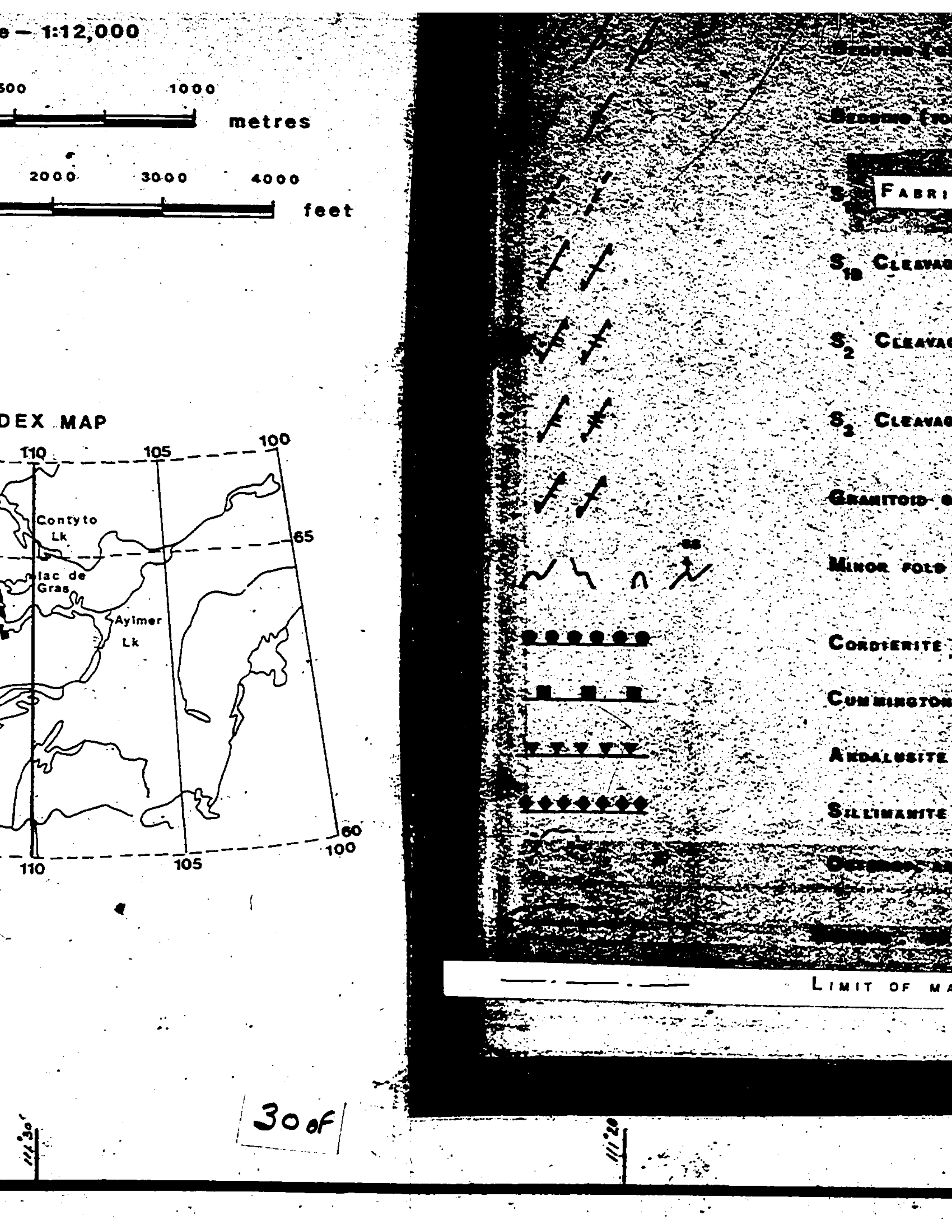
pillowed basalt

- anthophyllite;
cummingtonite;
KY - Kyanite;





29OF



e – 1:12,000
500
1000
metres
2000
3000
4000
feet
DEX MAP
110
105
100
65
Contyto
Lk
lac de
Gras
Aylmer
Lk
60
100
110
105
FABRI
S_{1b} CLEAVAG
S_2 CLEAVAG
S_3 CLEAVAG
GRANITOID
MINOR FOLD
CORDIERITE
CUMMINGTON
ANDALUSITE
SILLIMANITE
LIMIT OF MA
30 of
111°30'
111°20'

...TOPS): INCLINED, VERTICAL, OVERTU...

...OWN): INCLINED, VERTICAL

...CLINED, DIP UNKNOWN

...CLINED, VERTICAL

...CLINED, VERTICAL

...CLINED, VERTICAL

...OSITY: INCLINED, VERTICAL

...ETRY: Z SENSE, S SENSE, SENS...
UNKNOWN, FOLD PLUNGE

...GRAD

...SOGRAD

...RAD

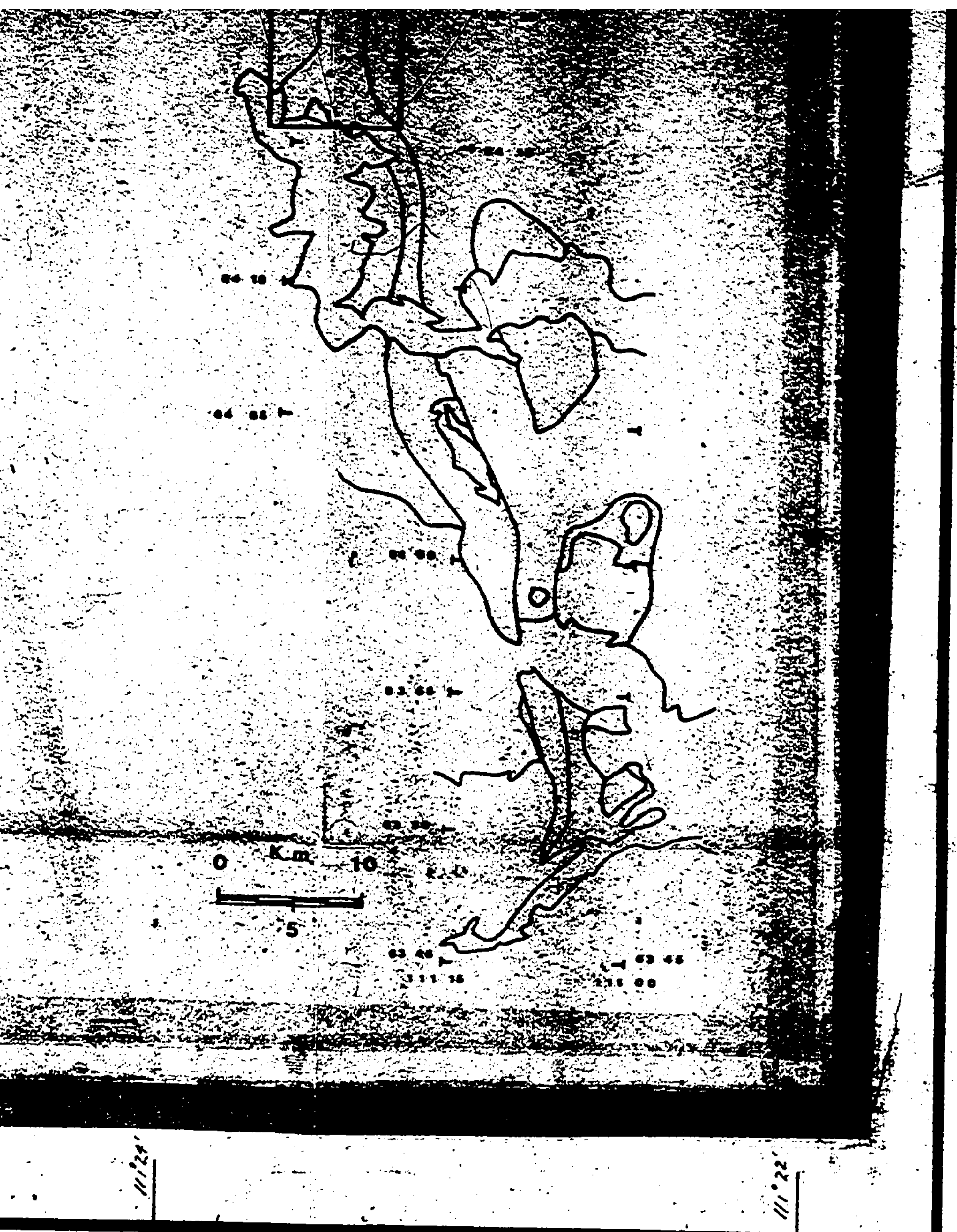
...GRAD

...NG

111°26'

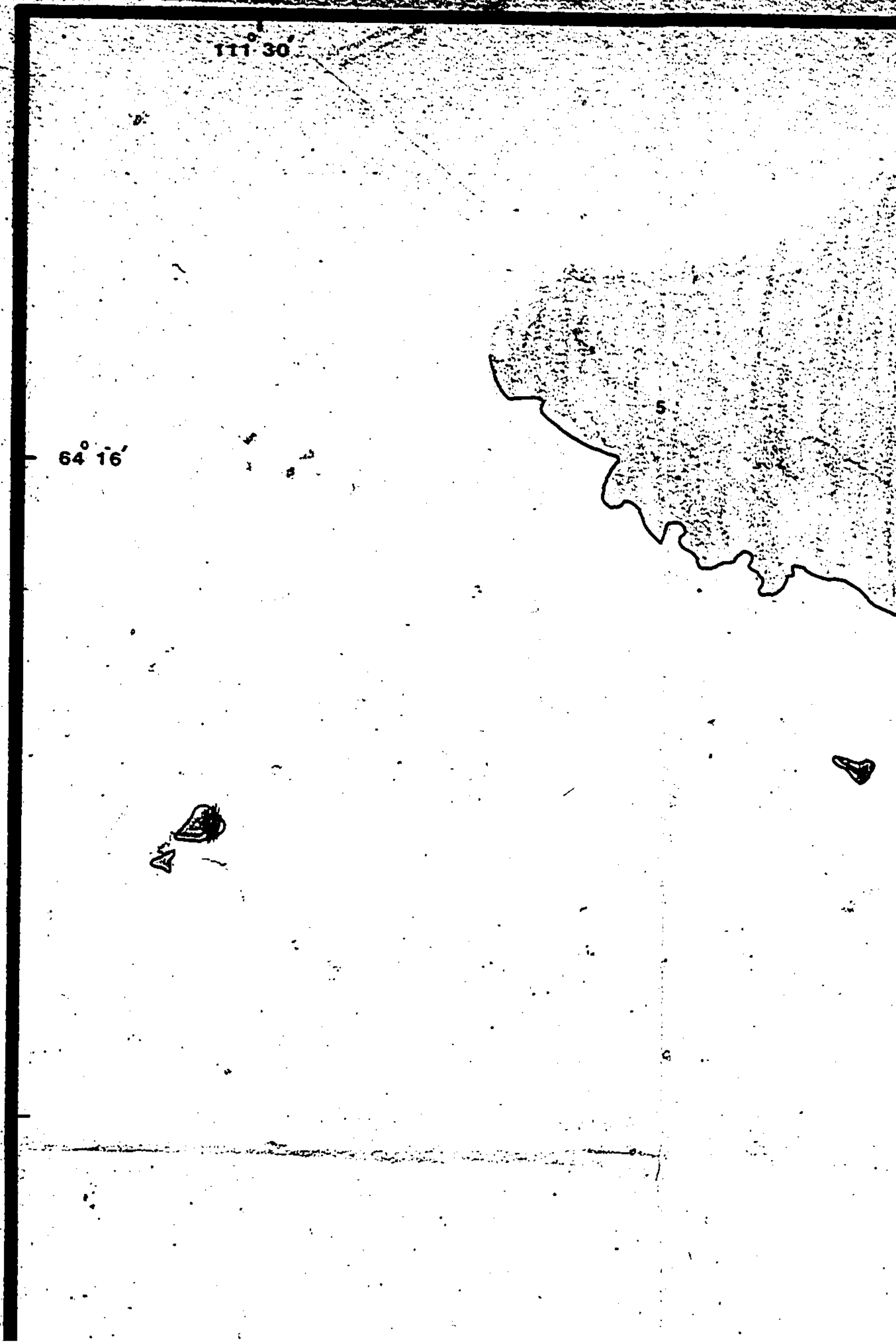
3/ OF

111°24'

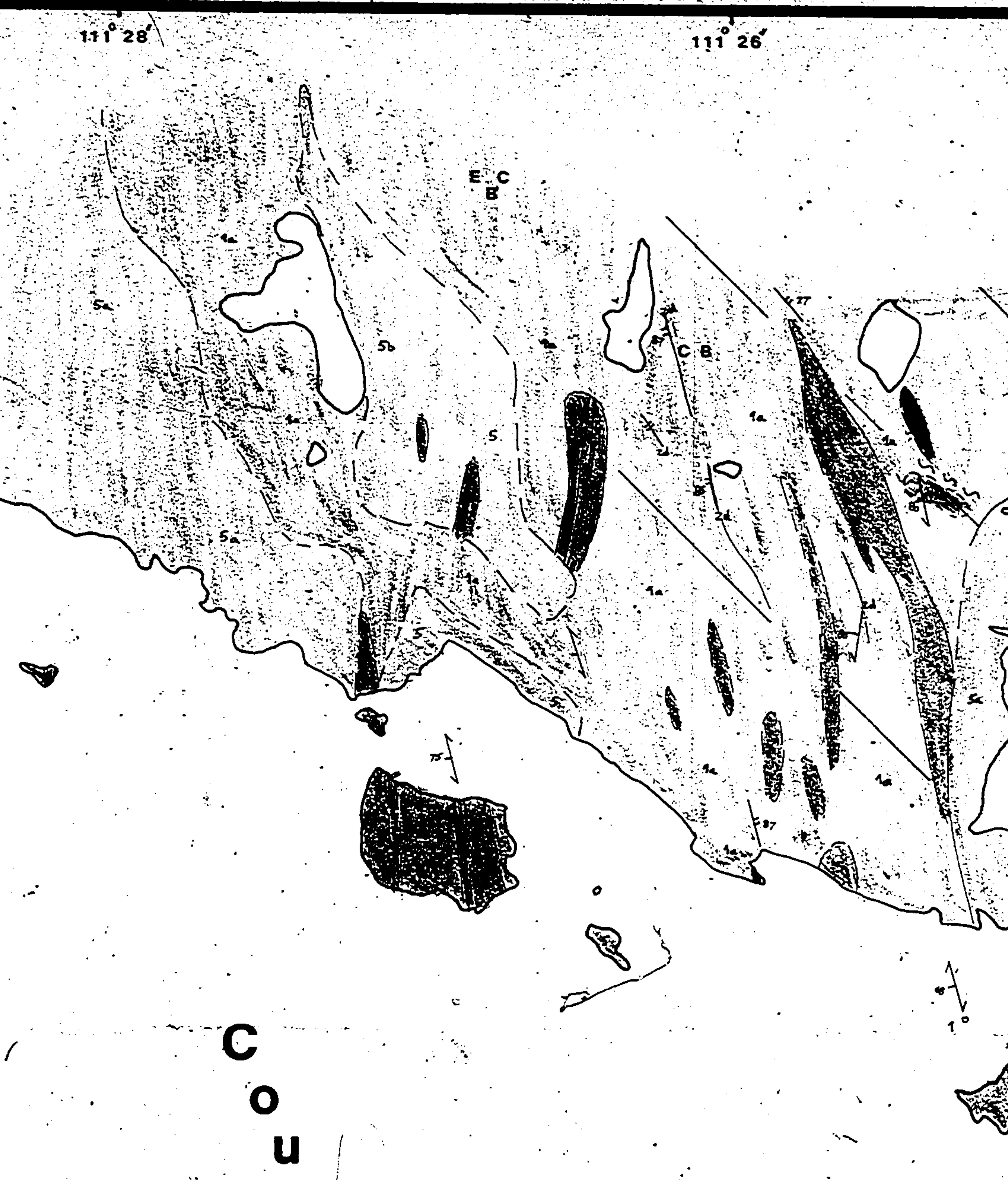

0 Km 10
5
111°24'
111°22'

MAP 2

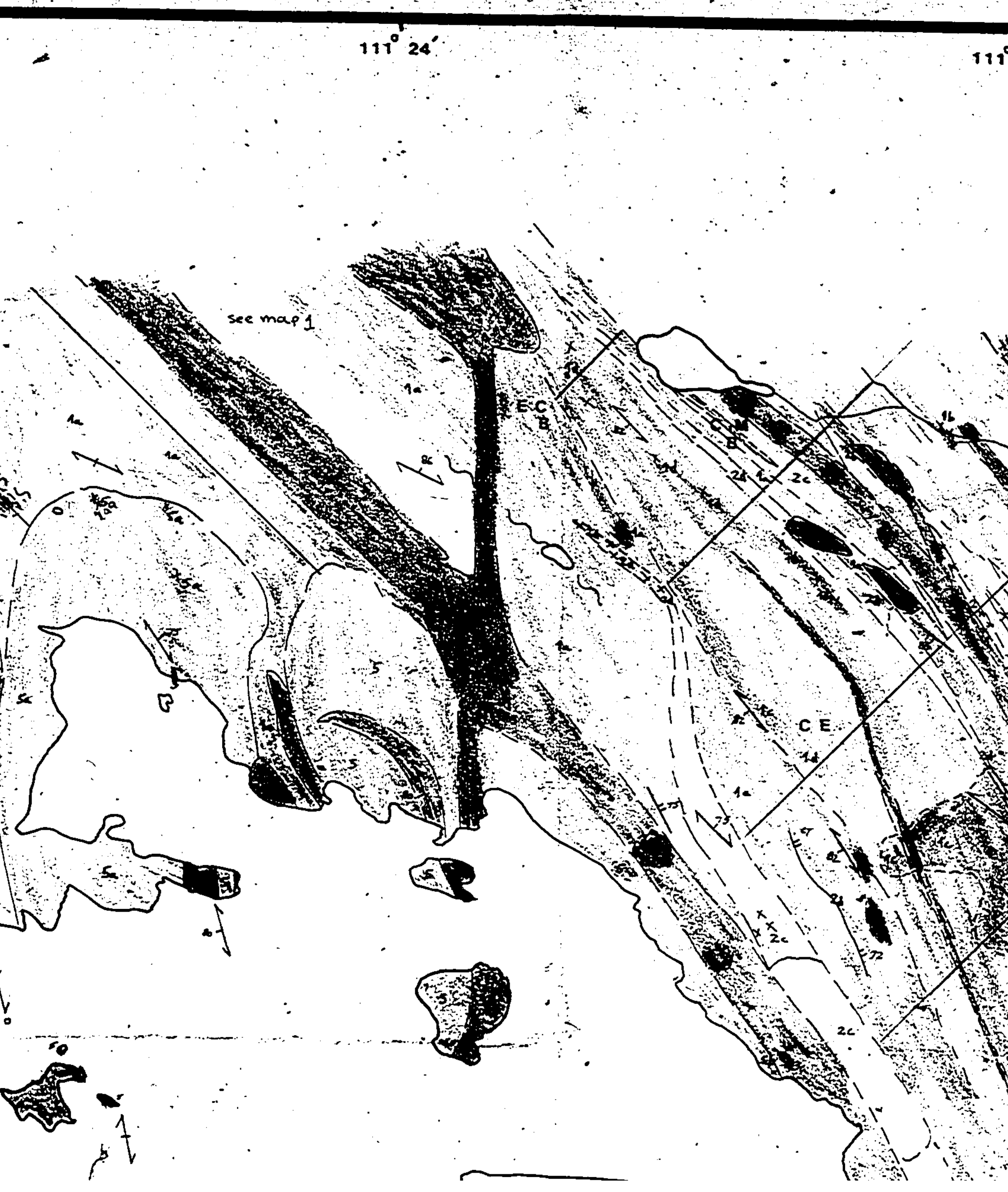
1 OF



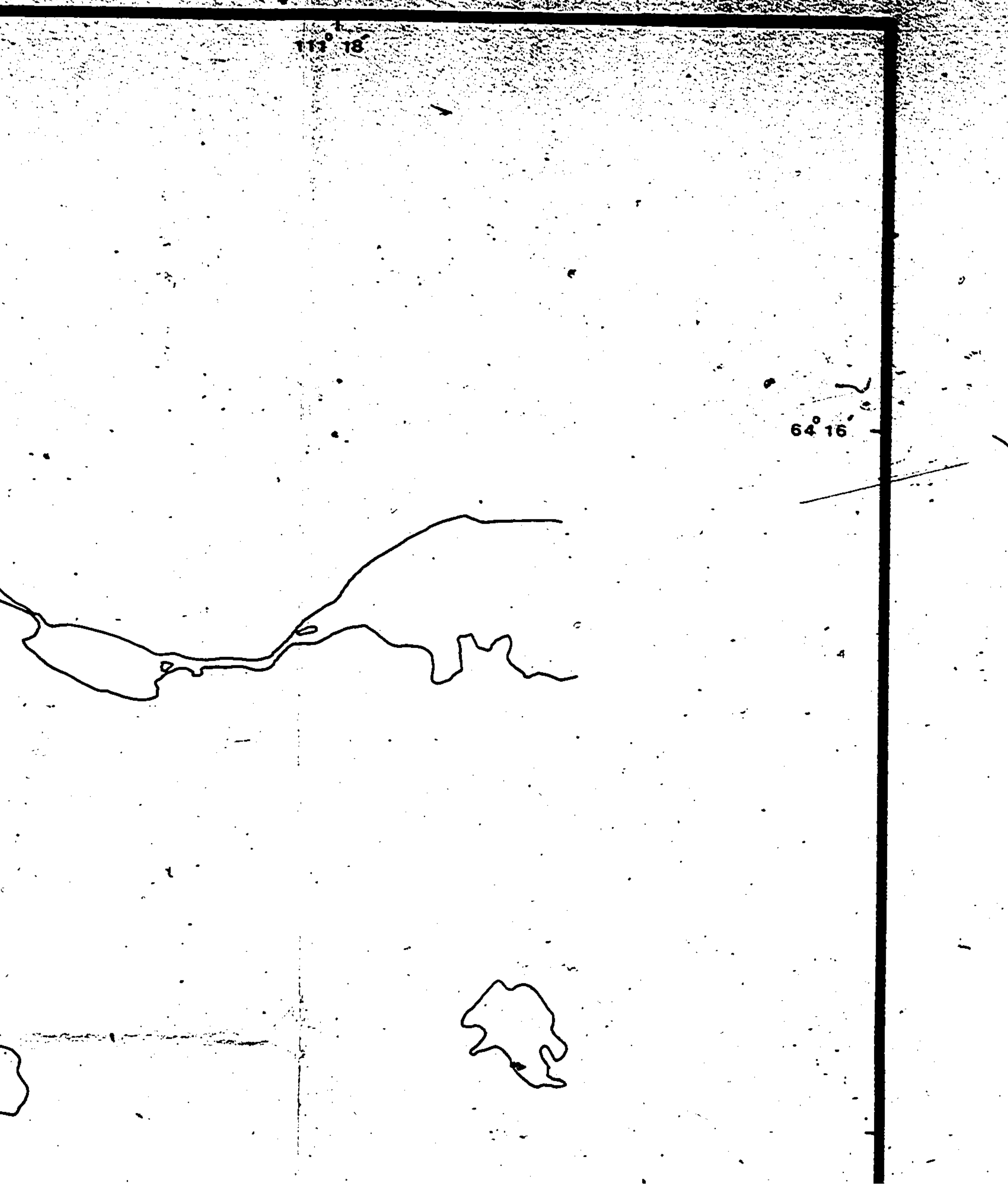
2 OF



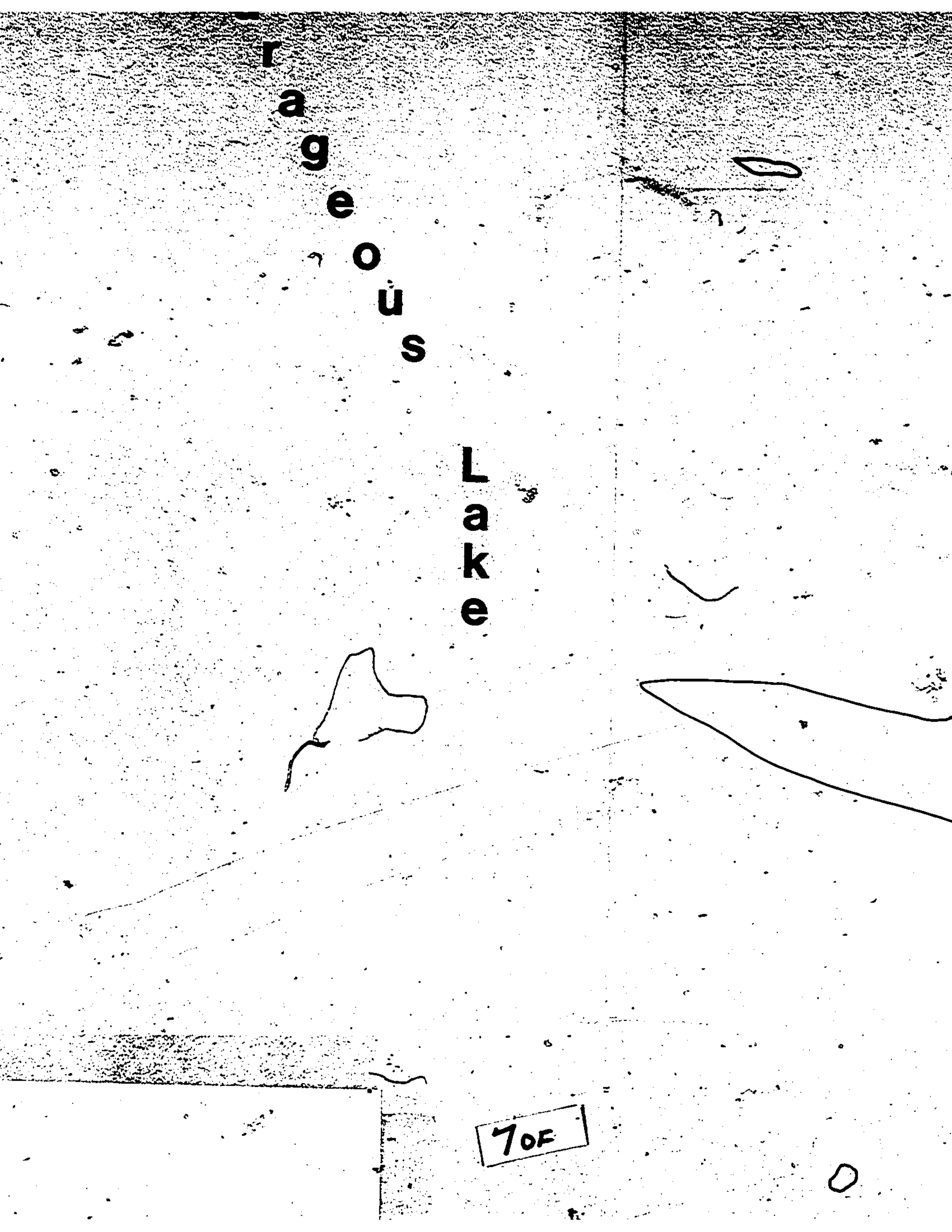
3 OF




111°22'
111°20'
C M
B
C M
B

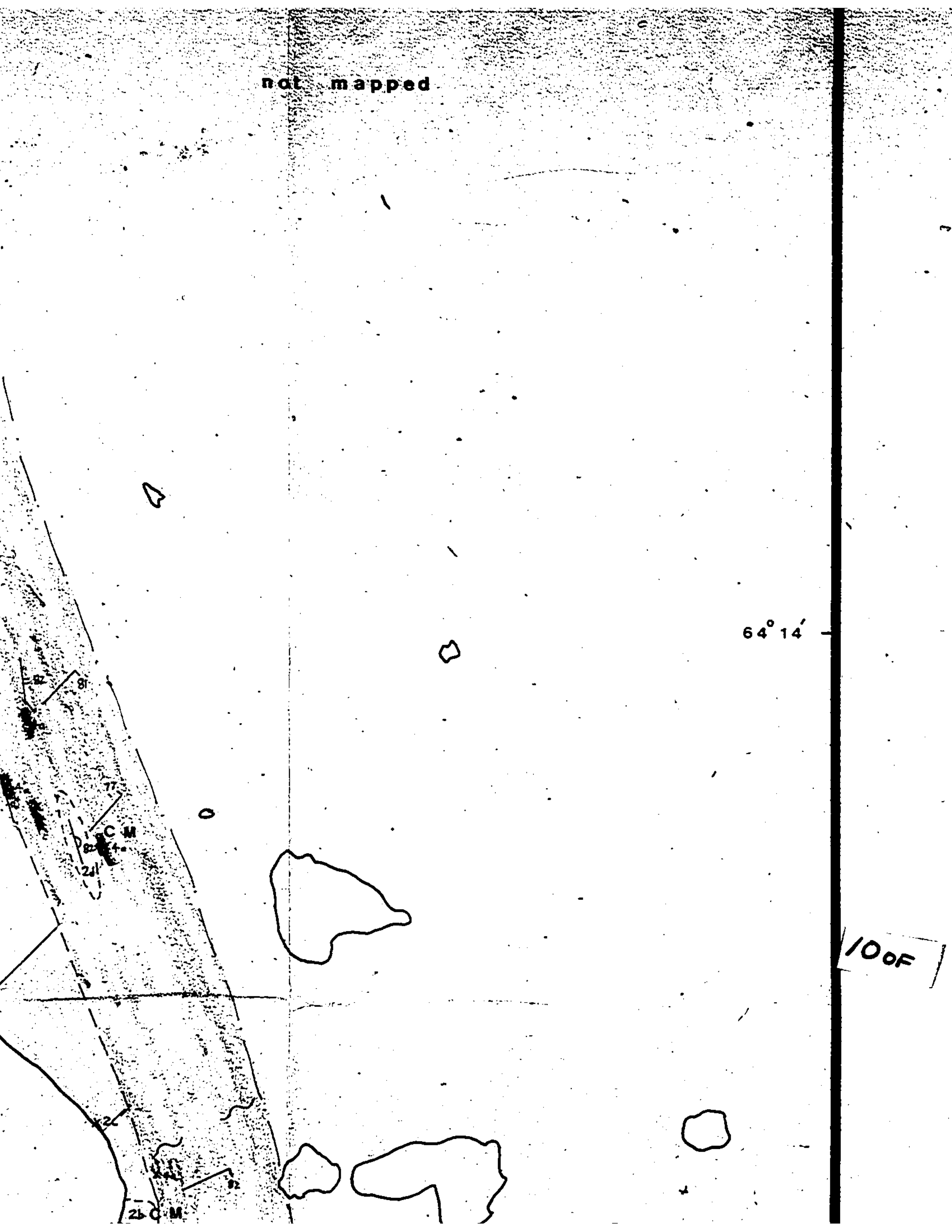

111° 18'
64° 16'


64°14′
6 OF


rageous Lake
7 OF

not mapped
x 5b
80F


90F
C M
B
2e
2c
2b
2d
1a
5a
2a
78
73
75
77
82
81


not mapped
64° 14′
C M
C M
81
82
77
10 OF

110F

64° 12′

LEGEND

INTRUSIVE ROCKS

PROTEROZOIC

Diabase: highly magnetic, steeply dipping d

ARCHEAN

6 — Pegmatite: biotite-muscovite pegmatite.

5 — Granitoid rocks: 5a) biotite granite (s granodiorite; 5c) biotite-hornblende tonali trondhjemite (synvolcanic to earlier?).

Metagabbro: feeder sills and dykes to the subunit 4a and unit 6, crosscuts 5b. 3a, 3b, massive, feldspar-porphyritic.

SUPRACRUSTAL ROCKS

YELLOWKNIFE SUPERGROUP

4a — Metasediments: 4a) greywacke, arkose 4b) intervolcanic argillite or phy conglomerate; 4d) pyritic banded chert; 4e conglomerate.

Cycle 2

2 — Metarhyolite to metadacite: 2a) massi block-breccia; 2c) rhyodacitic quart volcaniclastic; 2d) dacitic ash to lap 2f) massive quartz-feldspar phyric intrusive

1 — Intermediate metavolcanics: 1c) massive flow; 1d) pillowed, amygdaloidal an 1h) andesitic fragmental rock.

1 — Mafic metavolcanics: 1a) massive basalt flow; 1e) massive feldspar phyric basalt fl phyric basalt; 1g) "banded" basalt (highly fla

Note: volcanic units without inclined rulin to a specific cycle.

Cycle 1

2 — Metarhyolite to metadacite: 2c) rhyodacit sized volcaniclastic; 2d) dacitic ash to la 2e) rhyodacitic block-breccia (highly chlori

g dykes.

e.

(synkinematic); 5b) biotite
nalite; 5d) biotite-hornblende

the volcanic pile, older than
3a, massive non-porphyritic;

kose, and slate turbidites;
phyllite; 4c) intervolcanic
; 4e) granitoid-volcanic clast

assive rhyolite; 2b) rhyolite
artz-feldspar lapilli-sized
lapilli-sized volcaniclastic;
sive rock.

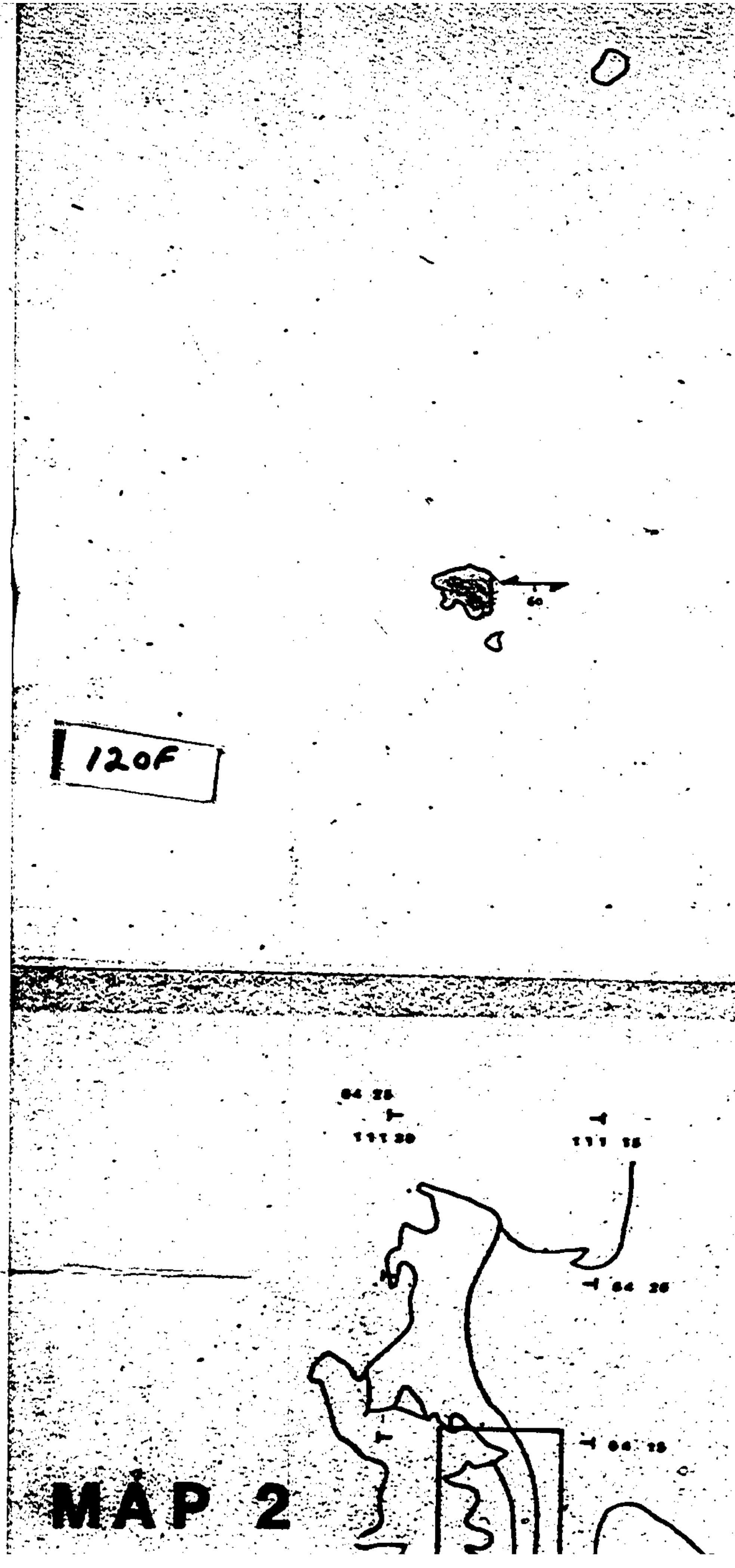
ssive, amydgaloidal andesite
andesite flow:

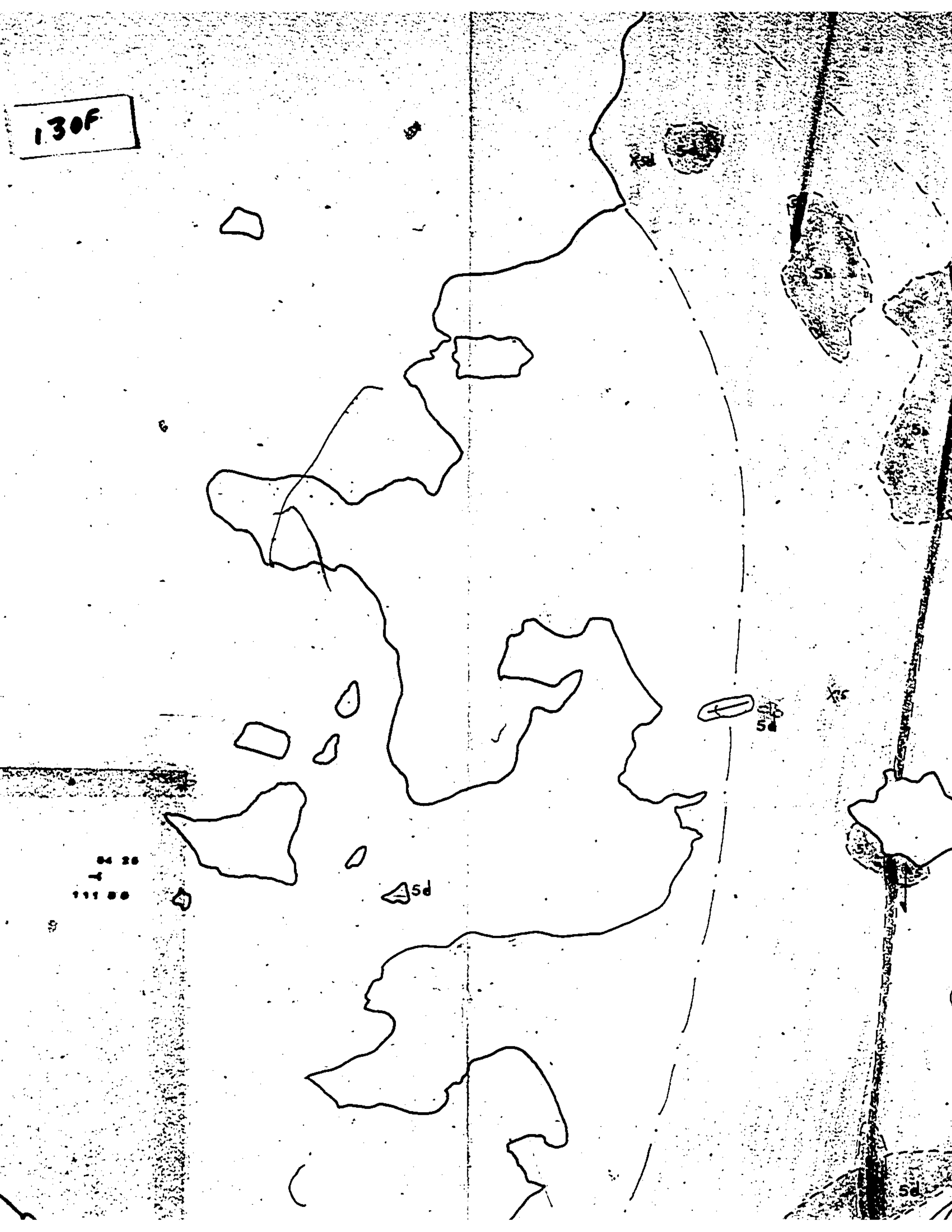
alt flow; 1b) pillowed basalt
lt flow; 1f) pillowed feldspar
y flattened).

ruling have not been related

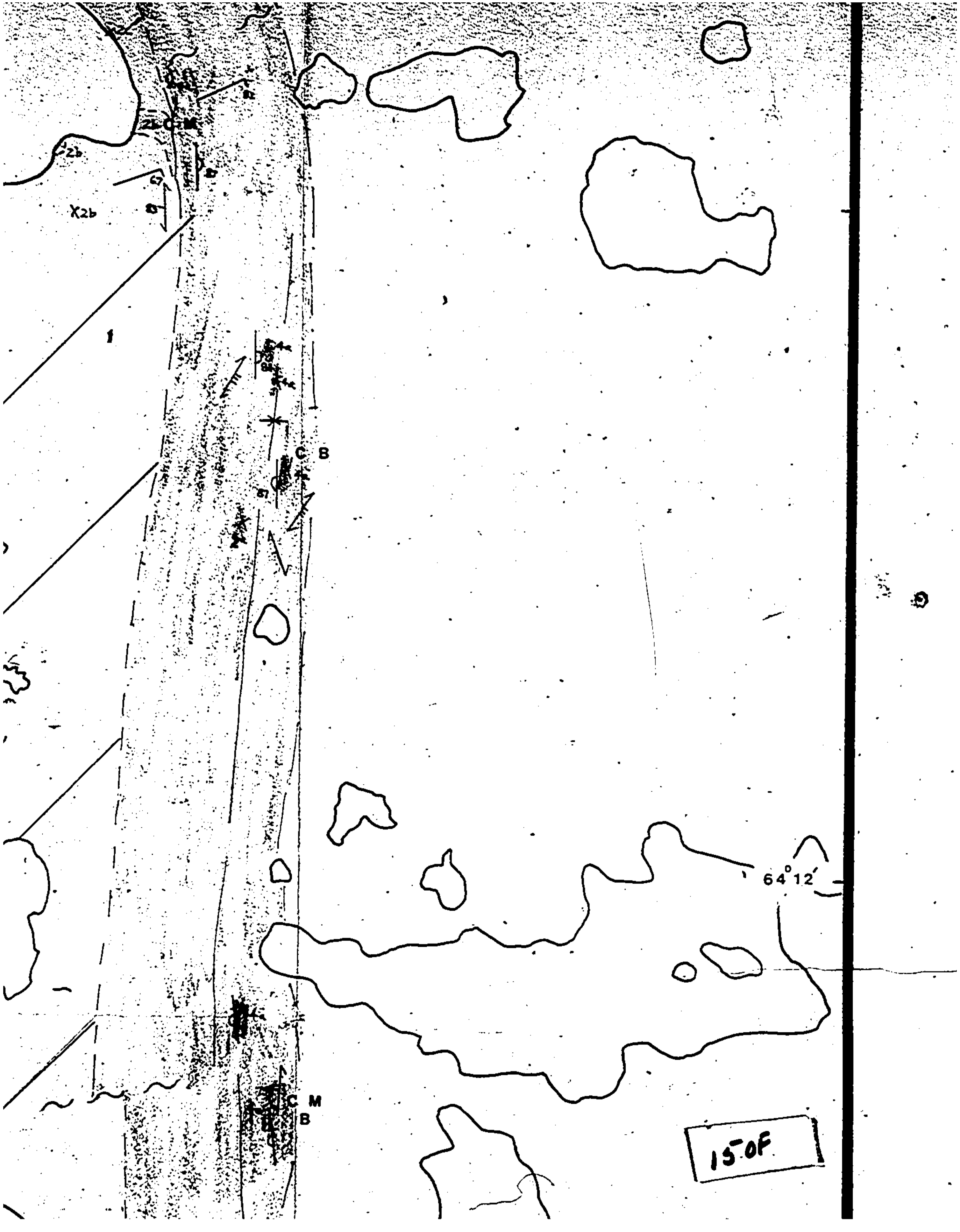
acitic quartz-feldspar lapilli-
lapilli-sized volcaniclastic;
loritic).

alt flow; 1b) pillowed basalt




1.30F
5d
5d

14 OF
CM
B
CM
B
X2b
2b
2d
2a
2c
2f
5a
5b
5c
5d
X5
X2am
2am
1a
78
82
2d


X2b
2b
C M
C B
C M
B
64°12'
15-OF

Metarhyolite to metadacite: 2c) rhyoda
sized volcaniclastic; 2d) dacitic ash to
2e) rhyodacitic block-breccia (highly chl

Mafic metavolcanics: 1a) massive basa
flow.

Metamorphic assemblages: A - anda
B - biotite; C - chlorite; CD - cordi
CX - clinopyroxene; E - epidote;
K - potassium feldspar; M - muscovite; S

m = carbonatized; s = sheared; n = silicif

SYMBOLS

SYNCLINE: DEFINED, APP

ANTICLINE: DEFINED, APP

[illegible]

FAULTS: DEFINED, [illegible]

PILLOW FACING

BEDDING (GRADED TOPS): IN

BEDDING (TOPS UNKNOWN): IN

S_{1A} FABRIC: INCLINED,

64° 10′

S_{1B} CLEAVAGE: INCLINED,

S_2 CLEAVAGE: INCLINED, V

160F

: 2c) rhyodacitic quartz-feldspar lapilli-
citic ash to lapilli-sized volcaniclastic;
a (highly chloritic).

nassive basalt flow; 1b) pillowed basalt

: A - andalusite; AT - anthophyllite;
CD - cordierite; CM - cummingtonite;
epidote; G - garnet; KY - Kyanite;
muscovite; S - sillimanite.

d; n = silicified.

NED, APPROXIMATE, ASSUMED

NED, APPROXIMATE, ASSUMED

, APPROXIMATE, ASSUMED

, APPROXIMATE, ASSUMED

G. INCLINED, VERTICAL, OVERTURNED

TOPS): INCLINED, VERTICAL, OVERTURNED

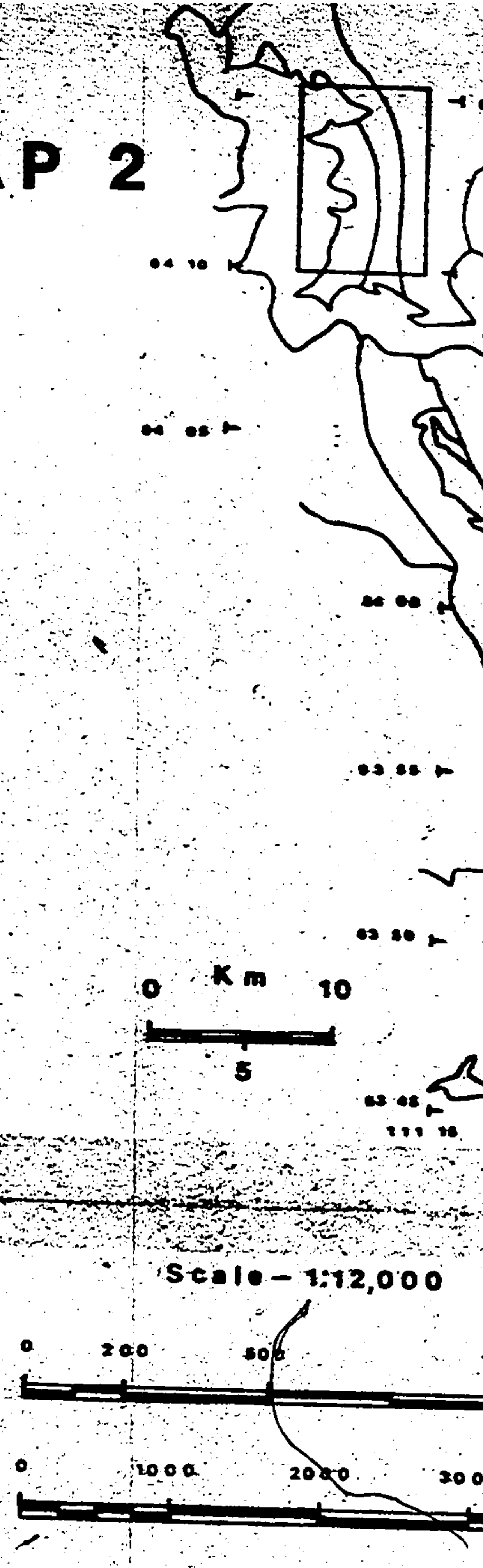
KNOWN): INCLINED, VERTICAL

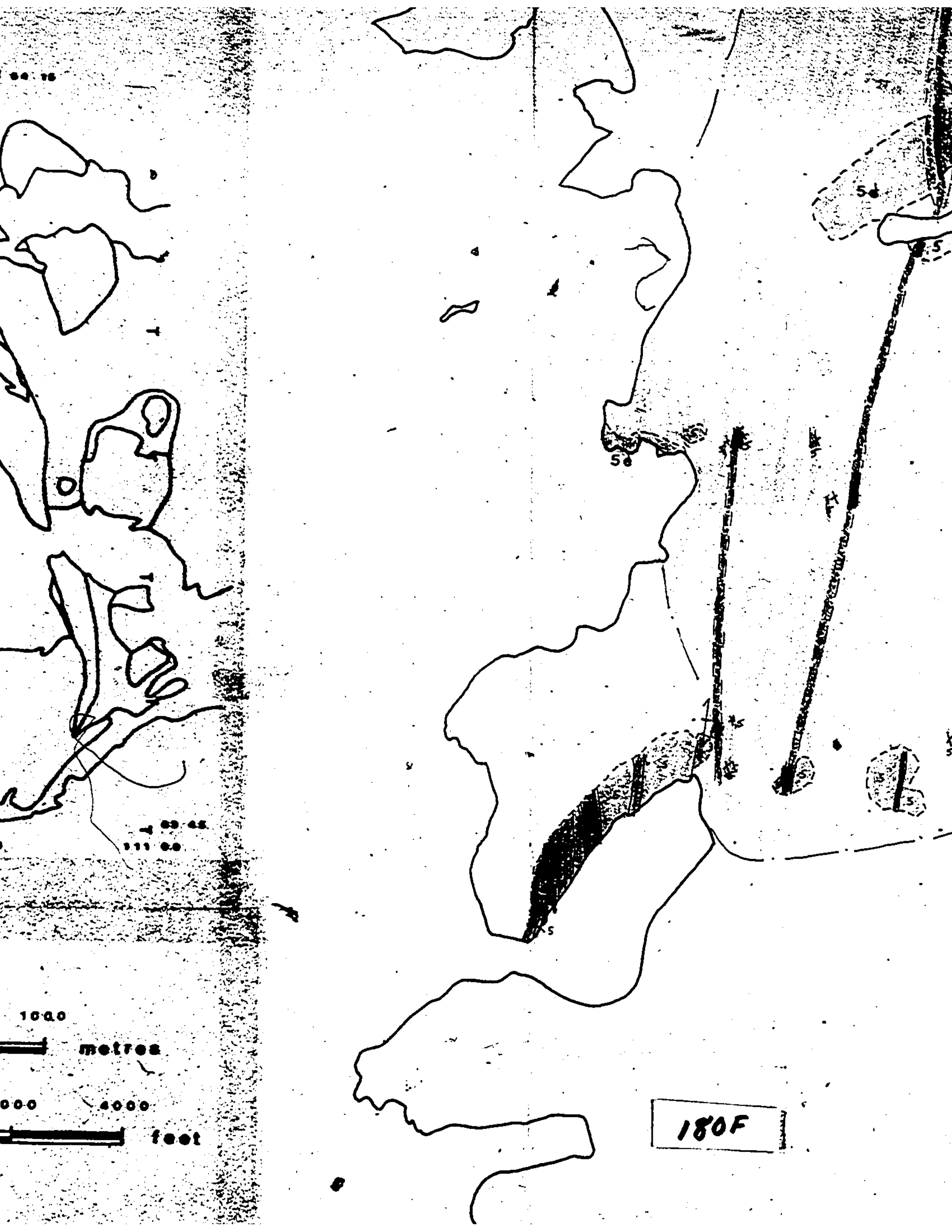
CLINED, DIP UNKNOWN

CLINED, VERTICAL

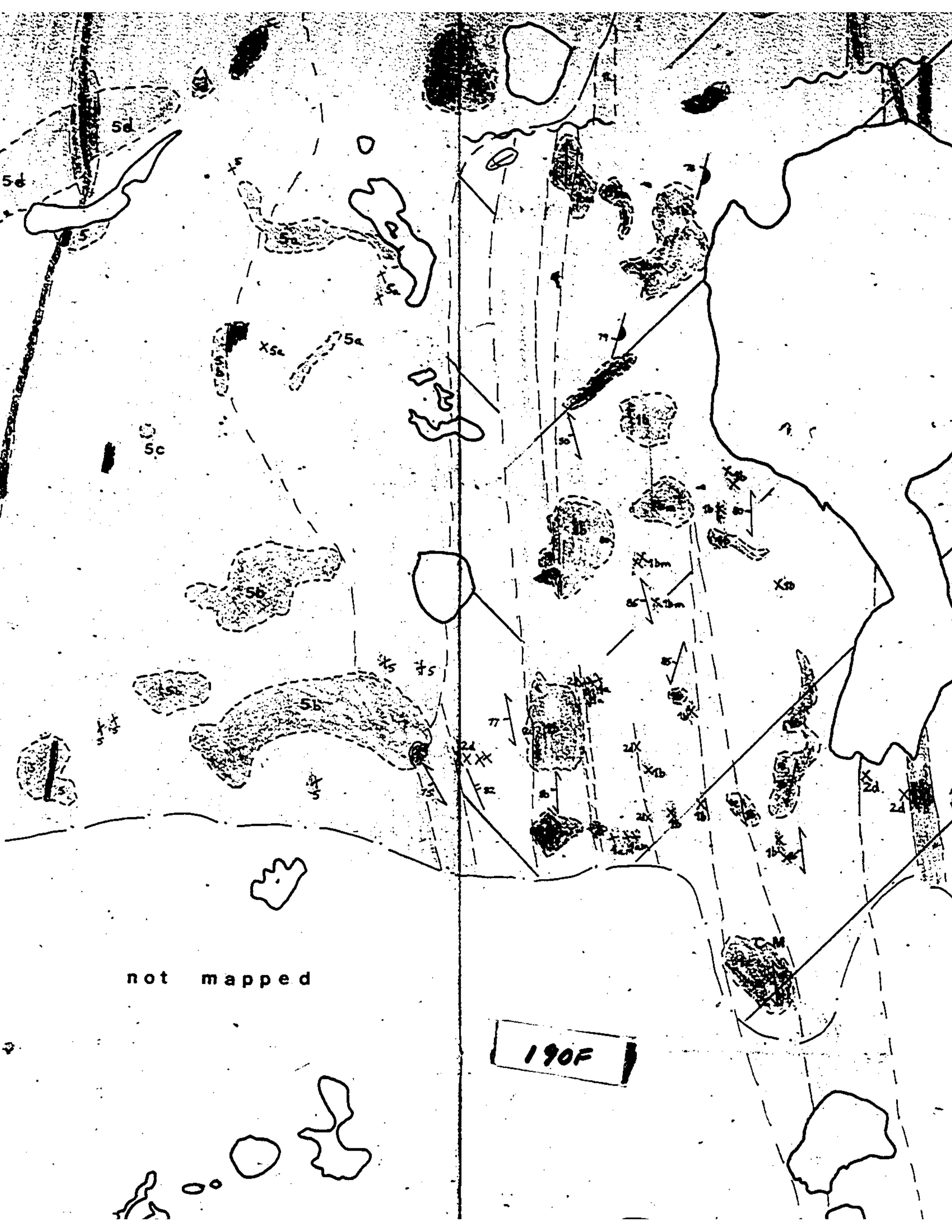
CLINED, VERTICAL

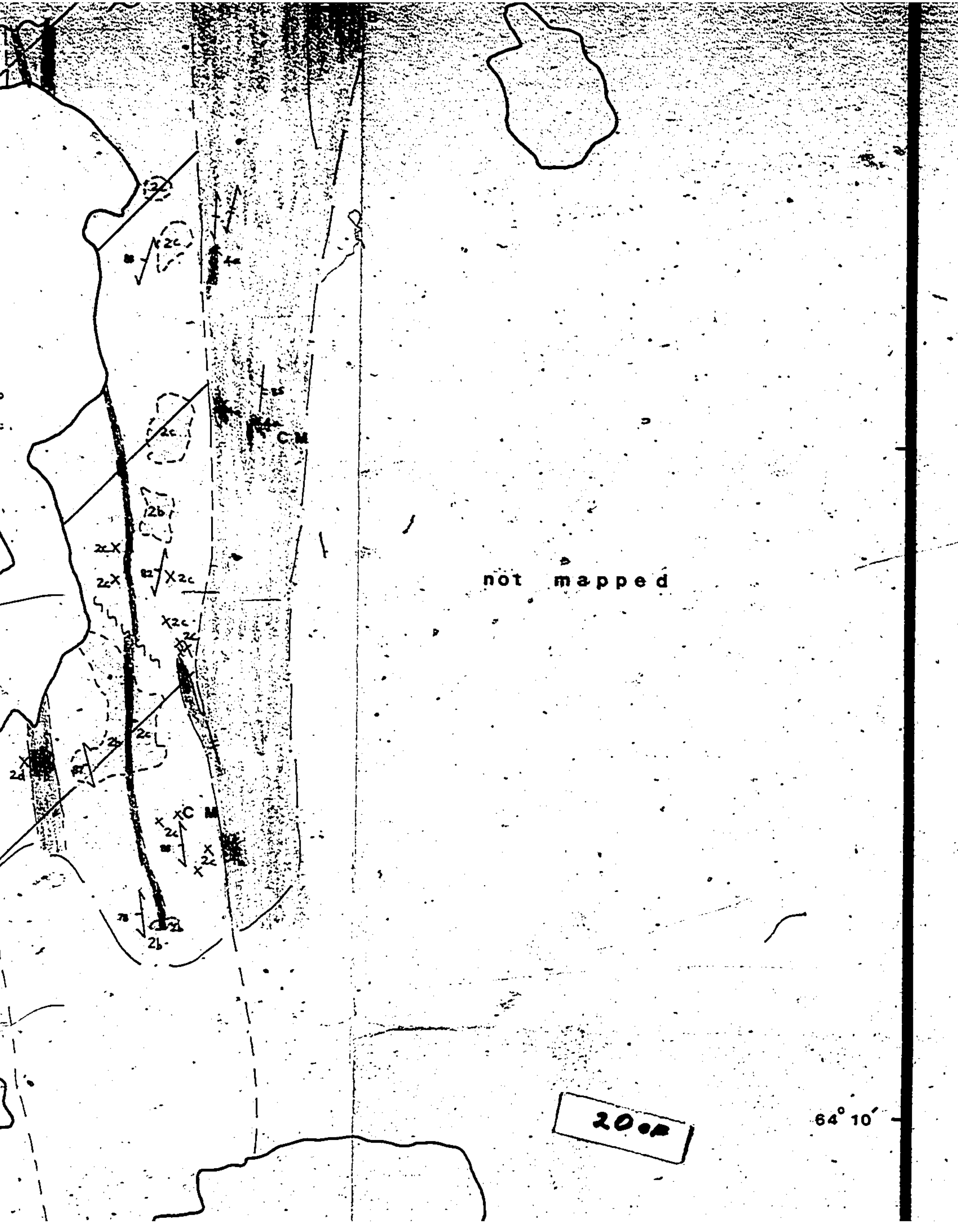
MAP 2

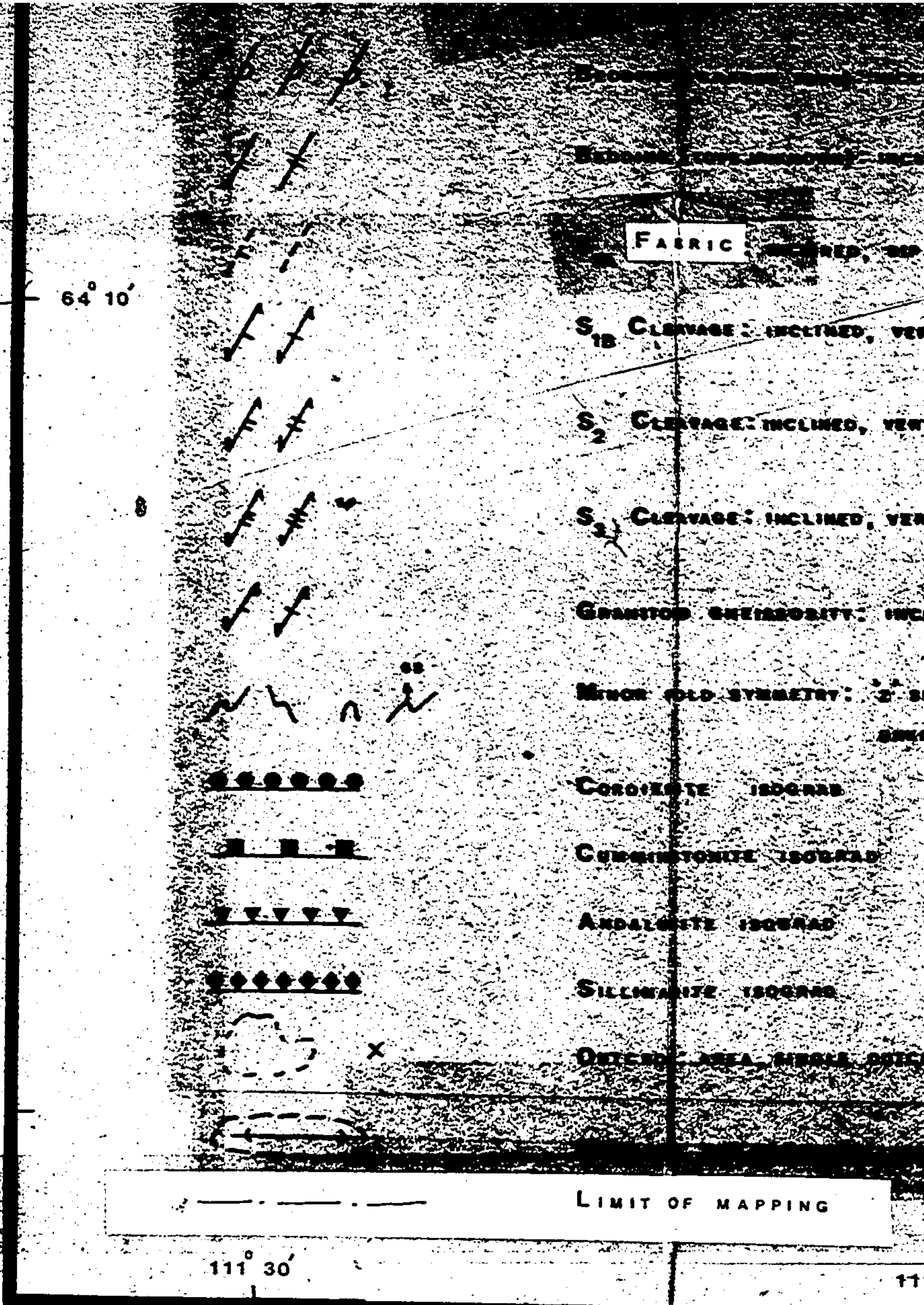




1000
metres
4000
feet
180F


5d
5a
5b
5c
not mapped
1b
1bm
2d
190F


not mapped
CM
C M
2c
2b
2d
64° 10′
20



FABRIC
64° 10′
S1B CLEAVAGE: INCLINED,
S2 CLEAVAGE: INCLINED,
S3 CLEAVAGE: INCLINED,
MINOR FOLD SYMMETRY:
CORDIERITE ISOGRAD
CUMMINGTONITE ISOGRAD
ANDALUSITE ISOGRAD
SILLIMANITE ISOGRAD
LIMIT OF MAPPING
111° 30′

21 OF

INCLINED, VERTICAL

, DIP UNKNOWN

, VERTICAL

VERTICAL

, VERTICAL

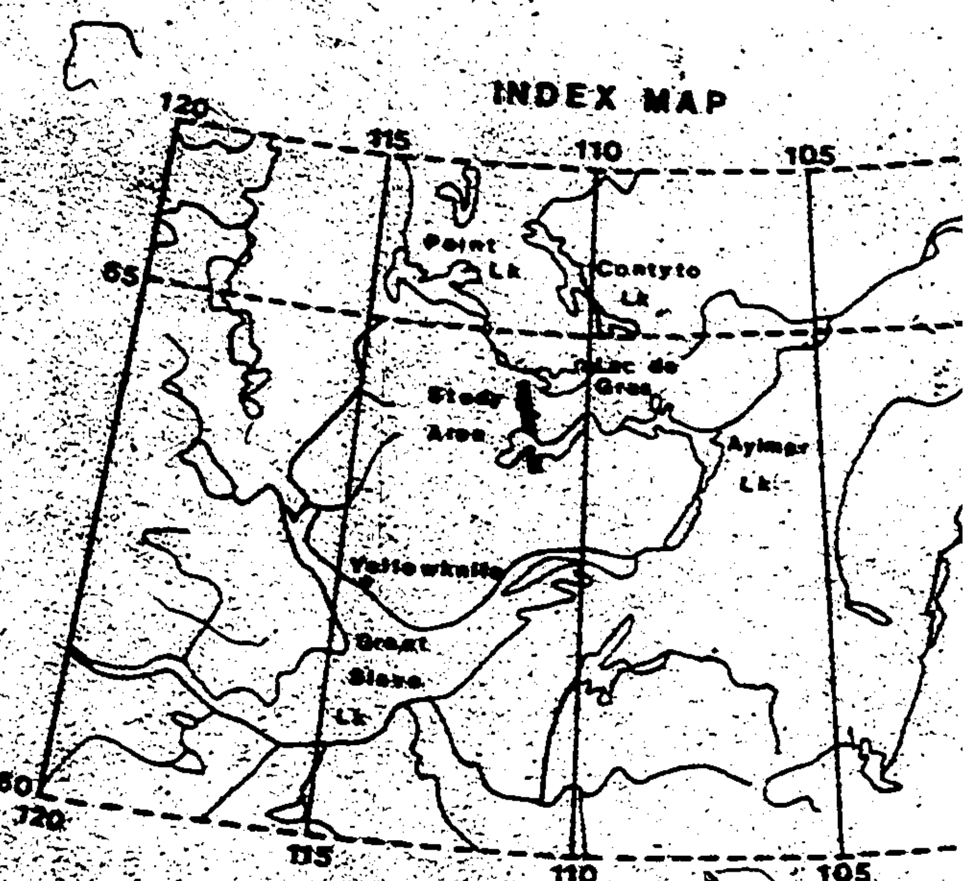
INCLINED, VERTICAL

Z SENSE, S SENSE, SENSE UNKNOWN, FOLD PLUNGE

D

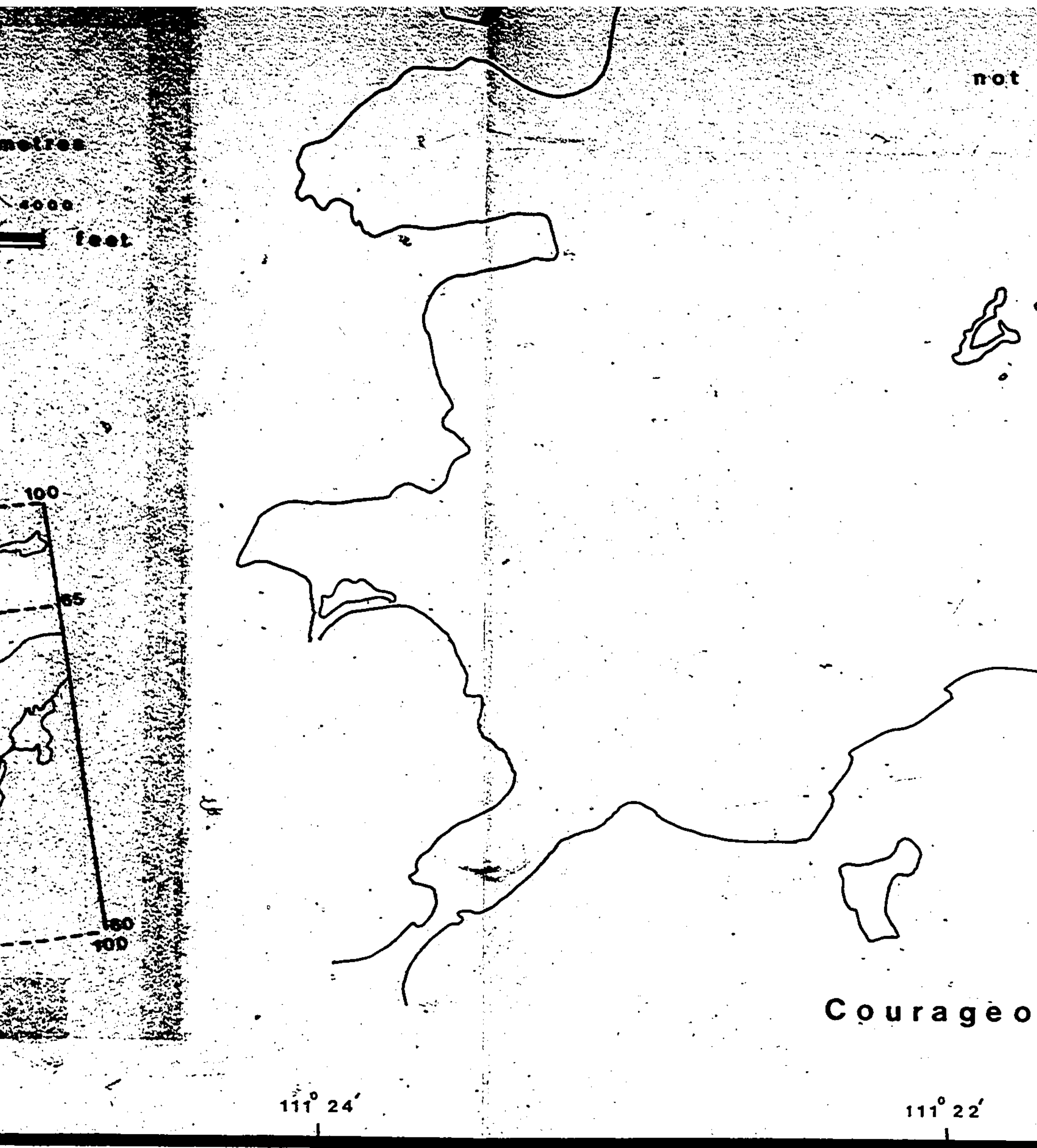
OUTCROP

Scale — 1:12,000

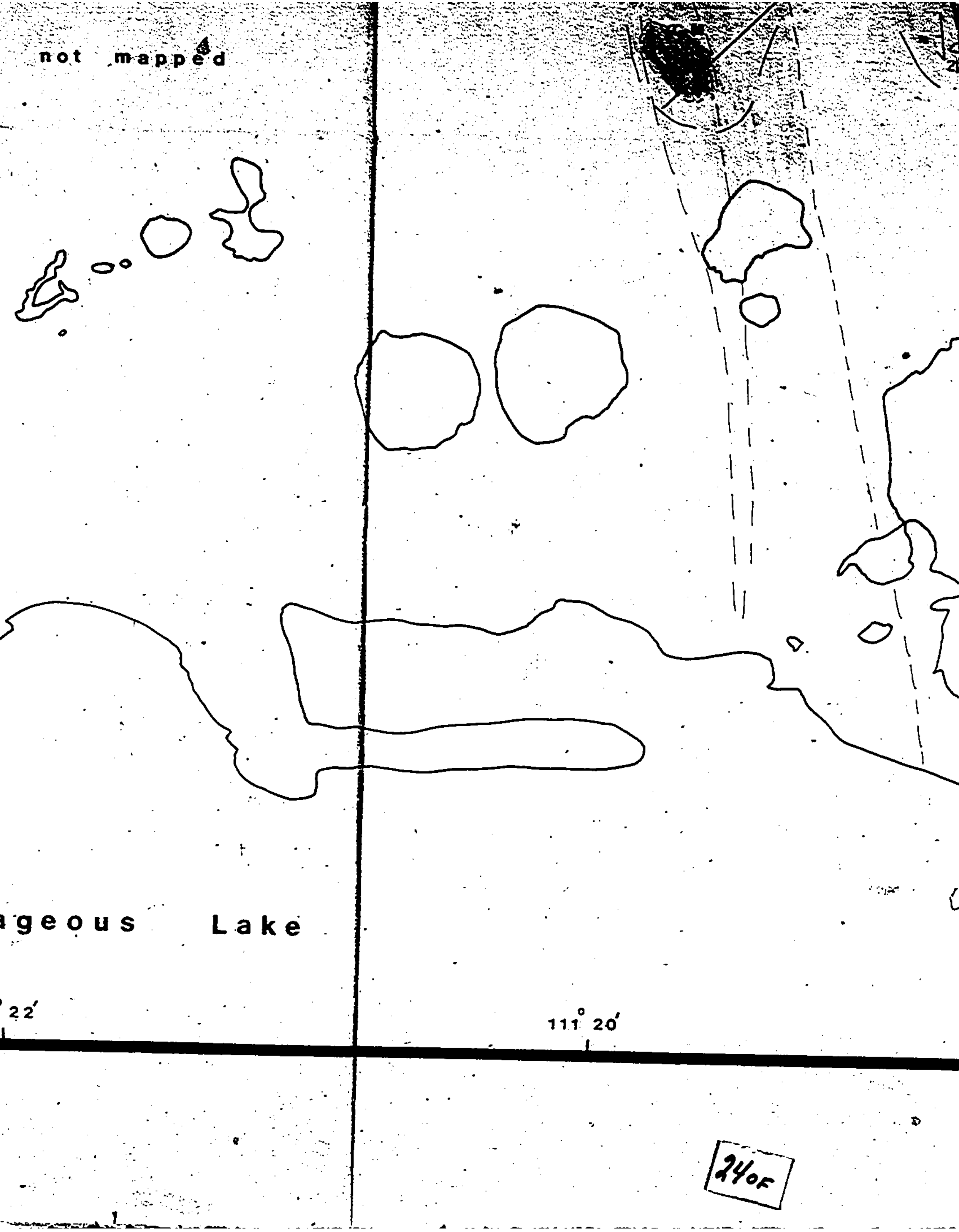


111° 28′ 111° 26′

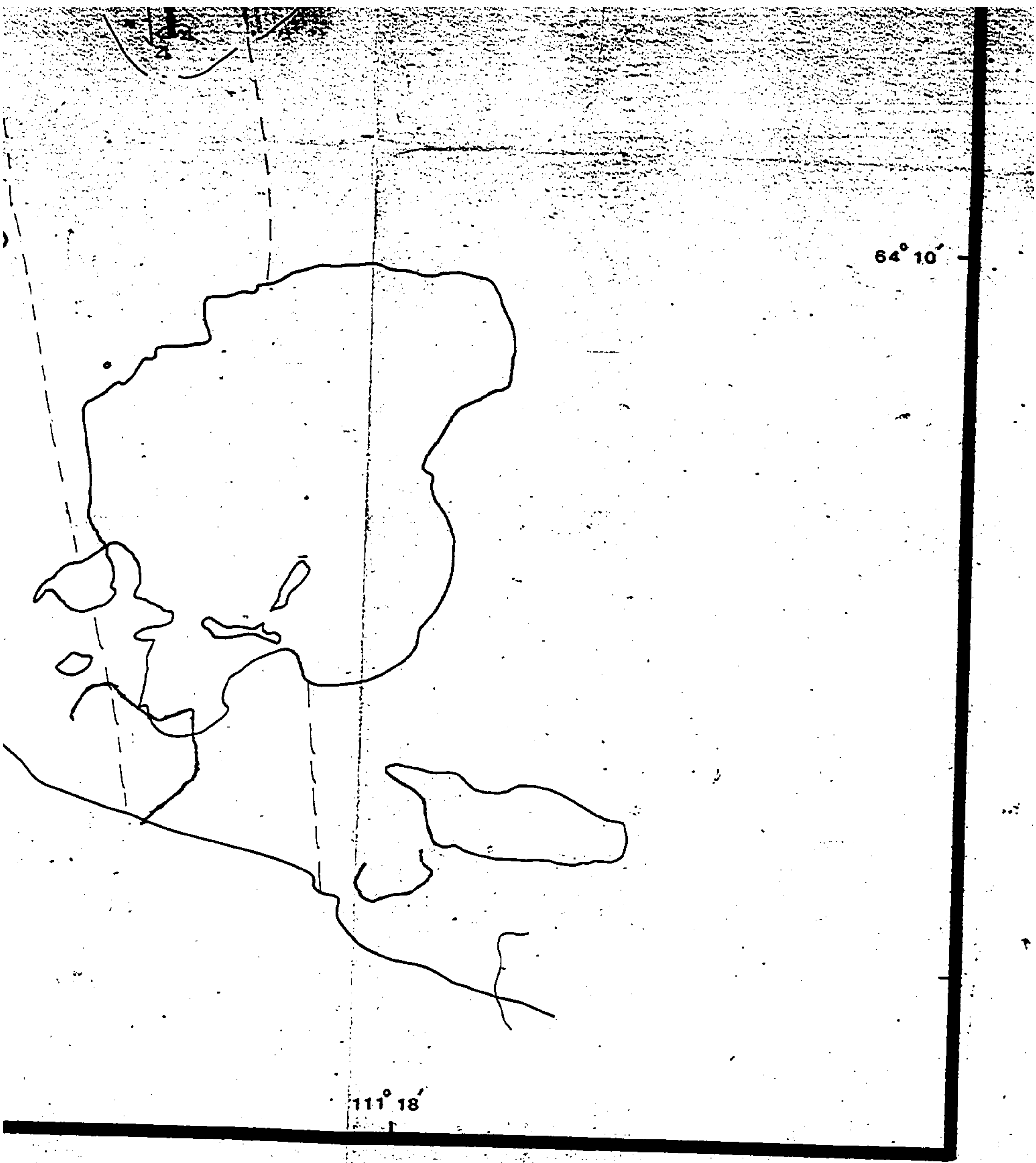
22 of



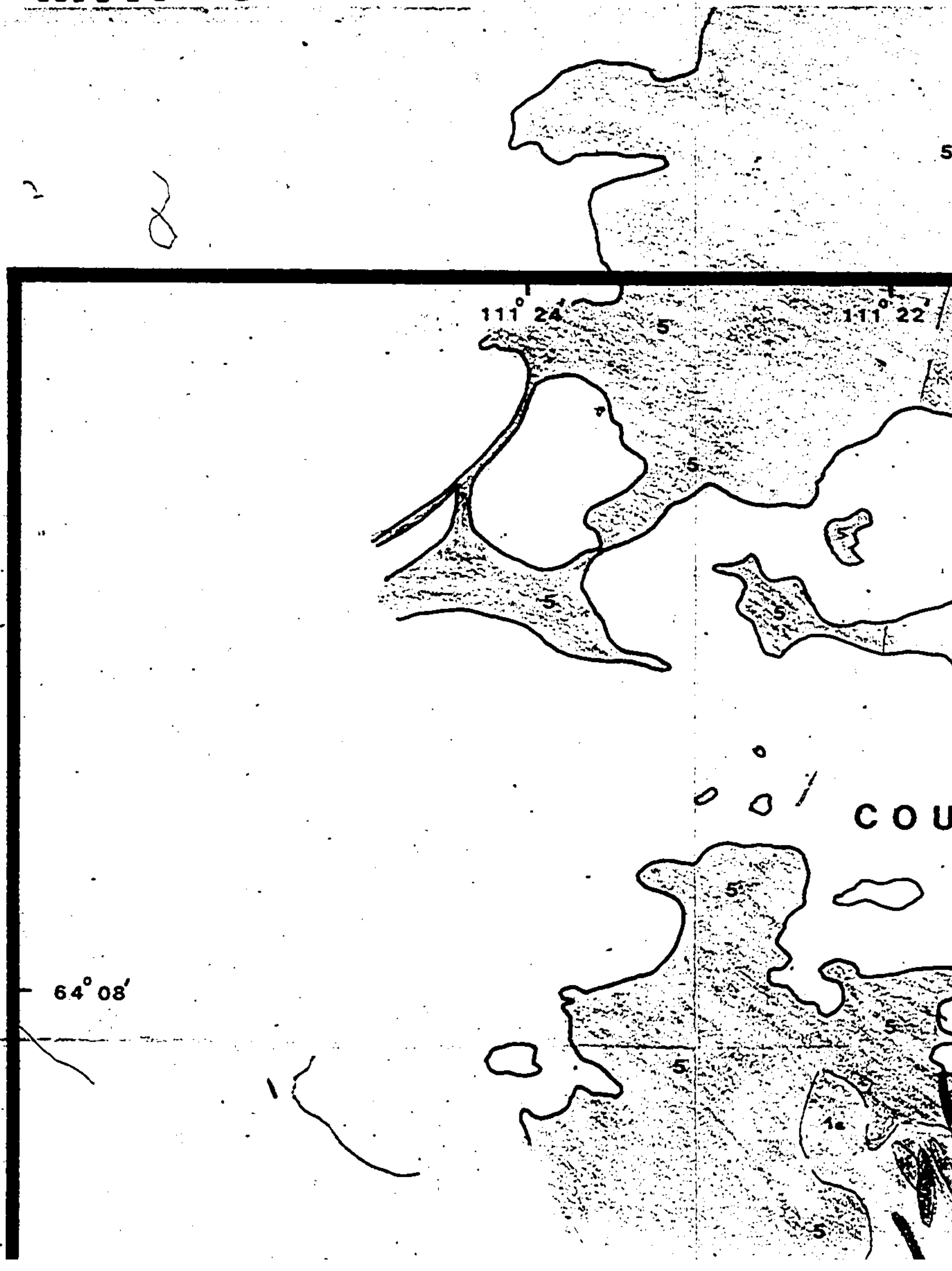
23 OF

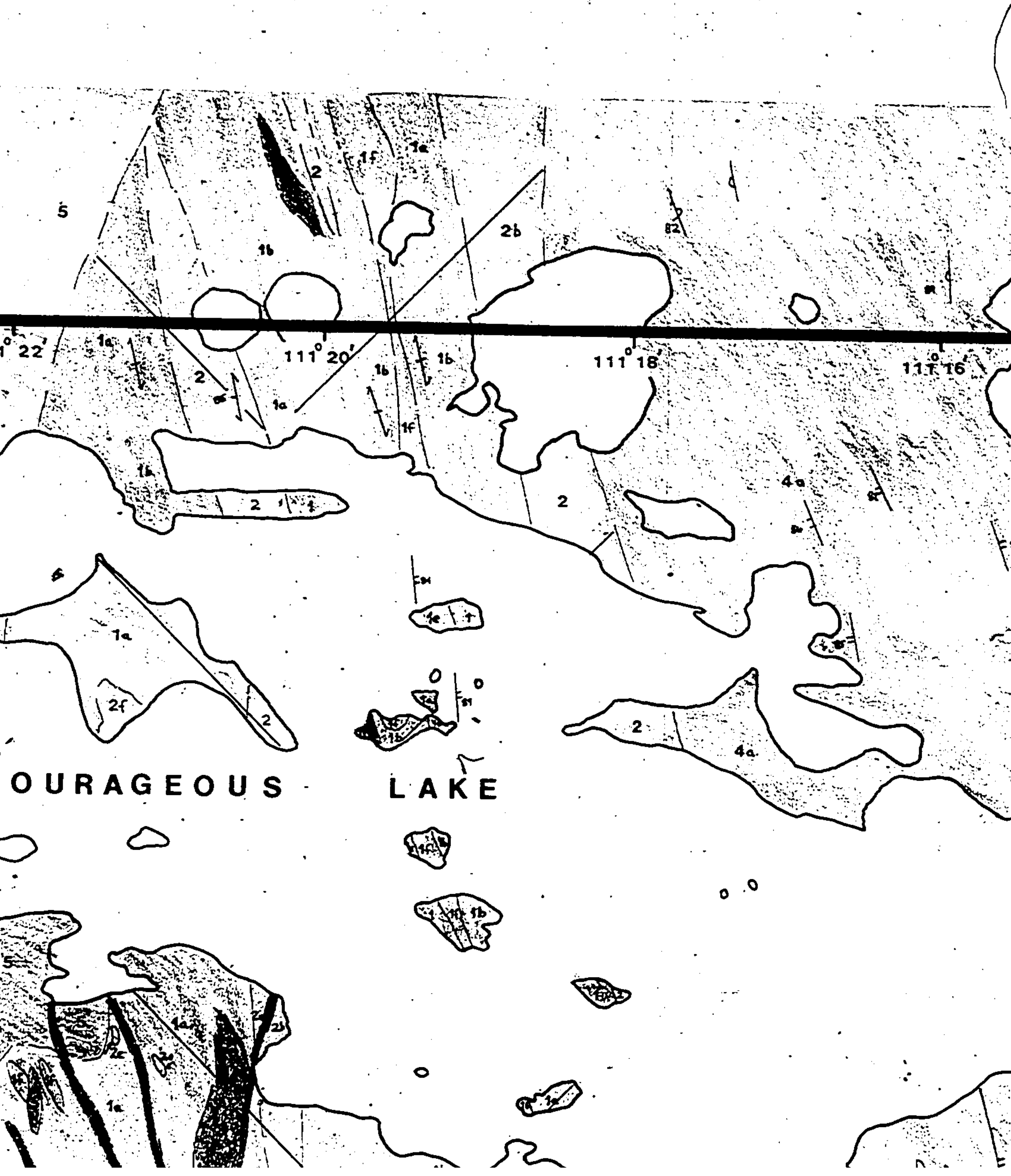


not mapped
ageous Lake
22′
111° 20′
24of

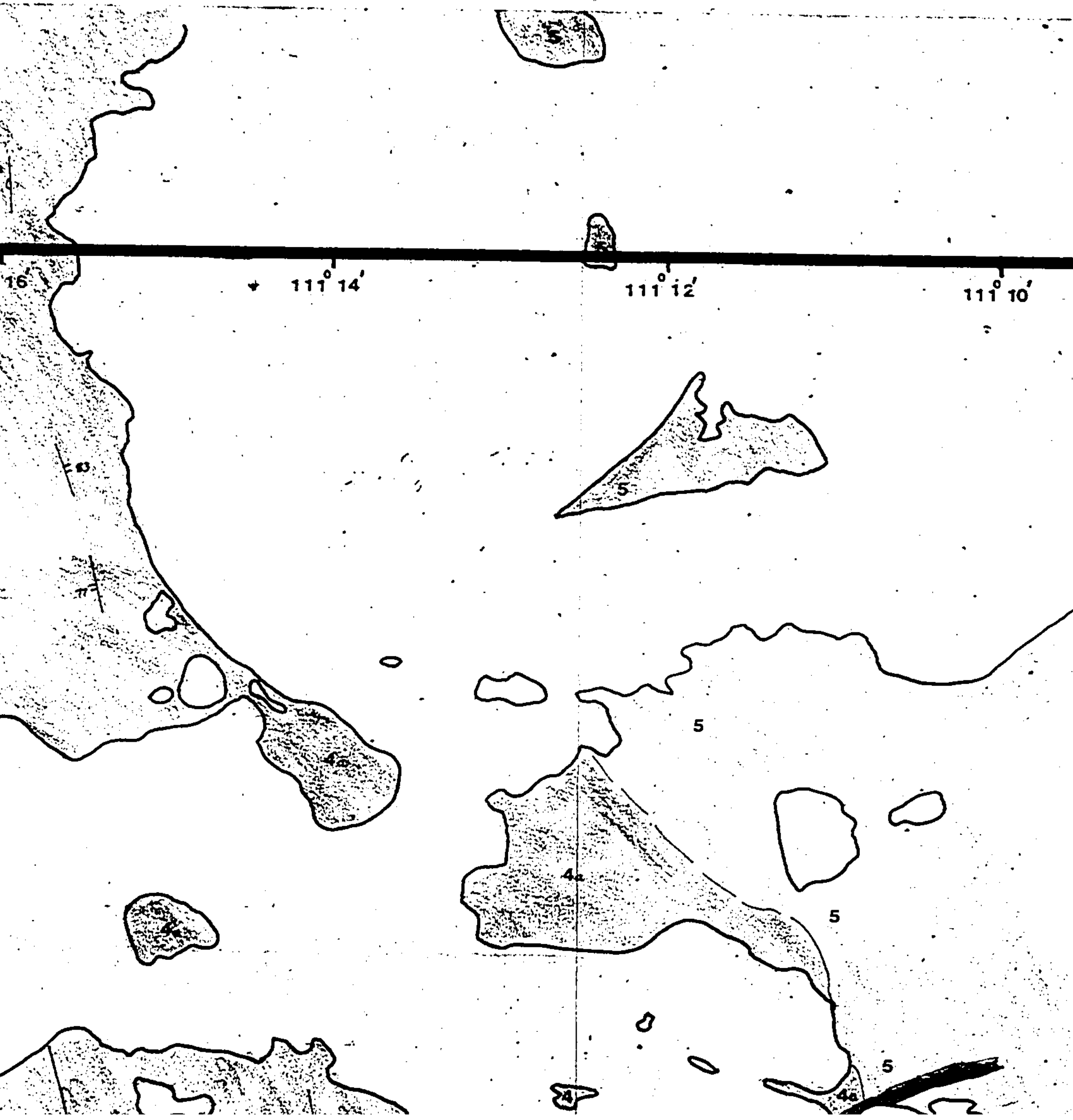

64° 10′
111° 18′

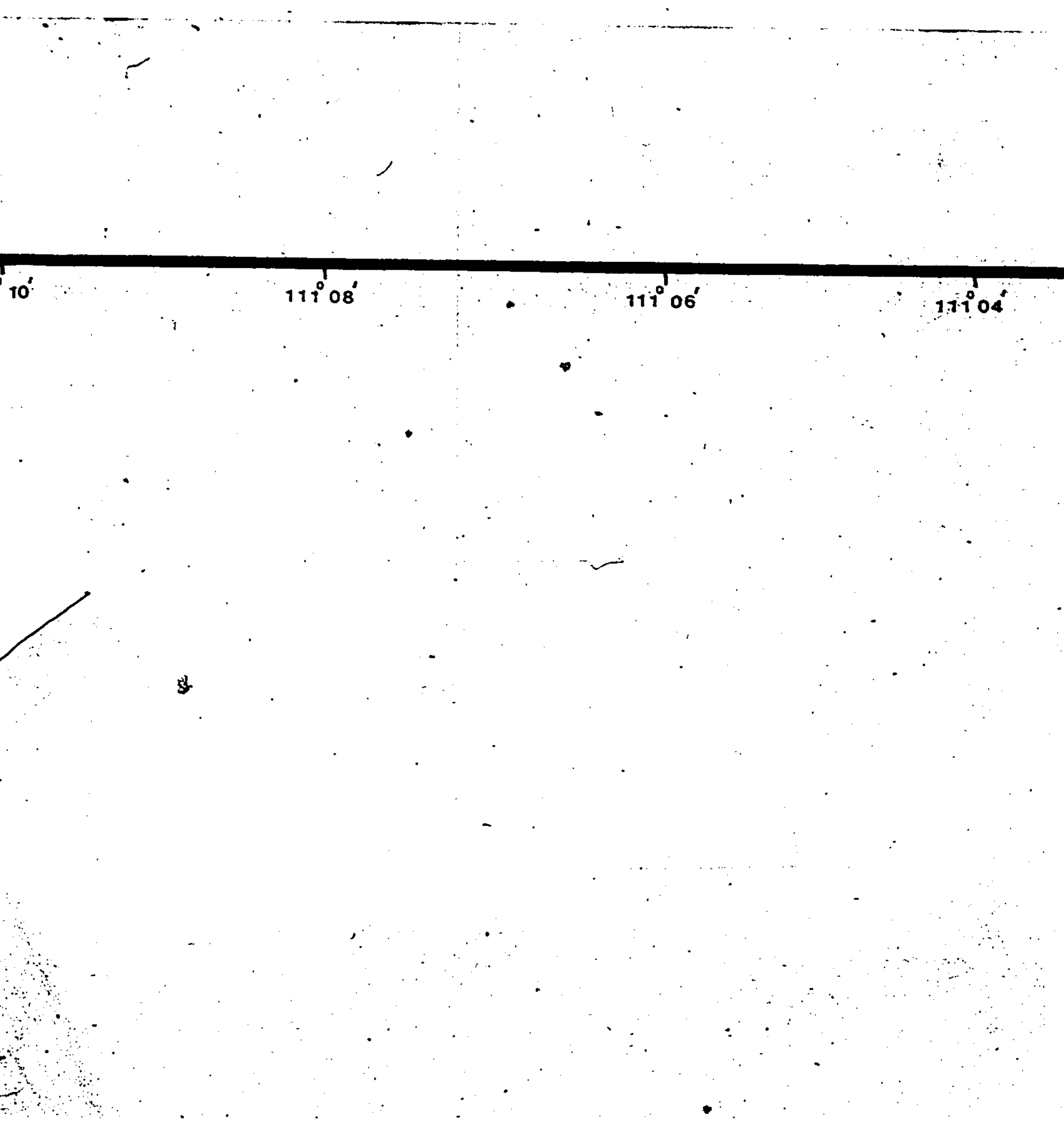
MAP 3

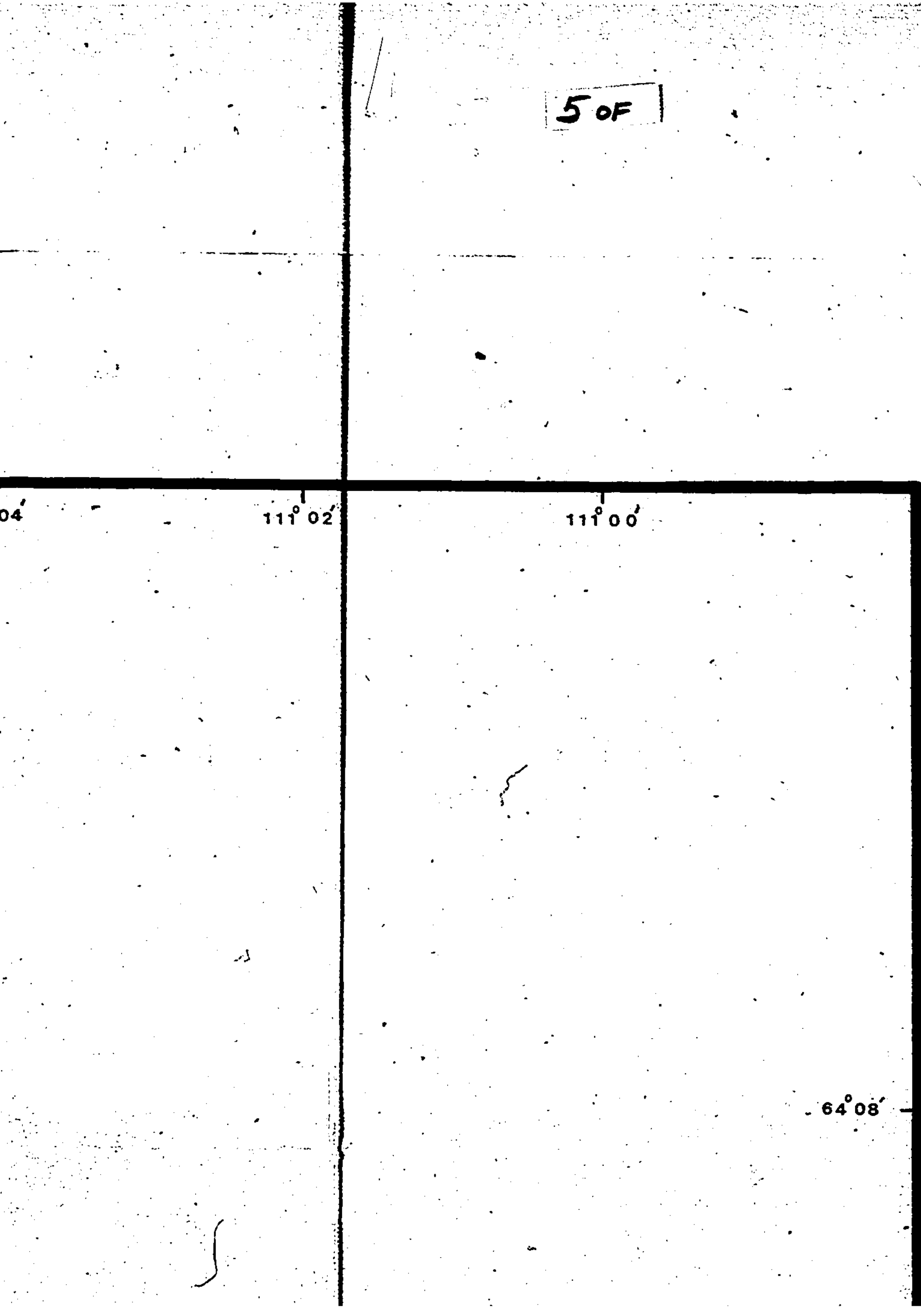


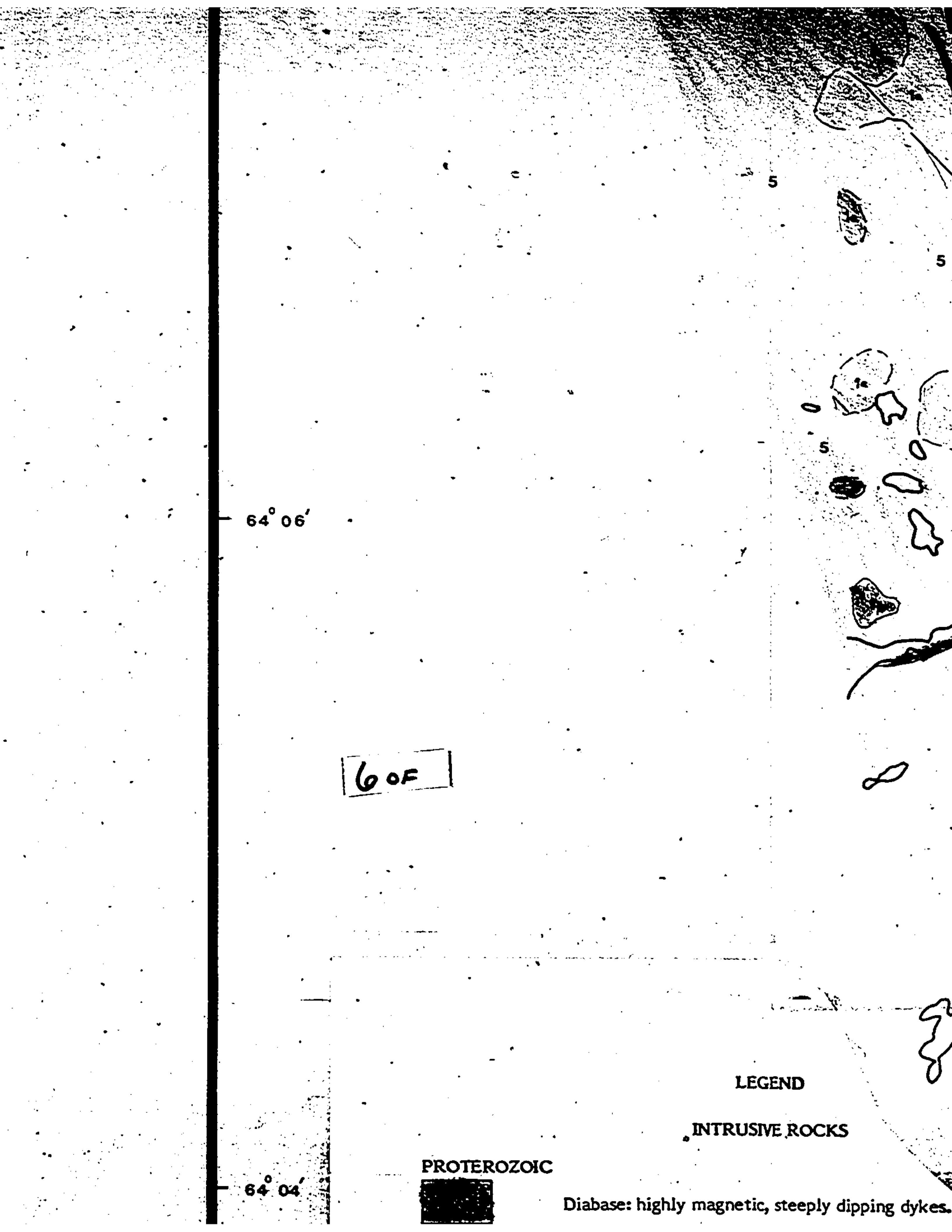


5
1b
2
1f
1a
2b
82
111° 22'
111° 20'
111° 18'
111 16
1a
2
1b
1f
4a
2
1a
2f
2
2
4a
OURAGEOUS
LAKE
1b
1a

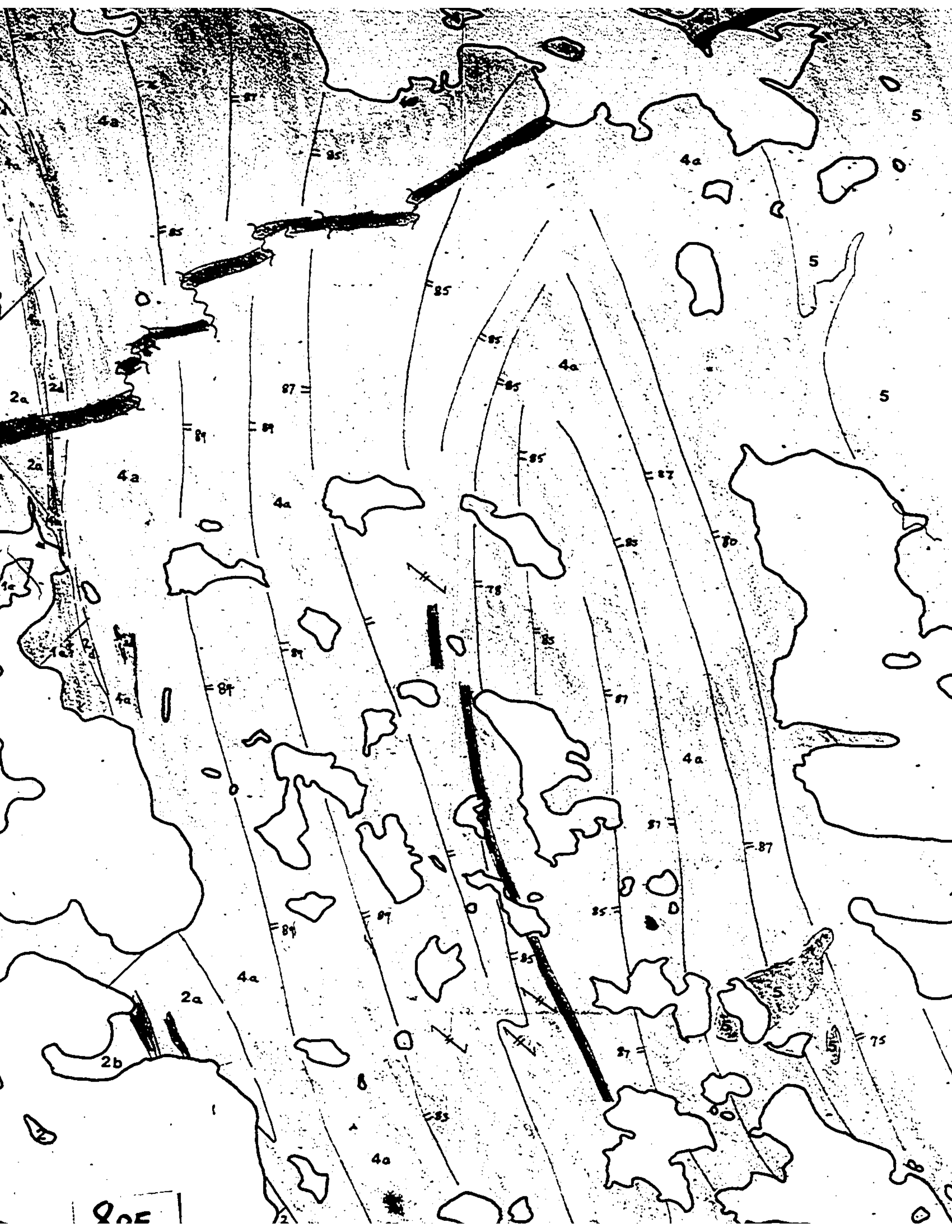

5
16'
111° 14'
111° 12'
111° 10'
5
5
4a
5
4a
5
4a
5
4a


10′
111° 08′
111° 06′
111° 04′


04′
111° 02′
111° 00′
64° 08′

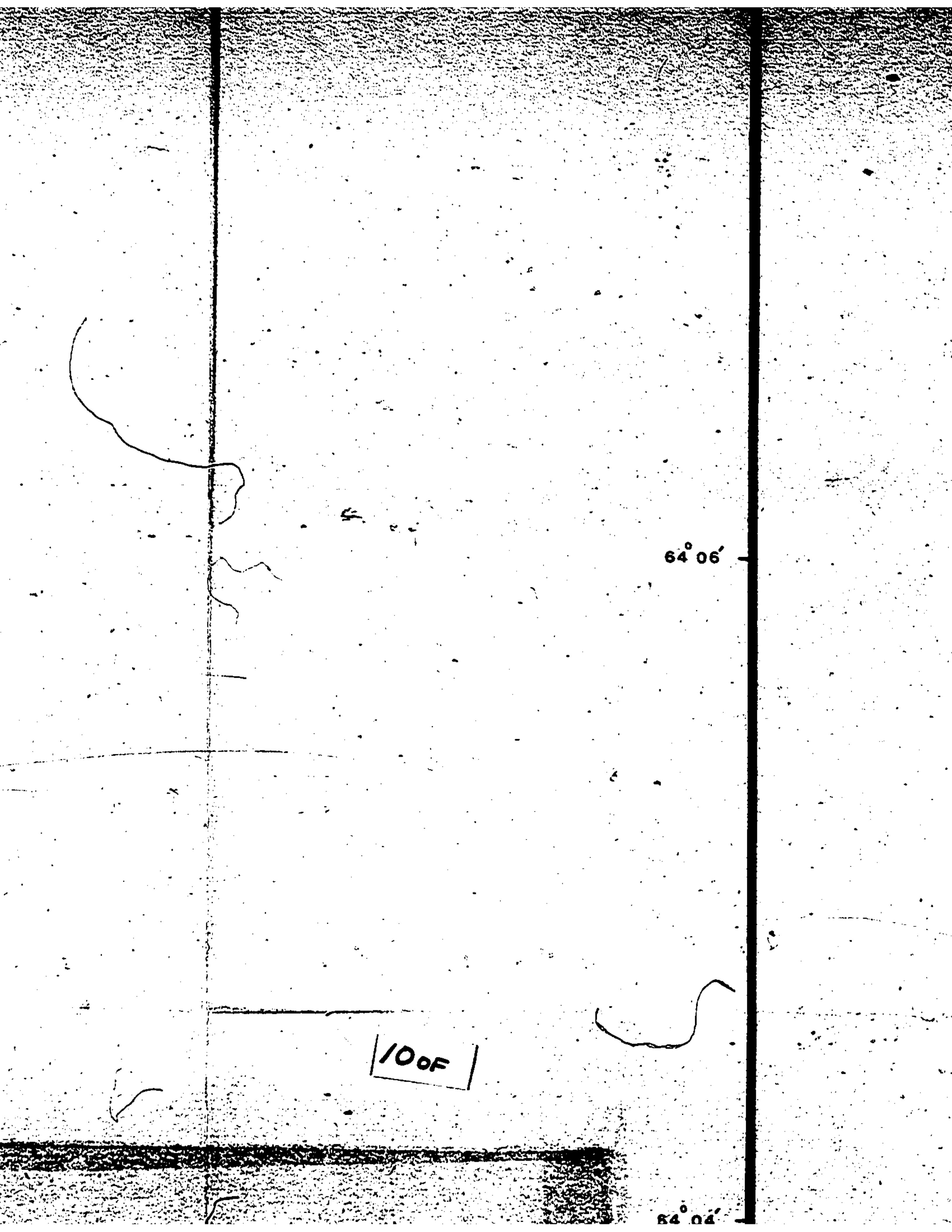

5
5
5
64° 06′
6 OF
64° 04′
LEGEND
INTRUSIVE ROCKS
PROTEROZOIC
Diabase: highly magnetic, steeply dipping dykes.

7OF
1b
2
1a
1c
2b
4a
1
2a
1a
5
1a
1c
2b
1a
0
2a
1a
1a
2a
1b
1a
1b
2b
5
1a
4b
2a
1b
5
2b
2b
2b
1a
1b
2e
2
2a
1b
25
2a
5
2e
1b
1a
1b
5
2f
2e
1a
2b
2
2f
1f
2a
es.



4a
5
2a
2b
85
87
89
80
78
75
83

9 OF


64° 06'
10 oF
64° 04'

ARCHEAN

Pegmatite: biotite-muscovite pegmatite.

Granitoid rocks: 5a) biotite granite (synkinema
granodiorite; 5c) biotite-hornblende tonalite; 5d) b
trondhjemite (synvolcanic to earlier?).

Metagabbro: feeder sills and dykes to the volcani
subunit 4a and unit 6, crosscuts 5b. 3a, massive
3b, massive, feldspar-porphyritic.

SUPRACRUSTAL ROCKS

YELLOWKNIFE SUPERGROUP

Metasediments: 4a) greywacke, arkose, and
4b) intervolcanic argillite or phyllite;
conglomerate; 4d) pyritic banded chert; 4e) granito
conglomerate.

Cycle 2

2

Metarhyolite to metadacite: 2a) massive rhyo
block-breccia; 2c) rhyodacitic quartz-feldspa
volcaniclastic; 2d) dacitic ash to lapilli-sized
2f) massive quartz-feldspar phyric intrusive rock.

64°02'

Intermediate metavolcanics: 1c) massive, amydg
flow; 1d) pillowed, amygdaloidal andesite
1h) andesitic fragmental rock.

110F

Mafic metavolcanics: 1a) massive basalt flow; 1b
flow; 1e) massive feldspar phyric basalt flow; 1f)
phyric basalt; 1g) "banded" basalt (highly flattened).

Note: volcanic units without inclined ruling have
to a specific cycle.

Cycle 1

2

Metarhyolite to metadacite: 2c) rhyodacitic quartz
sized volcaniclastic; 2d) dacitic ash to lapilli-size
2e) rhyodacitic block-breccia (highly chloritic).

Mafic metavolcanics: 1a) massive basalt flow; 1b
flow.

Metamorphic assemblages: A - andalusite; AT
B - biotite; C - chlorite; CD - cordierite; CM
CX - clinopyroxene; E - epidote; G - garnet;
K - potassium feldspar; M - muscovite; S - sillimanit

m = carbonatized; s = sheared; n = silicified.

e.

(synkinematic); 5b) biotite
alite; 5d) biotite-hornblende

the volcanic pile, older than
3a, massive non-porphyritic;

ose, and slate turbidites;
hyllite; 4c) intervolcanic
4e) granitoid-volcanic clast

ssive rhyolite; 2b) rhyolite
rtz-feldspar lapilli-sized
apilli-sized volcaniclastic;
ve rock.

ve, amydgaloidal andesite
andesite flow:

t flow; 1b) pillowed basalt
flow; 1f) pillowed feldspar
flattened).

ling have not been related

tic quartz-feldspar lapilli-
apilli-sized volcaniclastic;
itic).

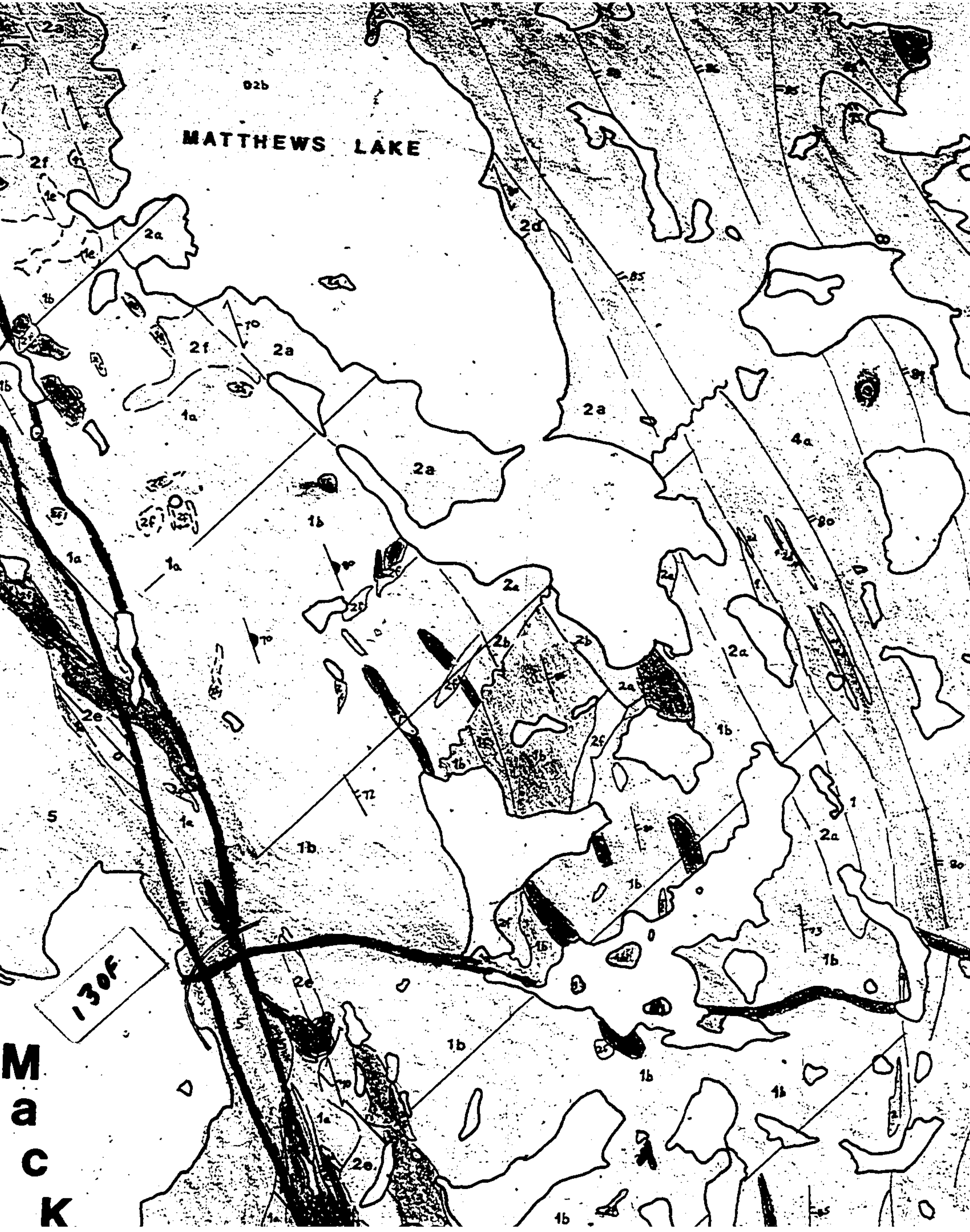
flow; 1b) pillowed basalt

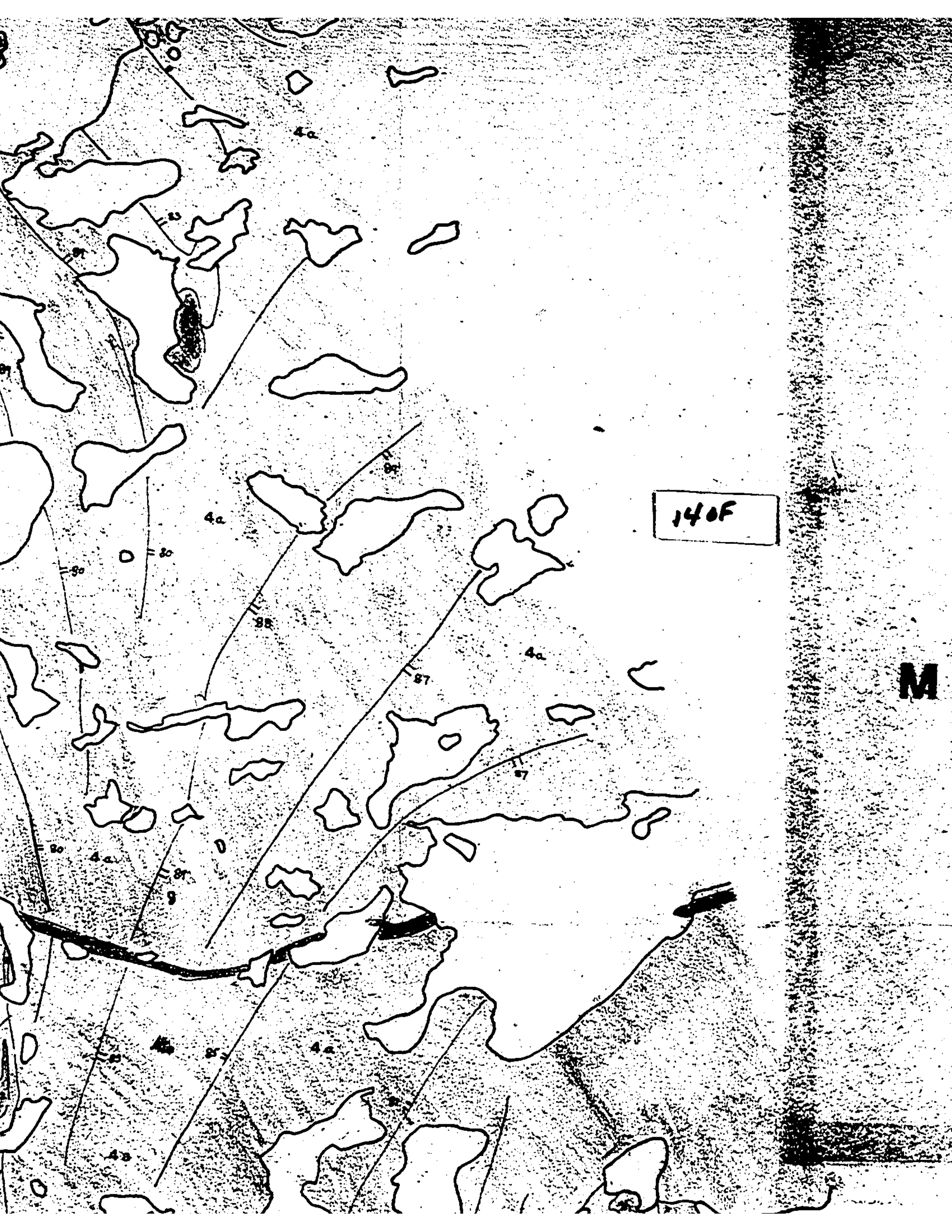
site; AT - anthophyllite;
ite; CM - cummingtonite;
- garnet; KY - Kyanite;
sillimanite.

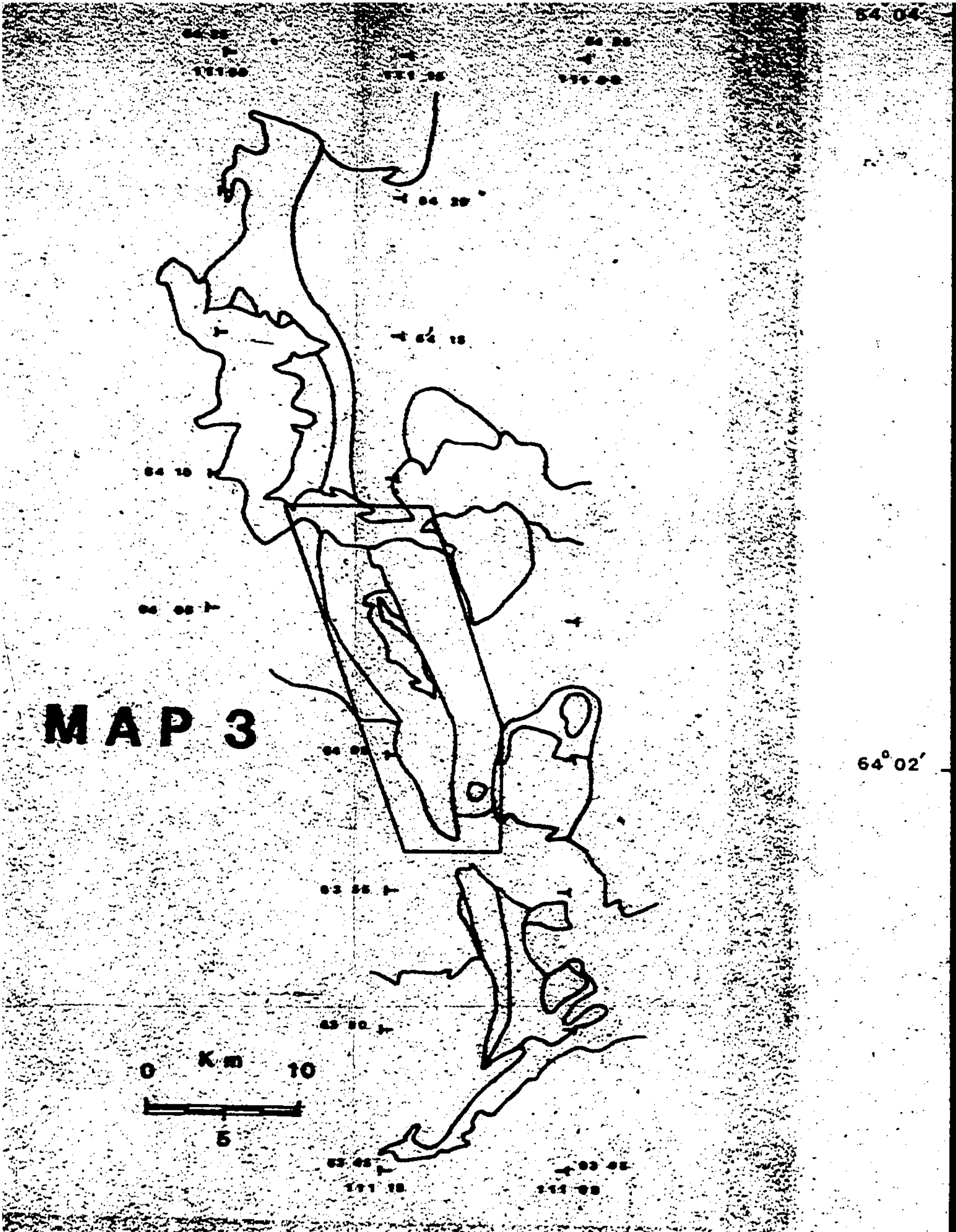
d.

120F

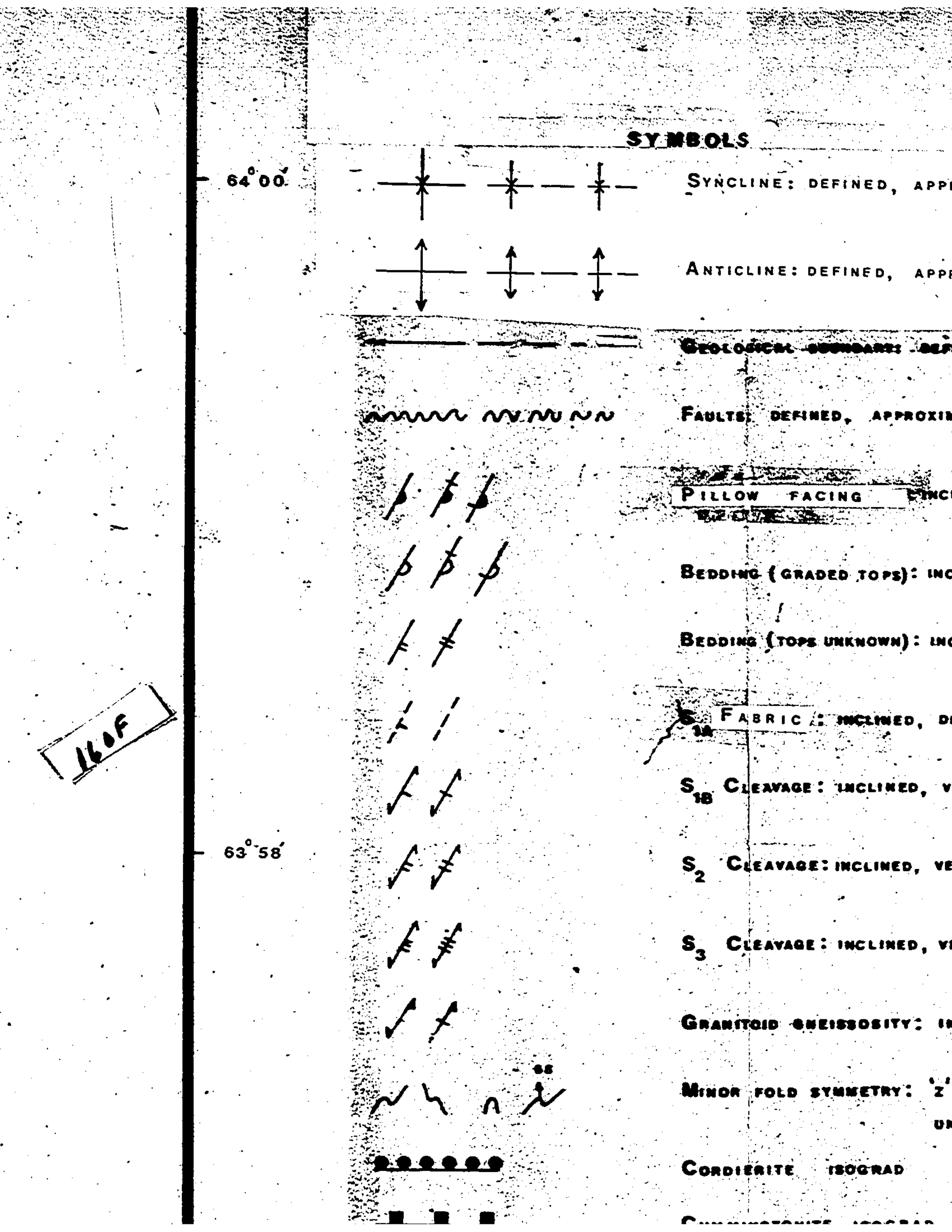
M
a
c


MATTHEWS LAKE
130F
Mack


4a
4a
4a
4a
4a
4a
140F
M
88
87
87
80
80
80



15 OF


SYMBOLS
64°00'
SYNCLINE: DEFINED, APP
ANTICLINE: DEFINED, APP
FAULTS: DEFINED, APPROXI
PILLOW FACING
BEDDING (GRADED TOPS): INC
BEDDING (TOPS UNKNOWN): INC
FABRIC: INCLINED, D
S_{1B} CLEAVAGE: INCLINED, V
63°58'
S_2 CLEAVAGE: INCLINED, VE
S_3 CLEAVAGE: INCLINED, V
GRANITOID GNEISSOSITY: IN
MINOR FOLD SYMMETRY: 'Z'
68
CORDIERITE ISOGRAD
160F

APPROXIMATE, ASSUMED

APPROXIMATE, ASSUMED

DEFINED, APPROXIMATE, ASSUMED

OXIMATE, ASSUMED

INCLINED, VERTICAL, OVERTURNED

: INCLINED, VERTICAL, OVERTURNED

: INCLINED, VERTICAL

, DIP UNKNOWN

D, VERTICAL

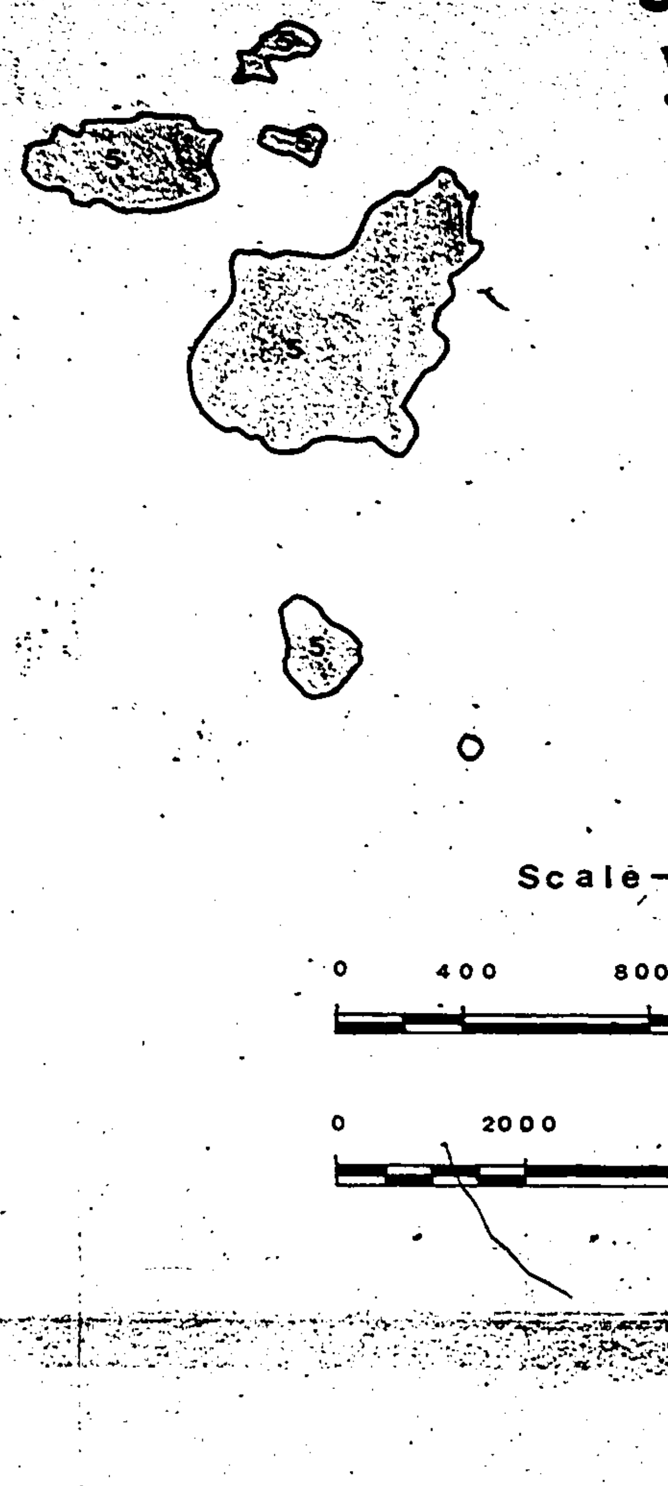
, VERTICAL

D, VERTICAL

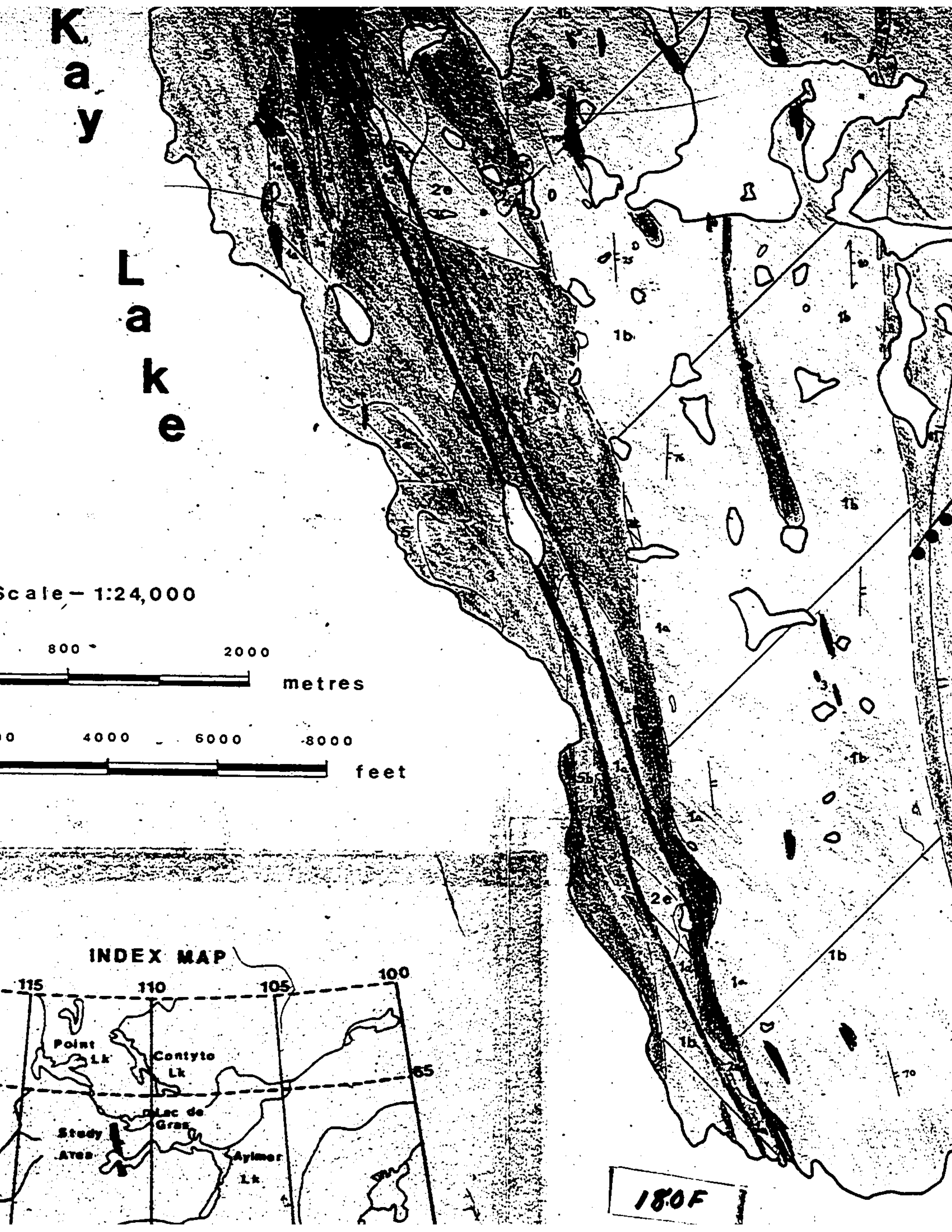
: INCLINED, VERTICAL

Z SENSE, S SENSE, SENSE
UNKNOWN, FOLD PLUNGE

AD

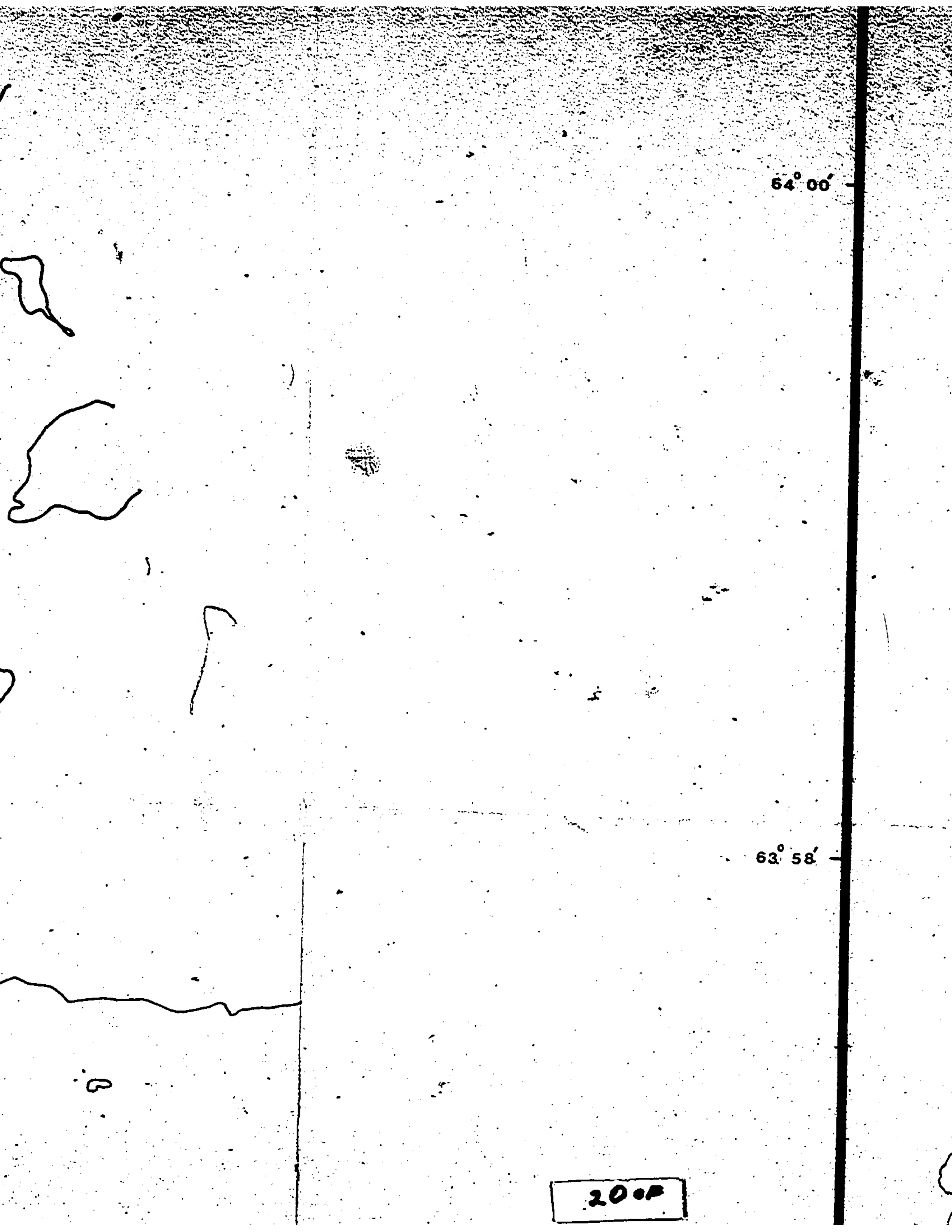


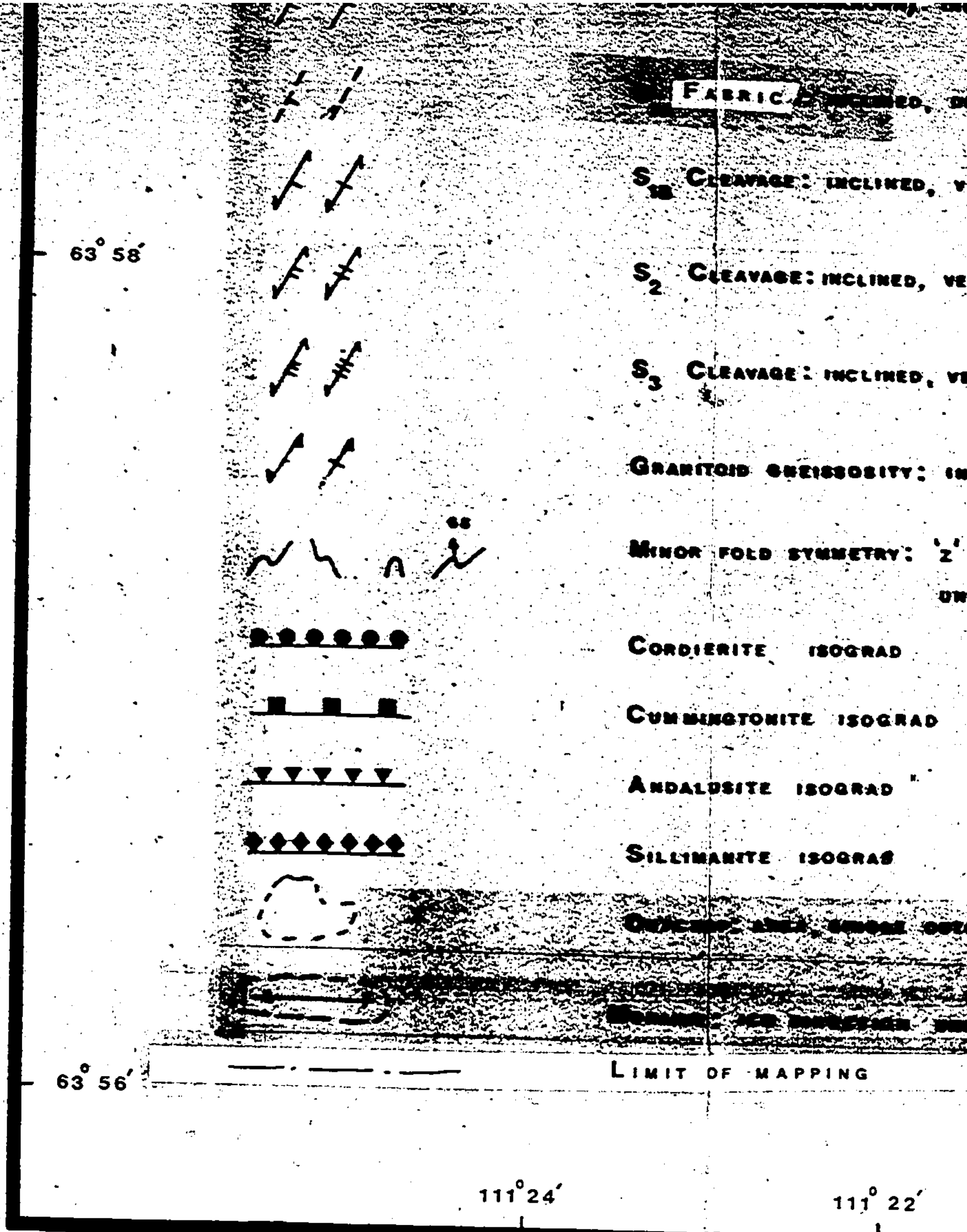
170F



Kay Lake
Scale – 1:24,000
800
2000
metres
4000
6000
8000
feet
INDEX MAP
115
110
105
100
65
Point Lk
Contyto Lk
Lac de Gras
Study Area
Aylmer Lk
1a
1b
2e
3
5b
180F


5
5c
4a
4a
5
4a
5
4a
5
MacKay Lake
190F


64° 00′
63° 58′
20 OF


FABRIC
CLEAVAGE: INCLINED,
S_2 CLEAVAGE: INCLINED,
S_3 CLEAVAGE: INCLINED,
GRANITOID GNEISSOSITY:
MINOR FOLD SYMMETRY: 'Z'
CORDIERITE ISOGRAD
CUMMINGTONITE ISOGRAD
ANDALUSITE ISOGRAD
SILLIMANITE ISOGRAD
LIMIT OF MAPPING
63° 58′
63° 56′
111°24′
111°22′

21 OF

ED, DIP UNKNOWN

ED, VERTICAL

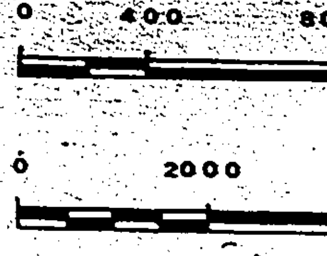
ED, VERTICAL

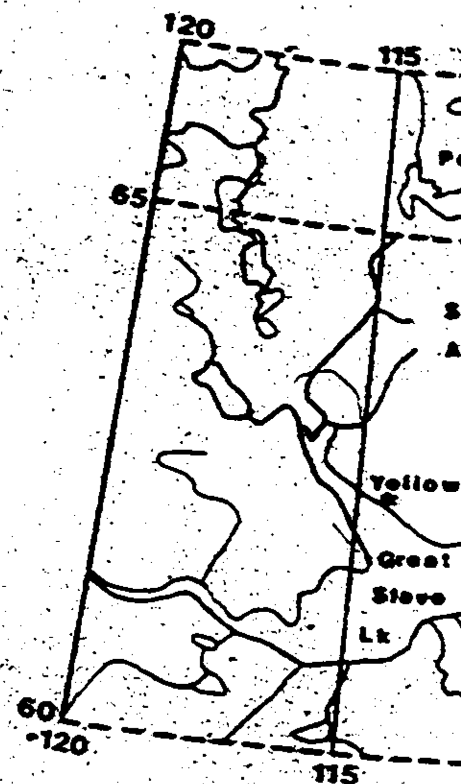
ED, VERTICAL

Y: INCLINED, VERTICAL

: Z SENSE, S SENSE, SENSE
UNKNOWN, FOLD PLUNGE

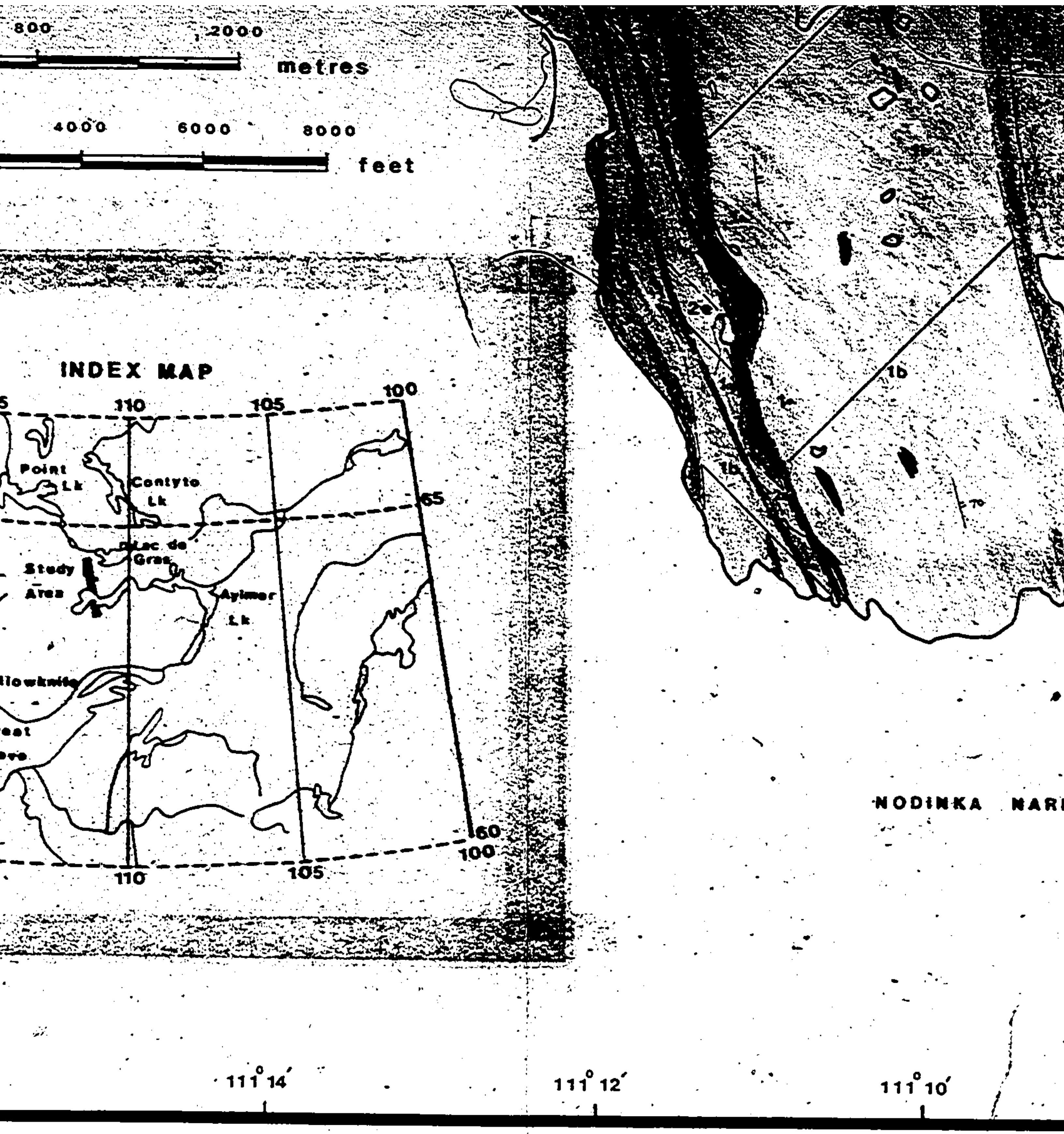
RAD



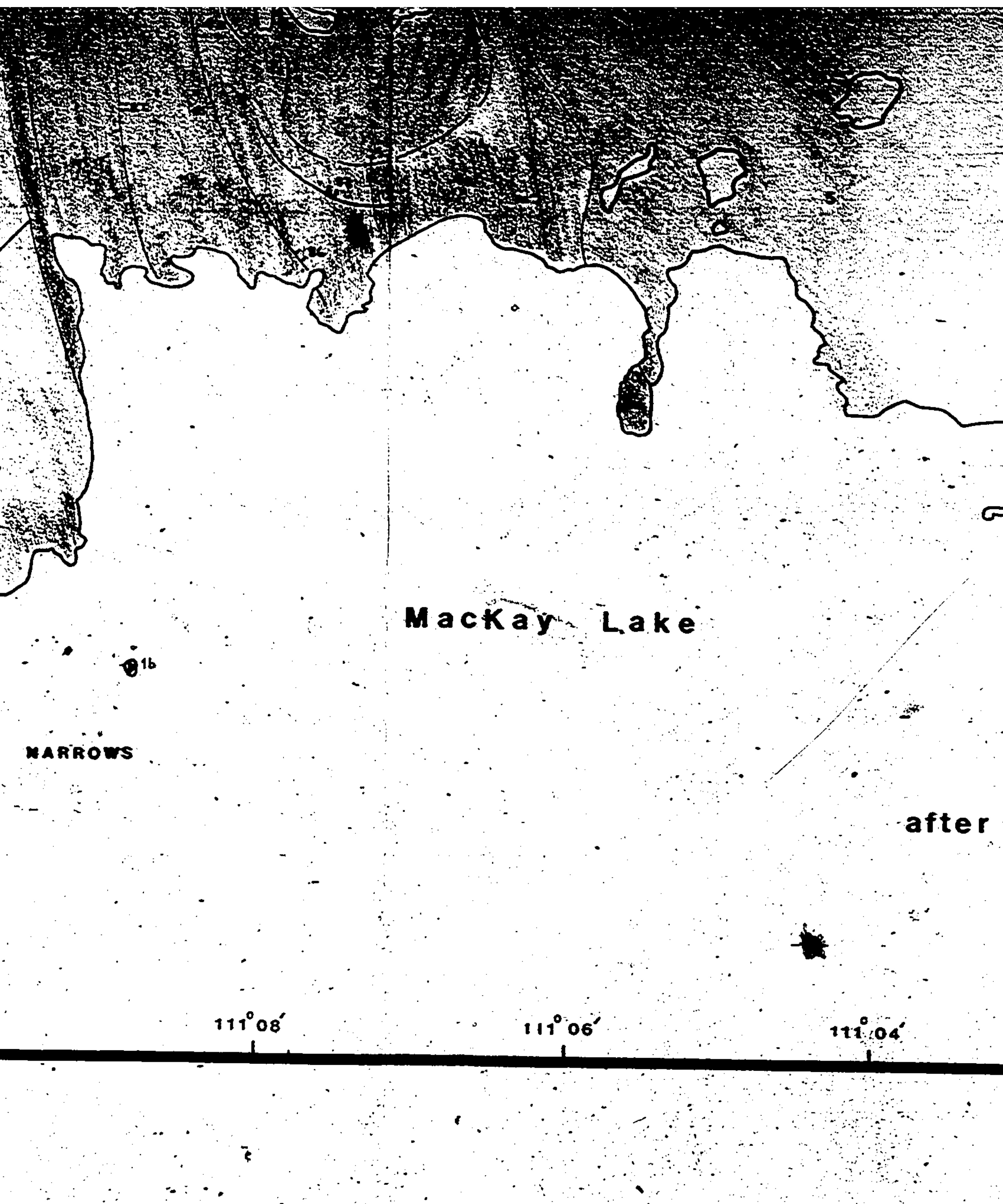


22′ 111° 20′ 111° 18′ 111° 16′

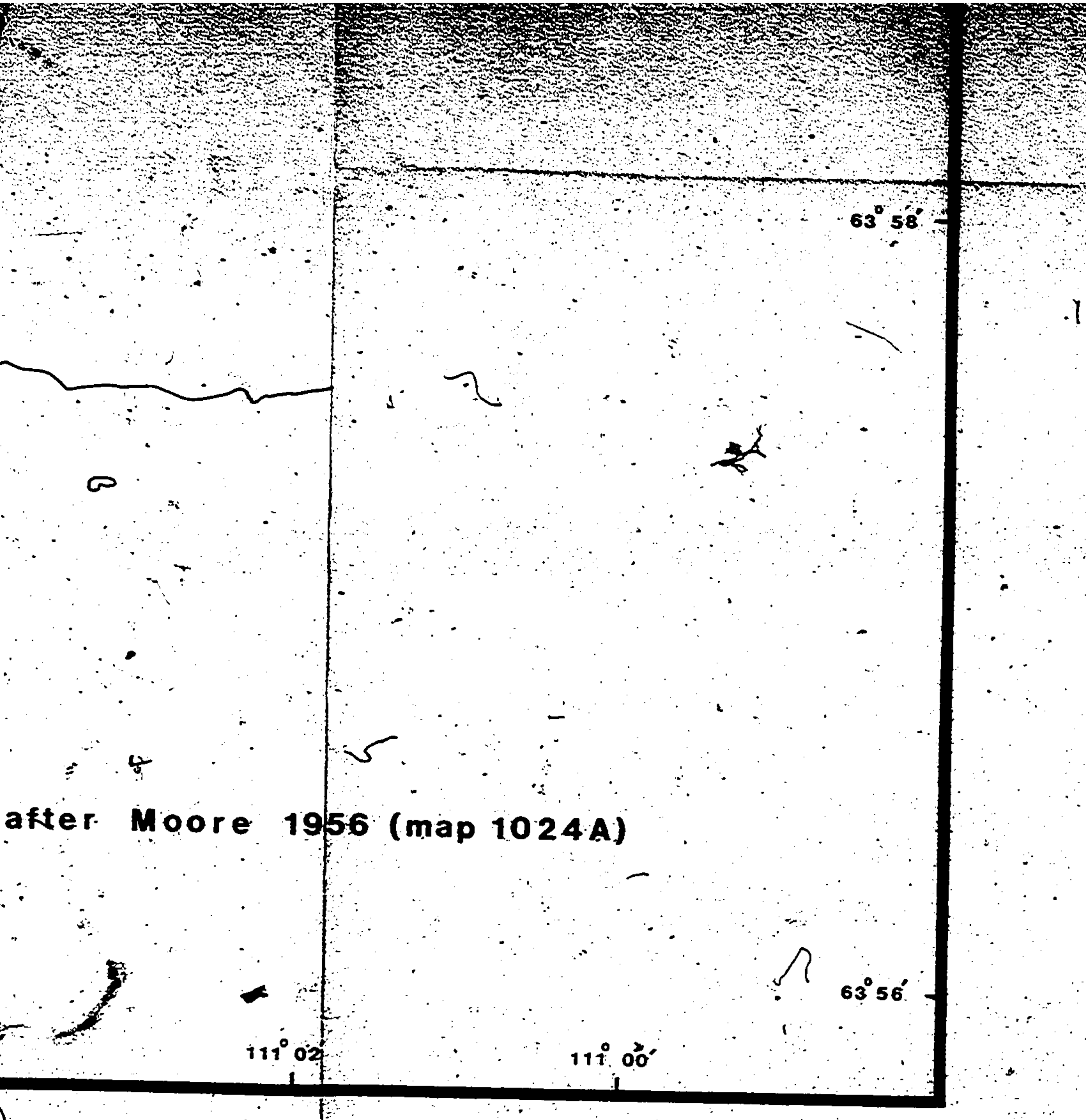
22 of


800
2000
metres
4000
6000
8000
feet
INDEX MAP
110
105
100
Point Lk
Contyto Lk
65
Lac de Gras
Study Area
Aylmer Lk
60
100
110
105
2a
1b
1c
1b
1b
70
NODINKA
111°14′
111°12′
111°10′

23 OF



24 OF


63° 58′
63° 56′
111° 02′
111° 00′
after Moore 1956 (map 1024A)

MAP 4

1 OF


08
111 06
C B CD
2 OF

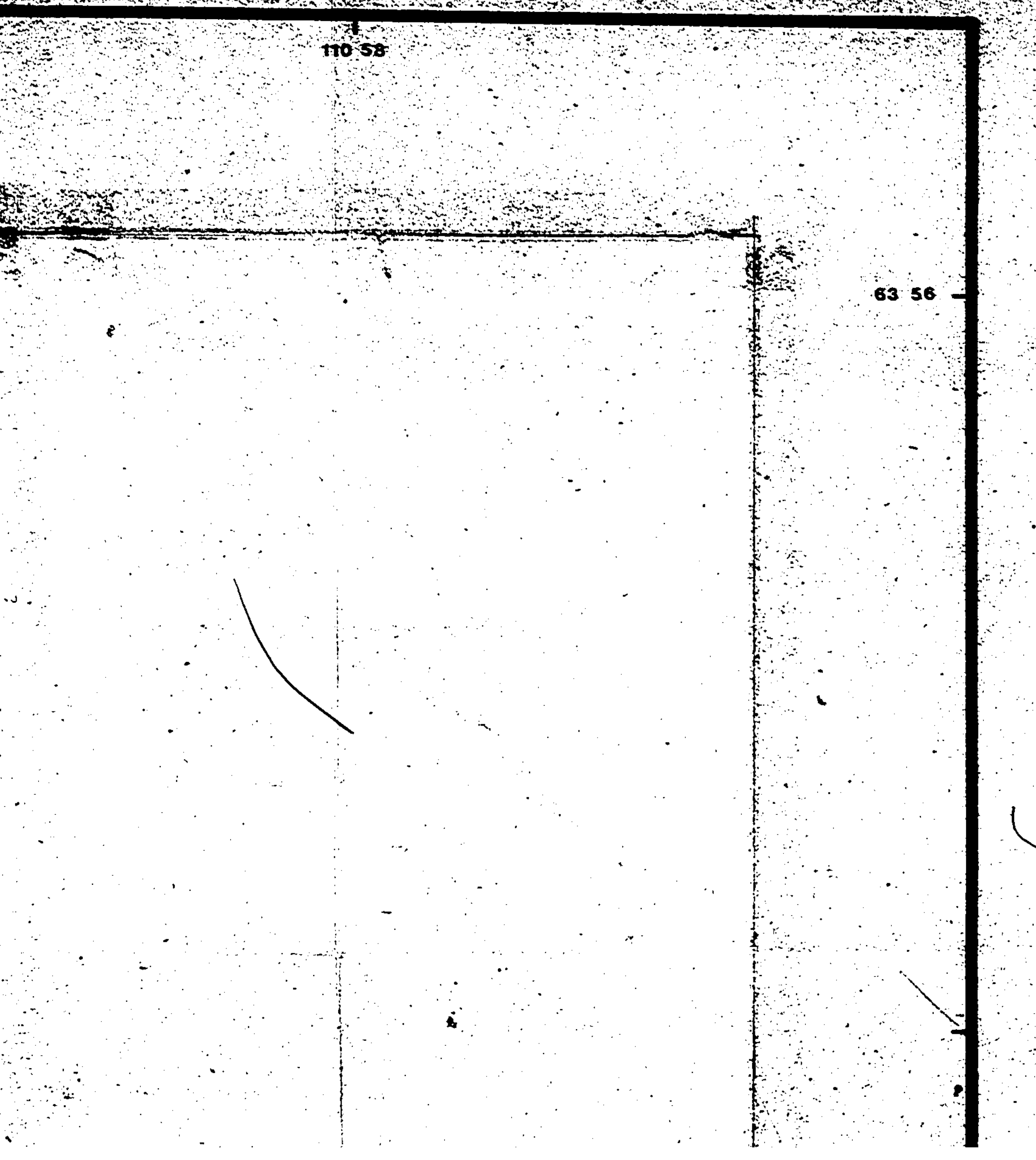
111 04

111 0

3 OF

111.02

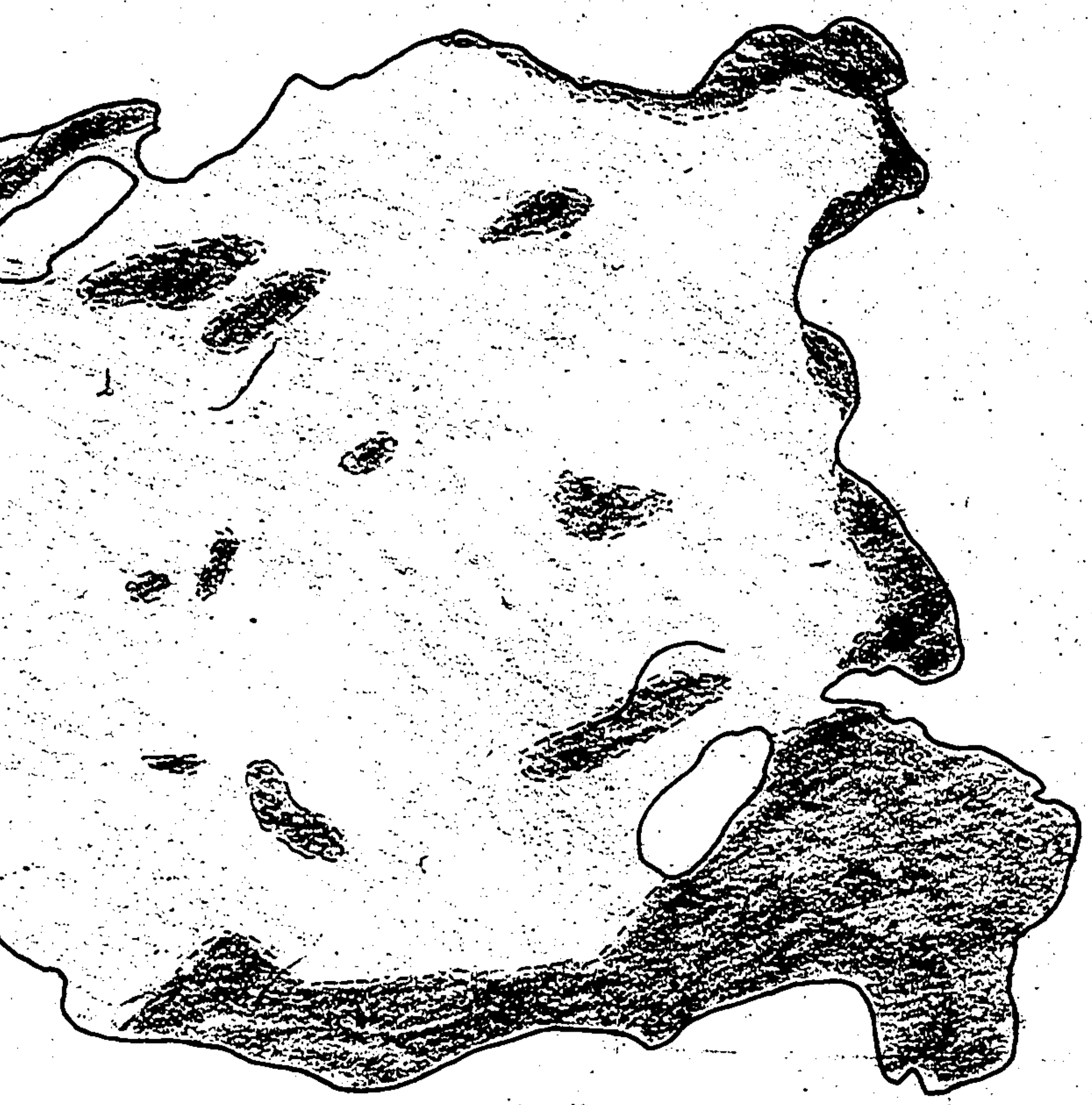
111.00


110 58
63 56


63 54
6 OF


1b
1b
1b
80
80
705

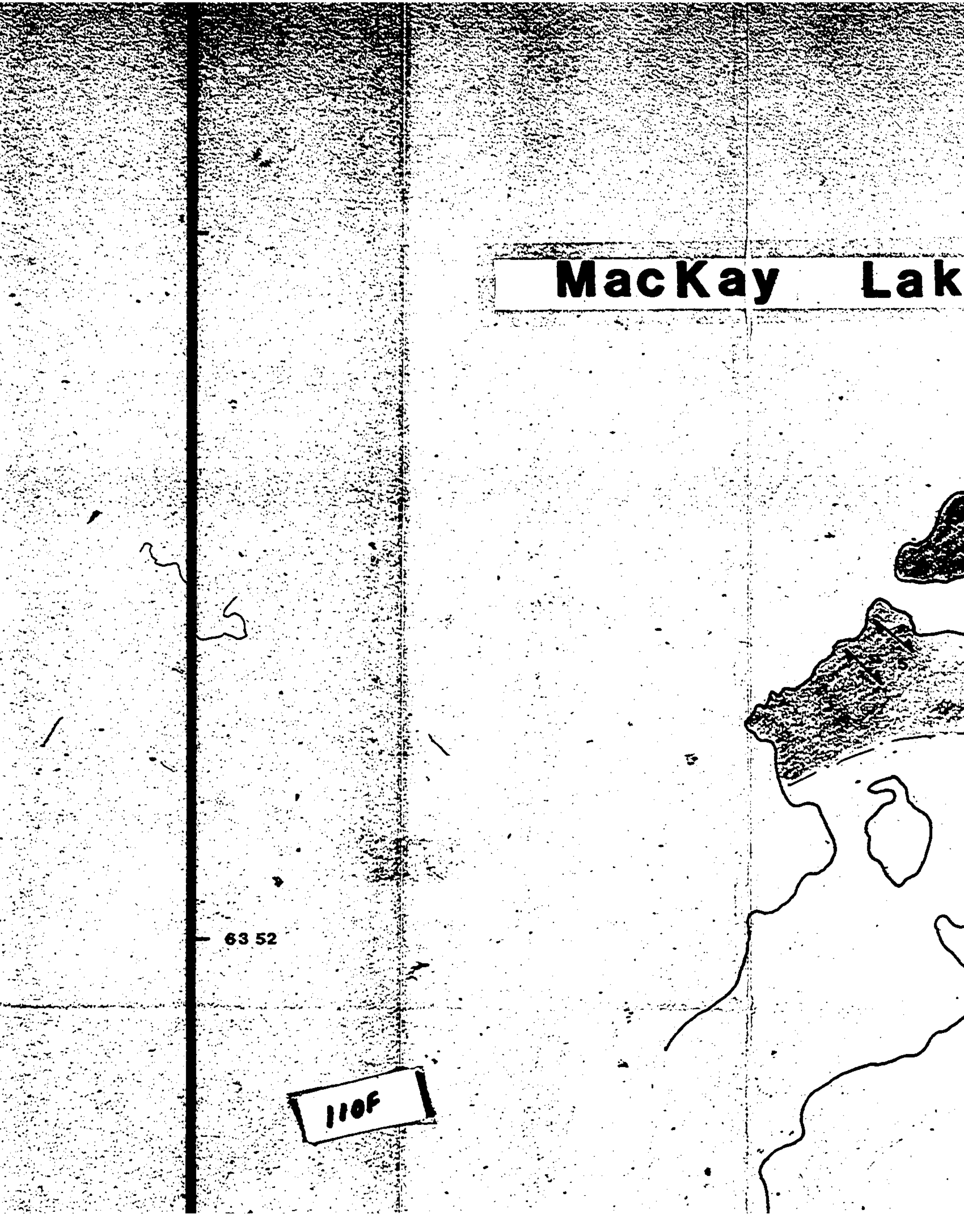
CD
75
4a
75
4a
75
85
4a
75
8 OF



90F

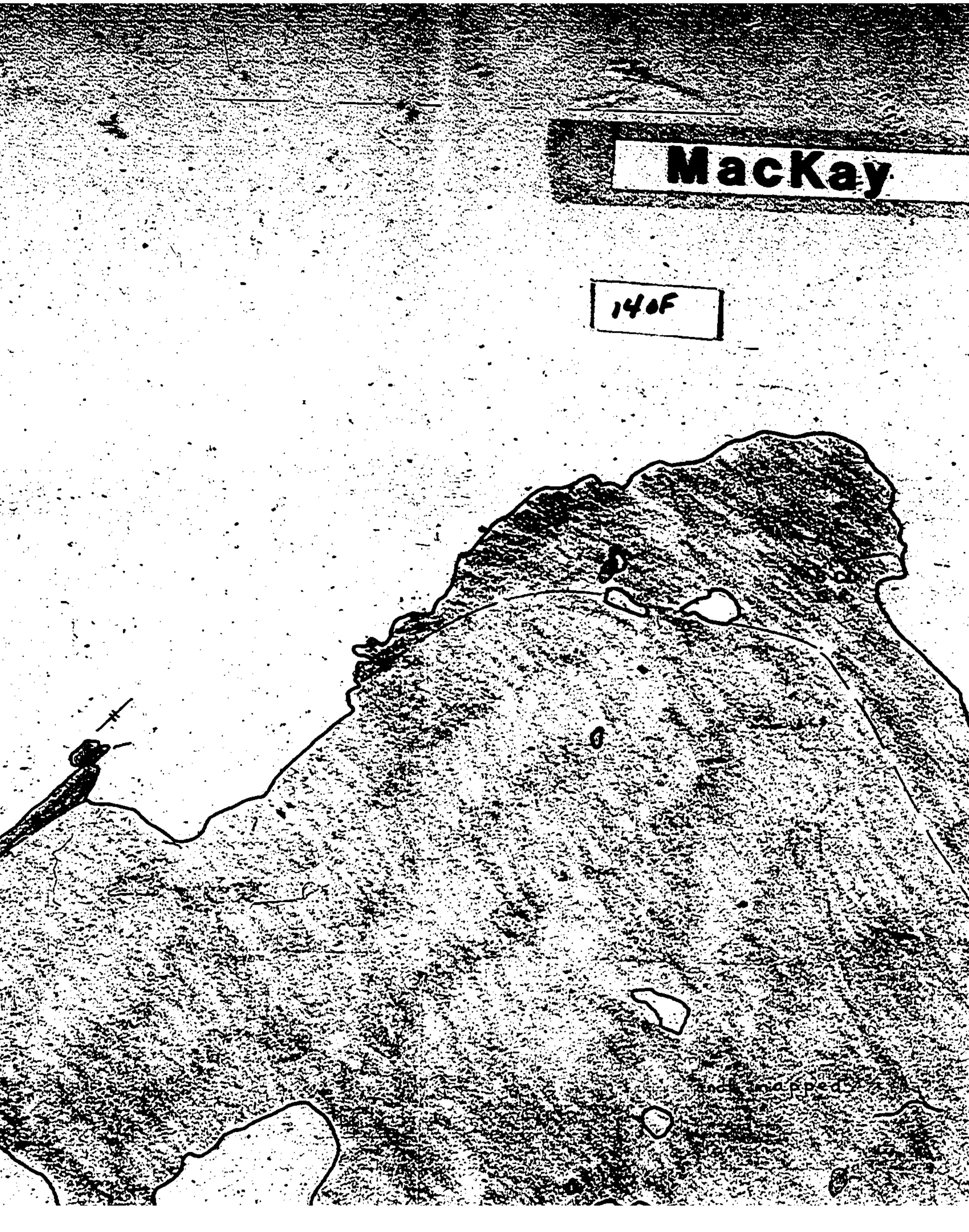
63 54

10 OF


MacKay Lak
63 52
110F


ake
120F

B CD
S
130F


MacKay
14 OF

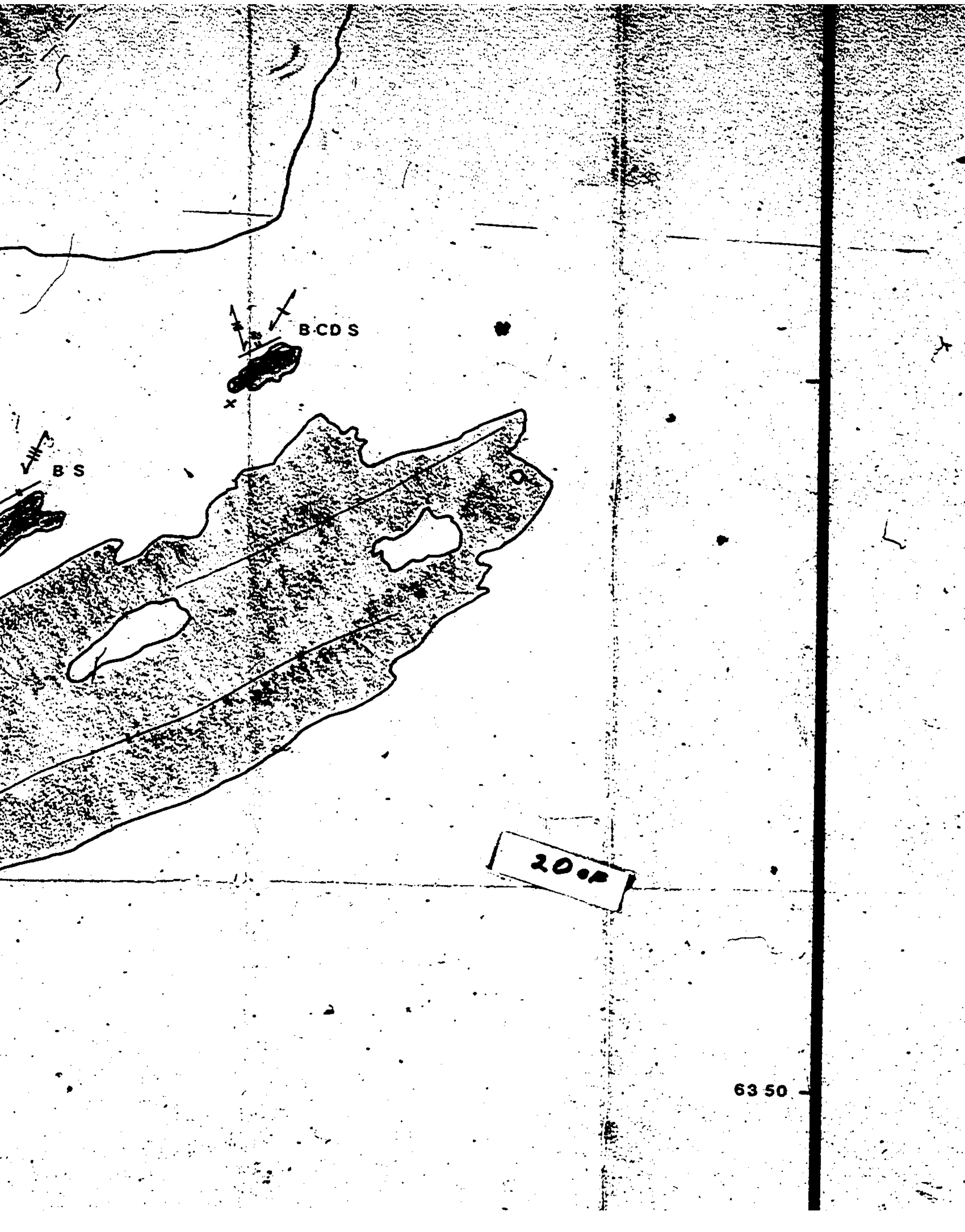

Lake
15 OF
63.52


160F
63 50

not mapped
170F


B CD
A S
B K
B CD
A S
180F

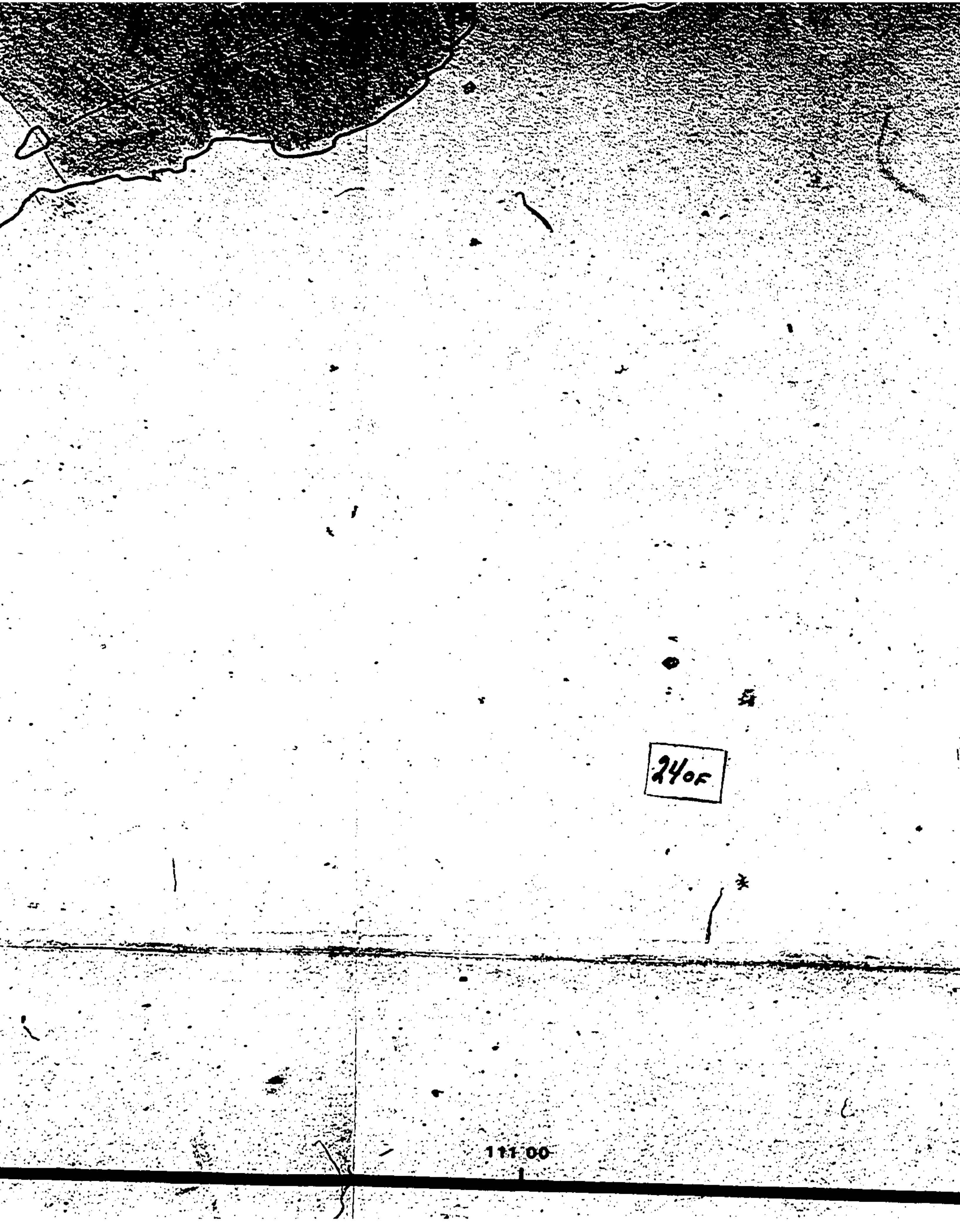
B CD
S
B CD
A S
190F


B CD S
B S
20
63 50


21 OF
11108


not mapped
111 06

not mapped
23 OF
111 04
111 02


24OF
111 00

25 OF

110·58

26OF

LEGEND

INTRUSIVE ROCKS

PROTEROZOIC

Diabase: highly magnetic, steeply dipping dyke

ARCHEAN

Pegmatite: biotite-muscovite-pegmatite.

Granitoid rocks: 5a) biotite granite (synk
granodiorite; 5c) biotite-hornblende tonalite;
trondhjemite (synvolcanic to earlier?).

Metagabbro: feeder sills and dykes to the vo
subunit 4a and unit 6, crosscuts 5b. 3a, mas
3b, massive, feldspar-porphyritic.

SUPRACRUSTAL ROCKS

YELLOWKNIFE SUPERGROUP

Metasediments: 4a) greywacke, arkose, a
4b) intervolcanic argillite or phyllite
conglomerate; 4d) pyritic banded chert; 4e) gr
conglomerate.

Cycle 2

2

Metarhyolite to metadacite: 2a) massive
block-breccia; 2c) rhyodacitic quartz-fe
volcaniclastic; 2d) dacitic ash to lapilli-
2f) massive quartz-fellspar phyric intrusive roc

Intermediate metavolcanics: 1c) massive, a
flow; 1d) pillowed, amygdaloidal andesi
1h) andesitic fragmental rock.

Mafic metavolcanics: 1a) massive basalt flow
flow; 1e) massive feldspar-phyric basalt flow;
phyric basalt; 1g) "banded" basalt (highly flatten

Note: volcanic units without inclined ruling ha
to a specific cycle.

Cycle 1

Metarhyolite to metadacite: 2a) ...

ing dykes.

ite.

e (synkinematic); 5b) biotite
onalite; 5d) biotite-hornblende

o the volcanic pile, older than
3 massive non-porphyritic;

kose, and slate turbidites;
phyllite; 4c) intervolcanic
t; 4e) granitoid-volcanic clast

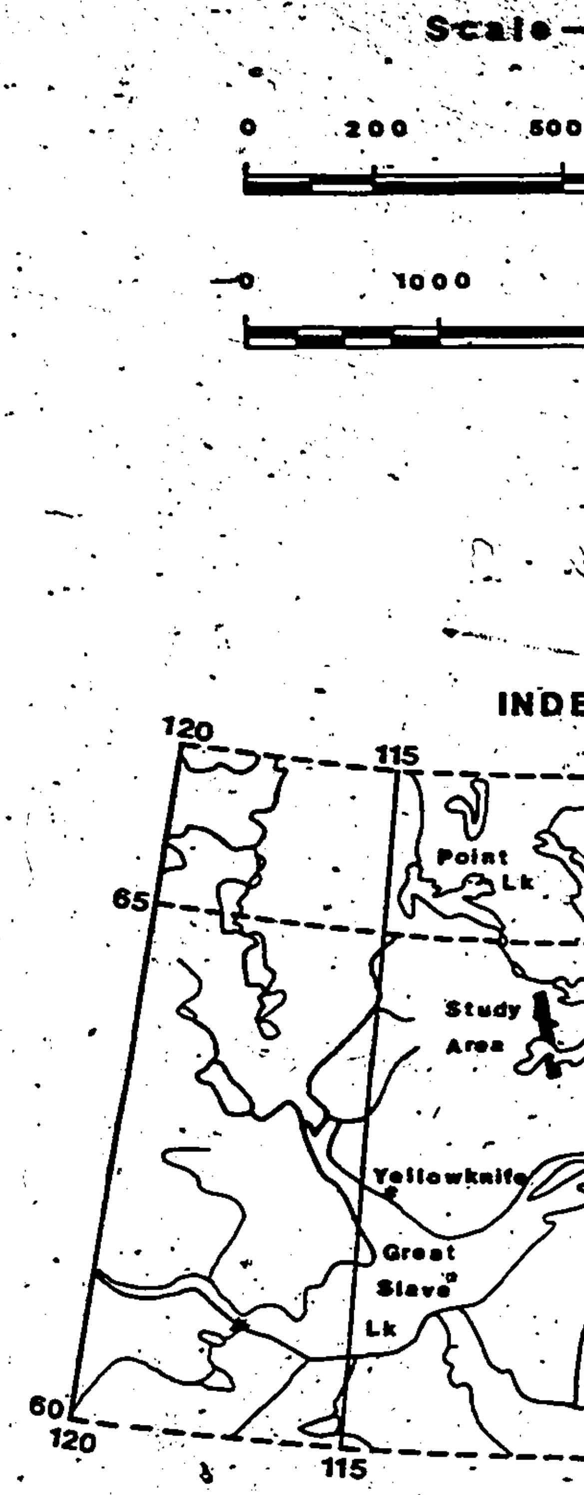
assive rhyolite; 2b) rhyolite
uartz-feldspar lapilli-sized
lapilli-sized volcaniclastic;
usive rock.

ssive, amydgaloidal andesite
andesite flow:

salt flow; 1b) pillowed basalt
lt flow; 1f) pillowed feldspar
ly flattened).

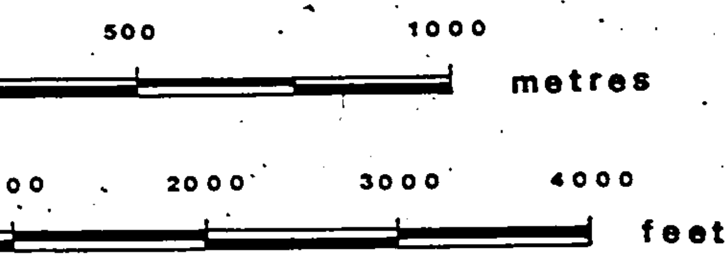
ruling have not been related

acitic quartz-feldspar lapilli-

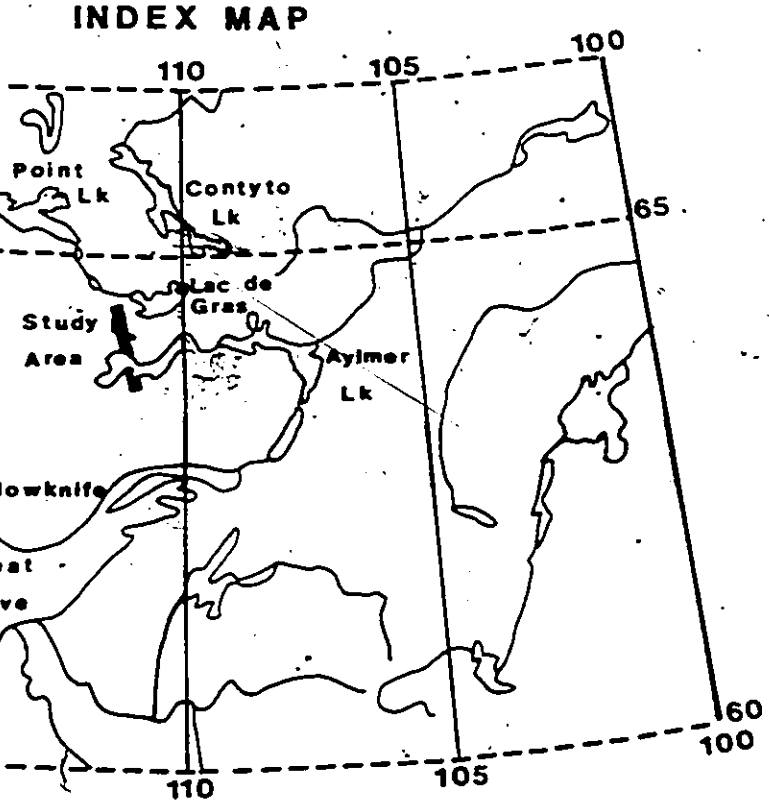


270P

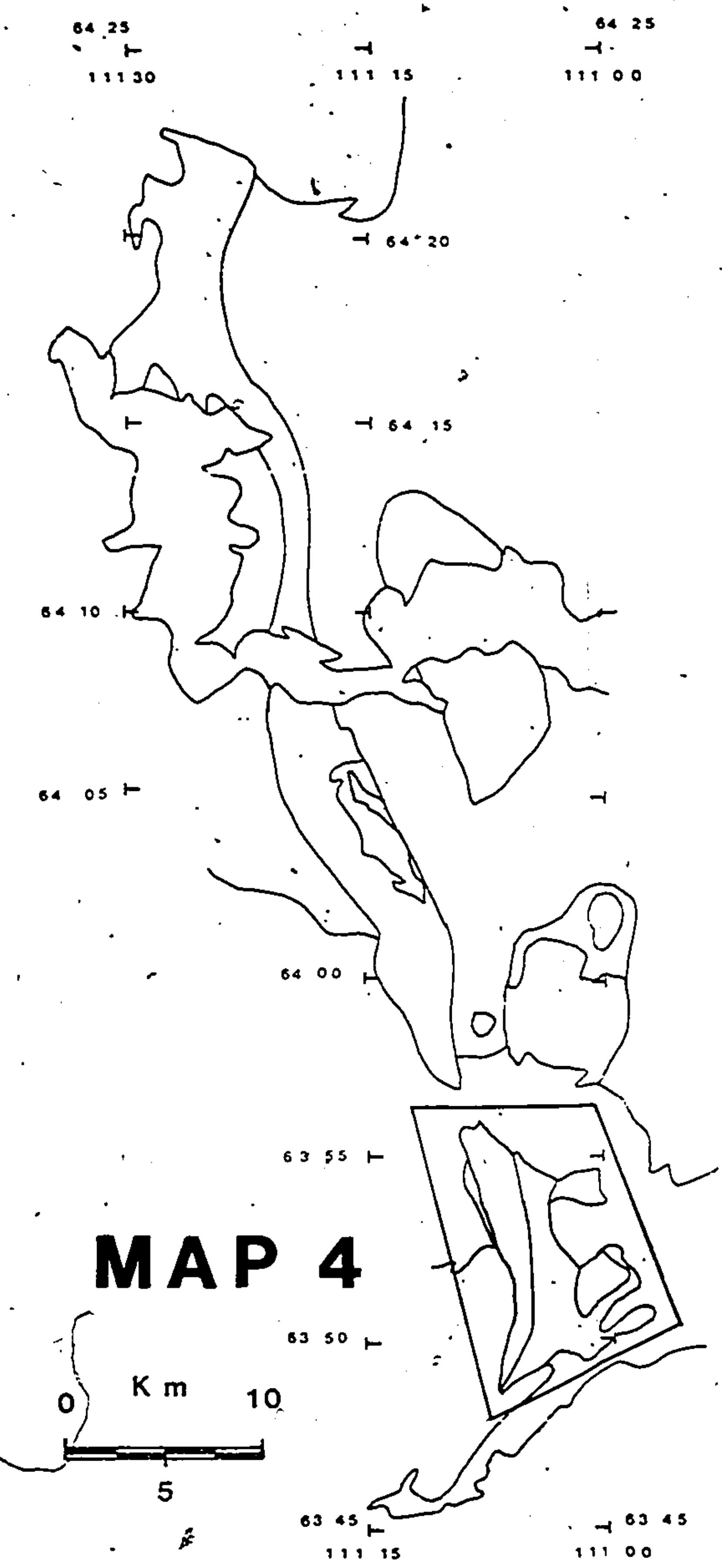
Scale – 1:12,000



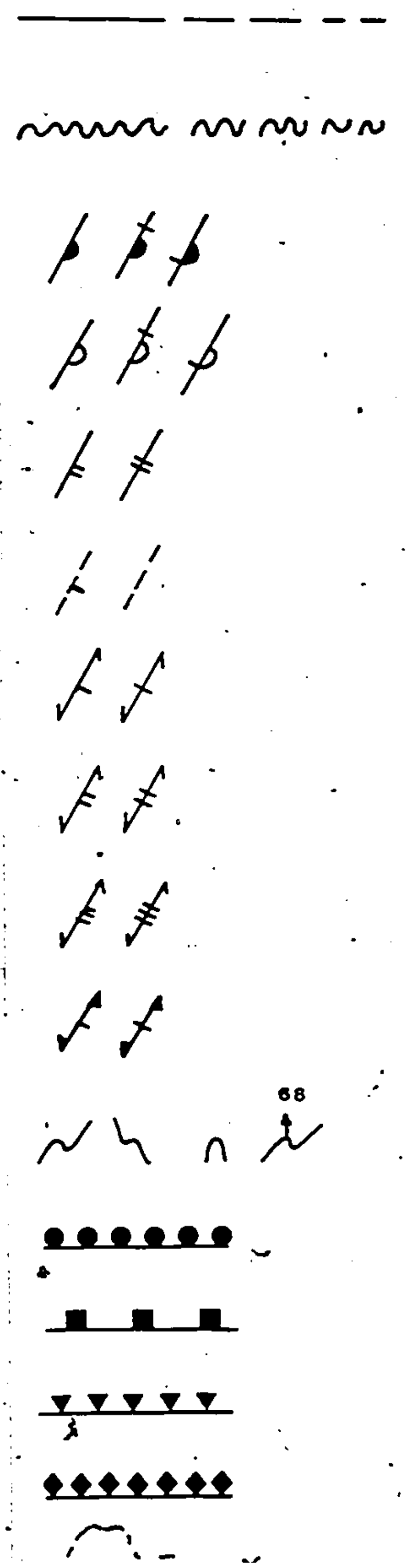
INDEX MAP



280F


64 25
111 30
111 15
64 25
111 00
64 20
64 15
64 10
64 05
64 00
63 55
63 50
63 45
111 15
63 45
111 00
MAP 4
Km
0
10
5

290F


68

SYMBOLS

GEOLOGICAL BOUNDARY: DEFINED, APPROXIMATE, ASSUMED

FAULTS: DEFINED, APPROXIMATE, ASSUMED

PILLOW FACING): INCLINED, VERTICAL, OVERTURNED

BEDDING (GRADED TOPS): INCLINED, VERTICAL, OVERTURNED

BEDDING (TOPS UNKNOWN): INCLINED, VERTICAL

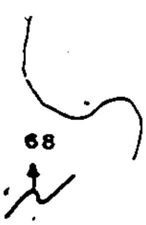
S_{1A} FABRIC : INCLINED, DIP UNKNOWN

S_{1B} CLEAVAGE: INCLINED, VERTICAL

S_2 CLEAVAGE: INCLINED, VERTICAL

S_3 CLEAVAGE: INCLINED, VERTICAL

GRANITOID GNEISSOSITY: INCLINED, VERTICAL



MINOR FOLD SYMMETRY: 'Z' SENSE, 'S' SENSE, SENSE UNKNOWN, FOLD PLUNGE

CORDIERITE ISOGRAD

CUMMINGTONITE ISOGRAD

ANDALUSITE ISOGRAD

SILLIMANITE ISOGRAD

30 of

YELLOWKNIFE SUPERGROUP

Metasediments: 4a) greywacke, arkose, 4b) intervolcanic argillite or phyllit conglomerate; 4d) pyritic banded chert; 4e) g conglomerate.

Cycle 2

2

Metarhyolite to metadacite: 2a) massive block-breccia; 2c) rhyodacitic quartz-f volcaniclastic; 2d) dacitic ash to lapilli 2f) massive quartz-feldspar phyric intrusive ro

Intermediate metavolcanics: 1c) massive, a flow; 1d) pillowed, amygdaloidal andes 1h) andesitic fragmental rock.

Mafic metavolcanics: 1a) massive basalt flow flow; 1e) massive feldspar phyric basalt flow; phyric basalt; 1g) "banded" basalt (highly flatte

Note: volcanic units without inclined ruling h to a specific cycle.

Cycle 1

2

Metarhyolite to metadacite: 2c) rhyodacitic sized volcaniclastic; 2d) dacitic ash to lap 2e) rhyodacitic block-breccia (highly chloritic).

Mafic metavolcanics: 1a) massive basalt flow flow.

Metamorphic assemblages: A - andalusite; B - biotite; C - chlorite; CD - cordierite; CX - clinopyroxene; E - epidote; G - garn K - potassium feldspar; M - muscovite; S - sillim

m = carbonatized; s = sheared; n = silicified.

3/ OF

e, arkose, and slate turbidites;
or phyllite; 4c) intervolcanic
chert; 4e) granitoid-volcanic clast

2a) massive rhyolite; 2b) rhyolite
quartz-feldspar lapilli-sized
to lapilli-sized volcaniclastic;
: intrusive rock.

:) massive, amydgaloidal andesite
idal andesite flow:

: basalt flow; 1b) pillowed basalt
basalt flow; 1f) pillowed feldspar
(highly flattened).

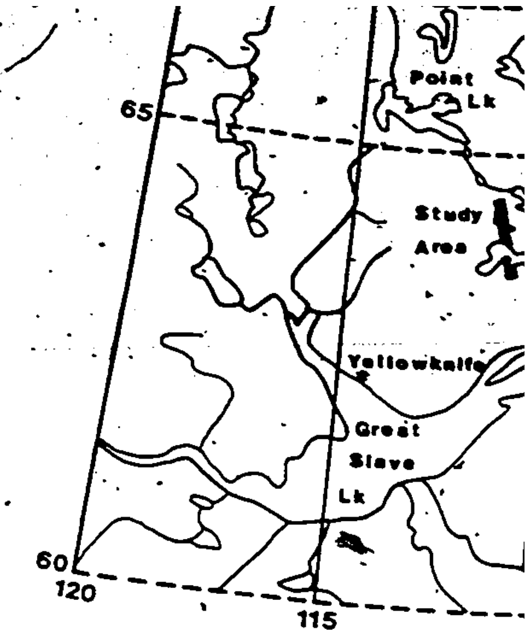
ined ruling have not been related

hyodacitic quartz-feldspar lapilli-
sh to lapilli-sized volcaniclastic;
ly chloritic).

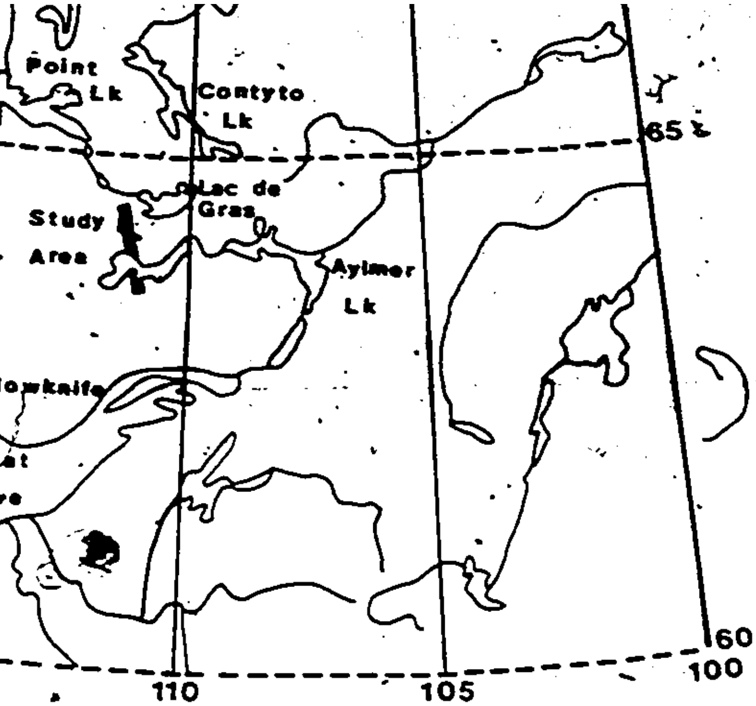
basalt flow; 1b) pillowed basalt

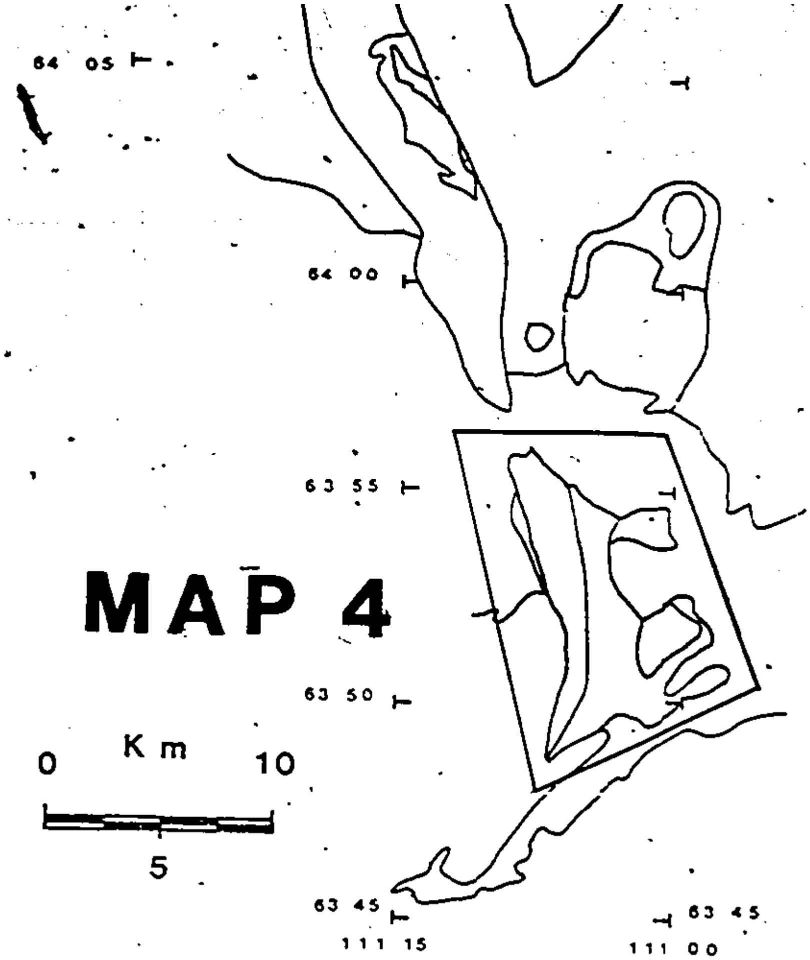
- andalusite; AT - anthophyllite;
cordierite; CM - cummingtonite;
; G - garnet; KY - Kyanite;
ite; S - sillimanite.

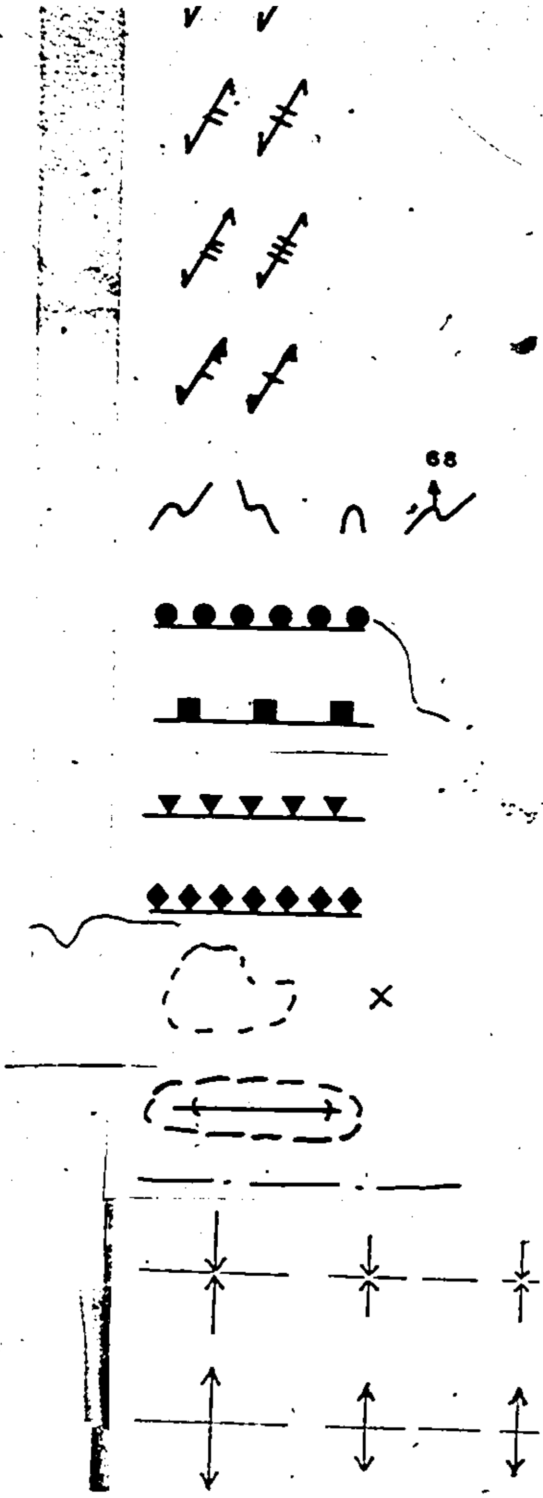
ilicified.



32 OF


Point
Lk
Contyto
Lk
65
Lac de
Gras
Study
Area
Aylmer
Lk
60
110
105
100





34 of

S_2 CLEAVAGE: INCLINED, VERTICAL

S_3 CLEAVAGE: INCLINED, VERTICAL

GRANITOID GNEISSOSITY: INCLINED, VERTICAL

MINOR FOLD SYMMETRY: 'Z' SENSE, 'S' SENSE, SENSE UNKNOWN, FOLD PLUNGE

CORDIERITE ISOGRAD

CUMMINGTONITE ISOGRAD

ANDALUSITE ISOGRAD

SILLIMANITE ISOGRAD

OUTCROP: AREA, SINGLE OUTCROP

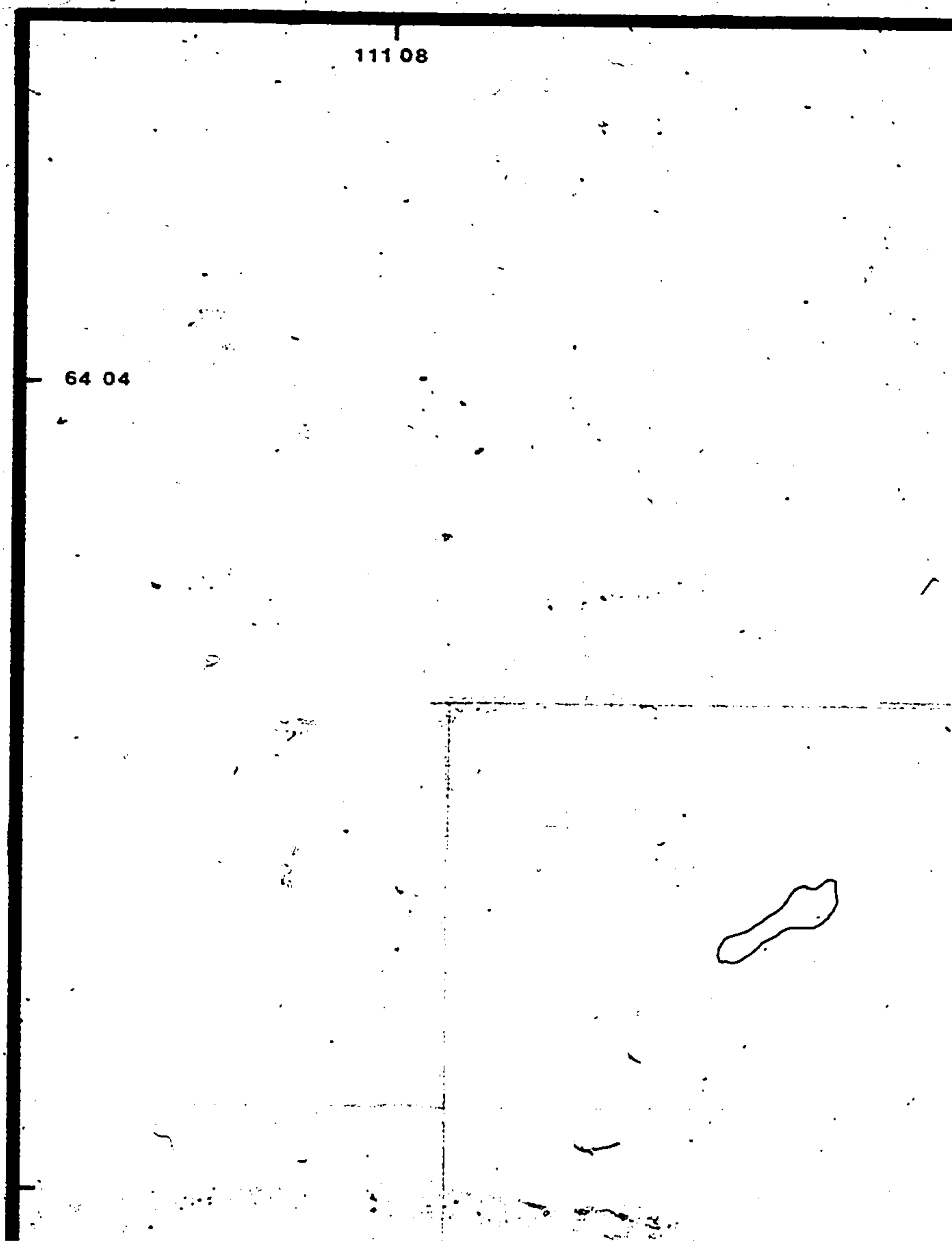
MORAINE: ICE DIRECTION UNKNOWN

LIMIT OF MAPPING

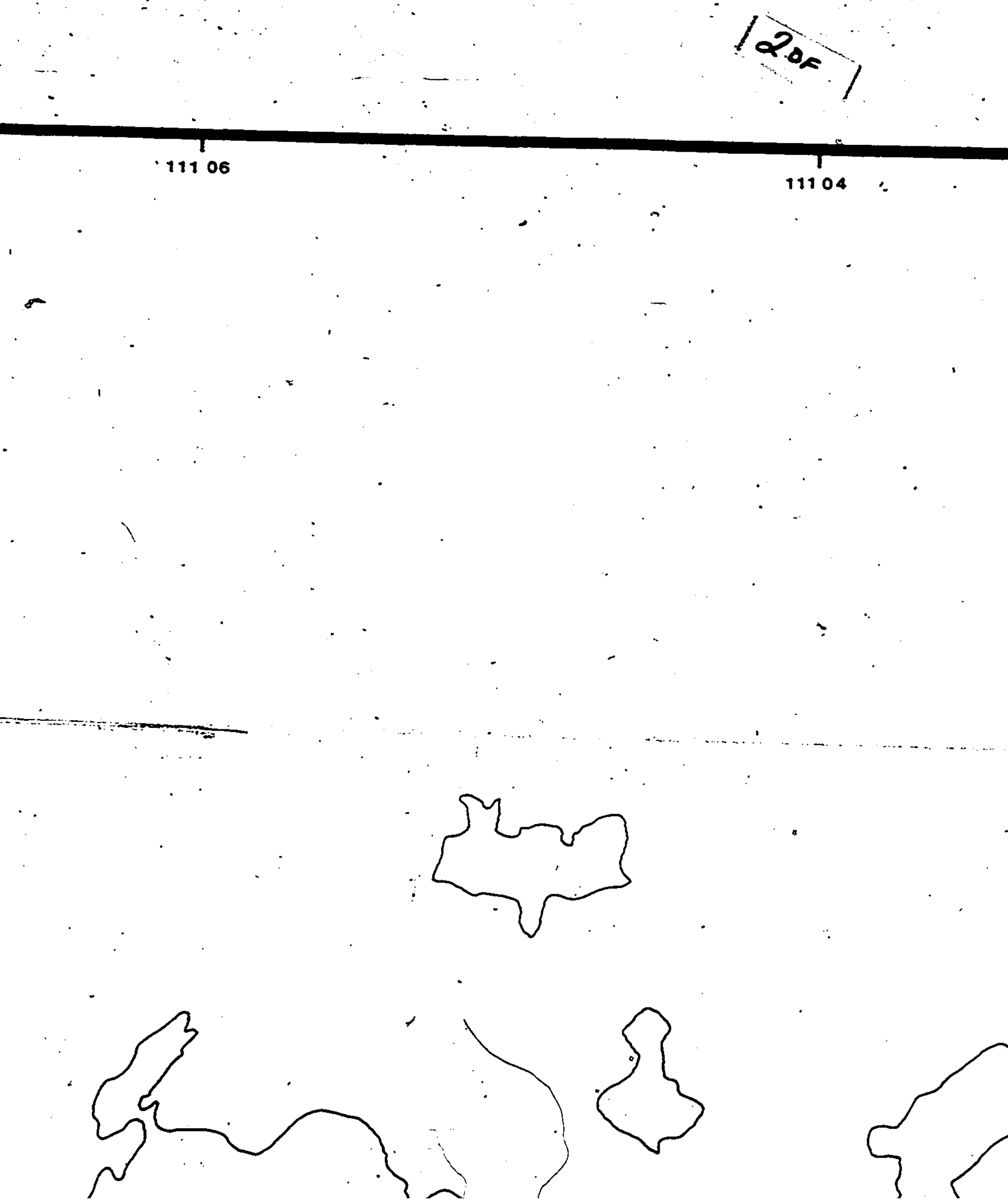
SYNCLINE: DEFINED, APPROXIMATE, ASSUMED

ANTICLINE: DEFINED, APPROXIMATE, ASSUMED

MAP 5

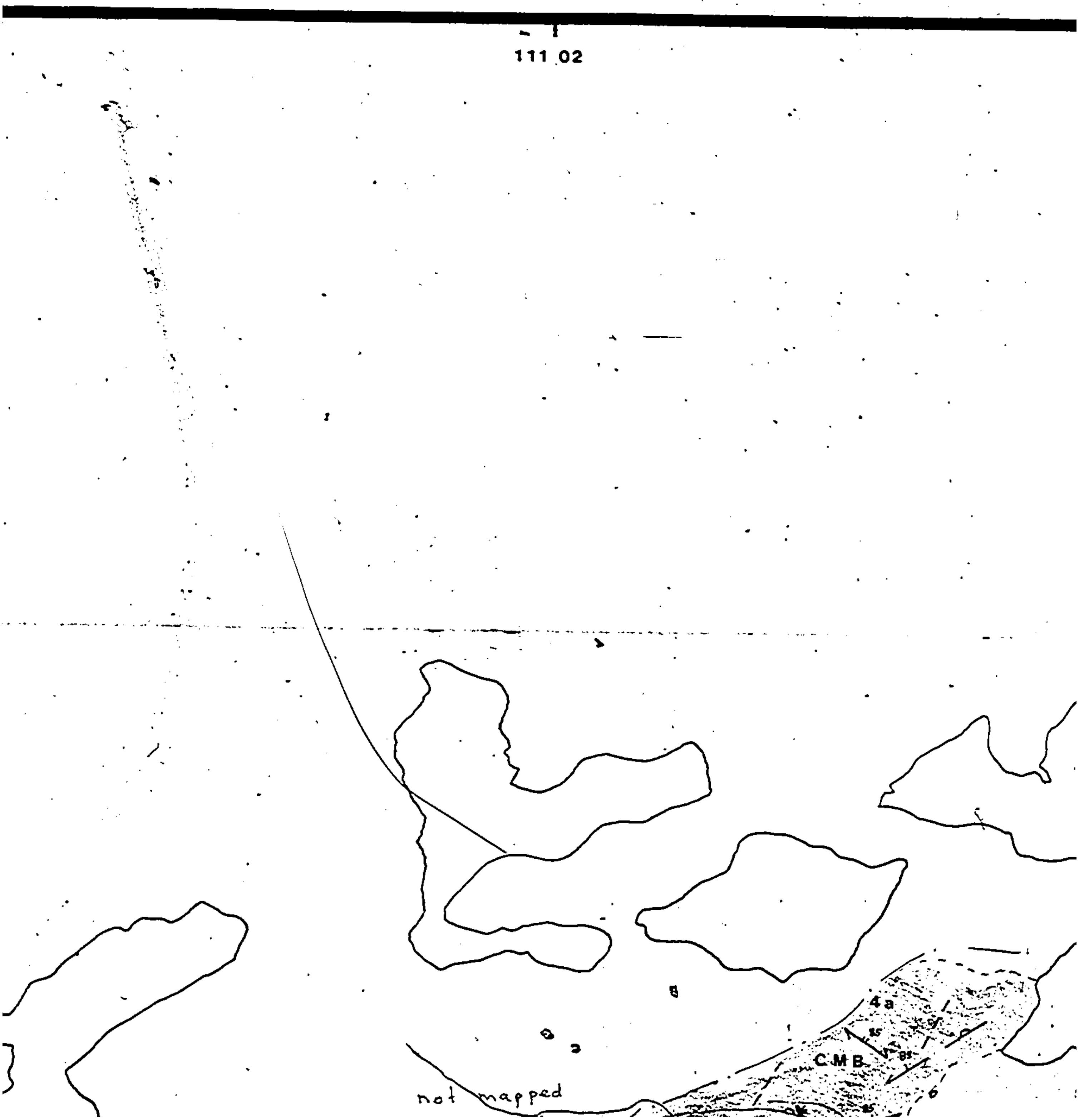


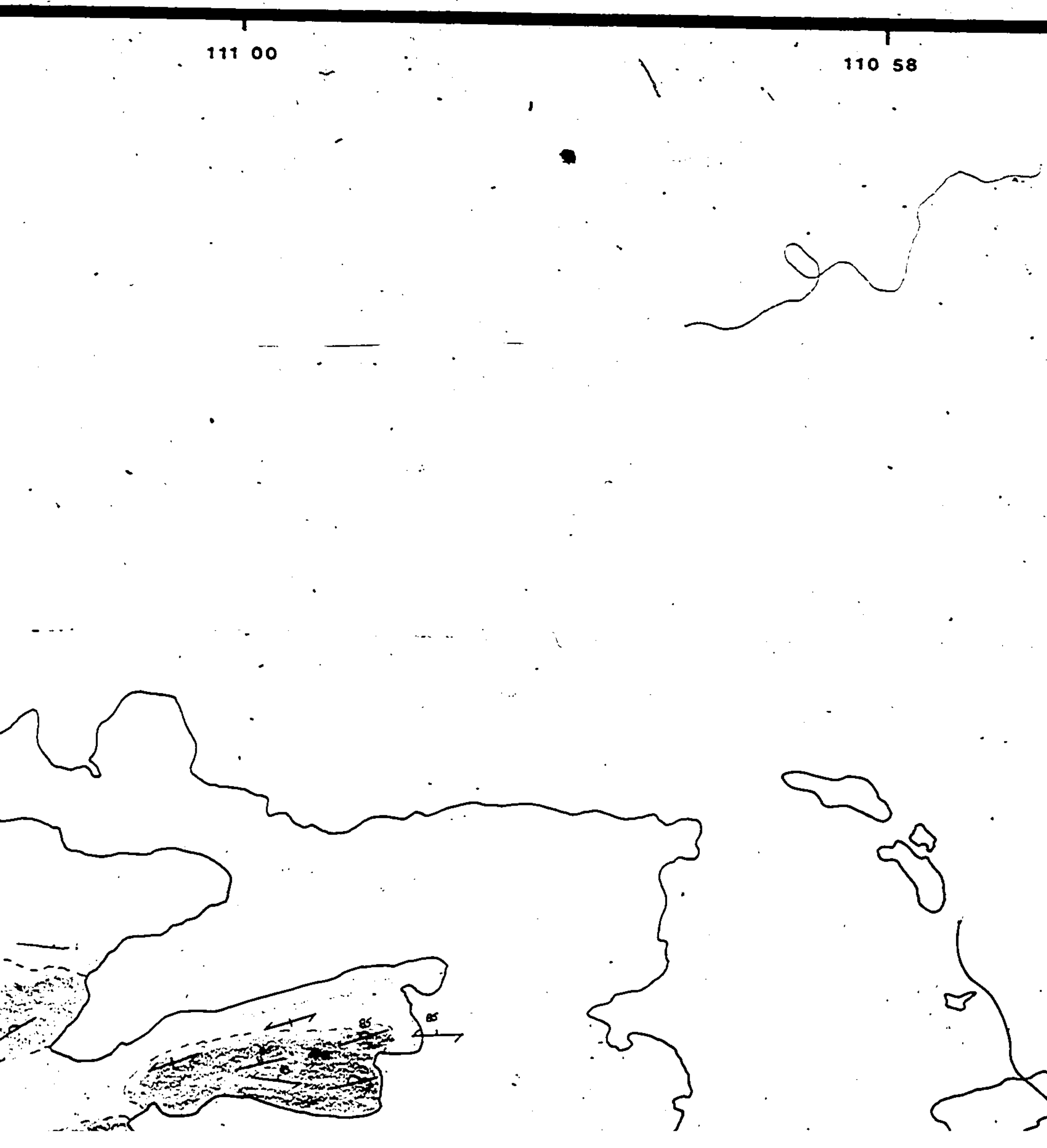
1 OF 1



2DF
111 06
111 04

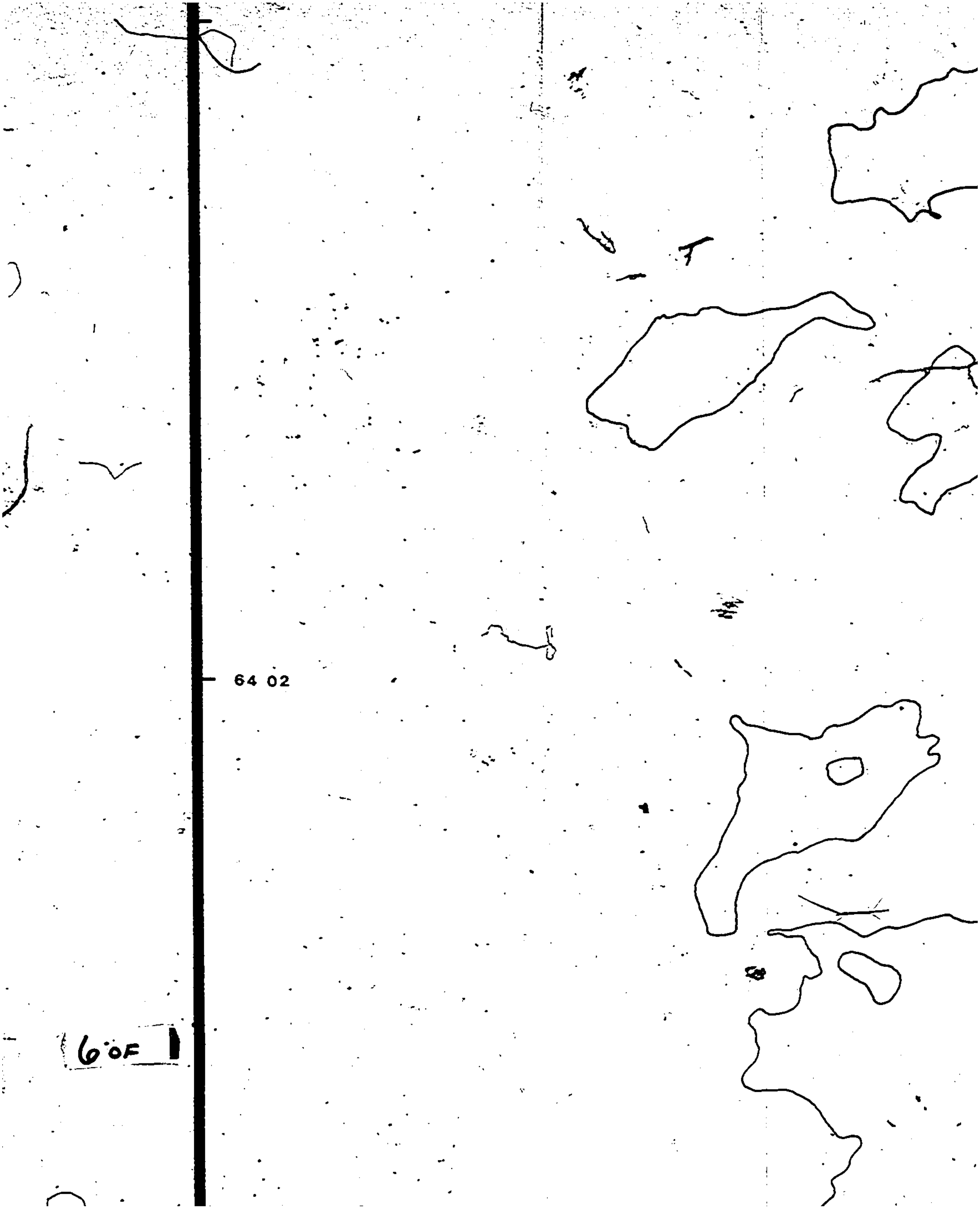
3 OF

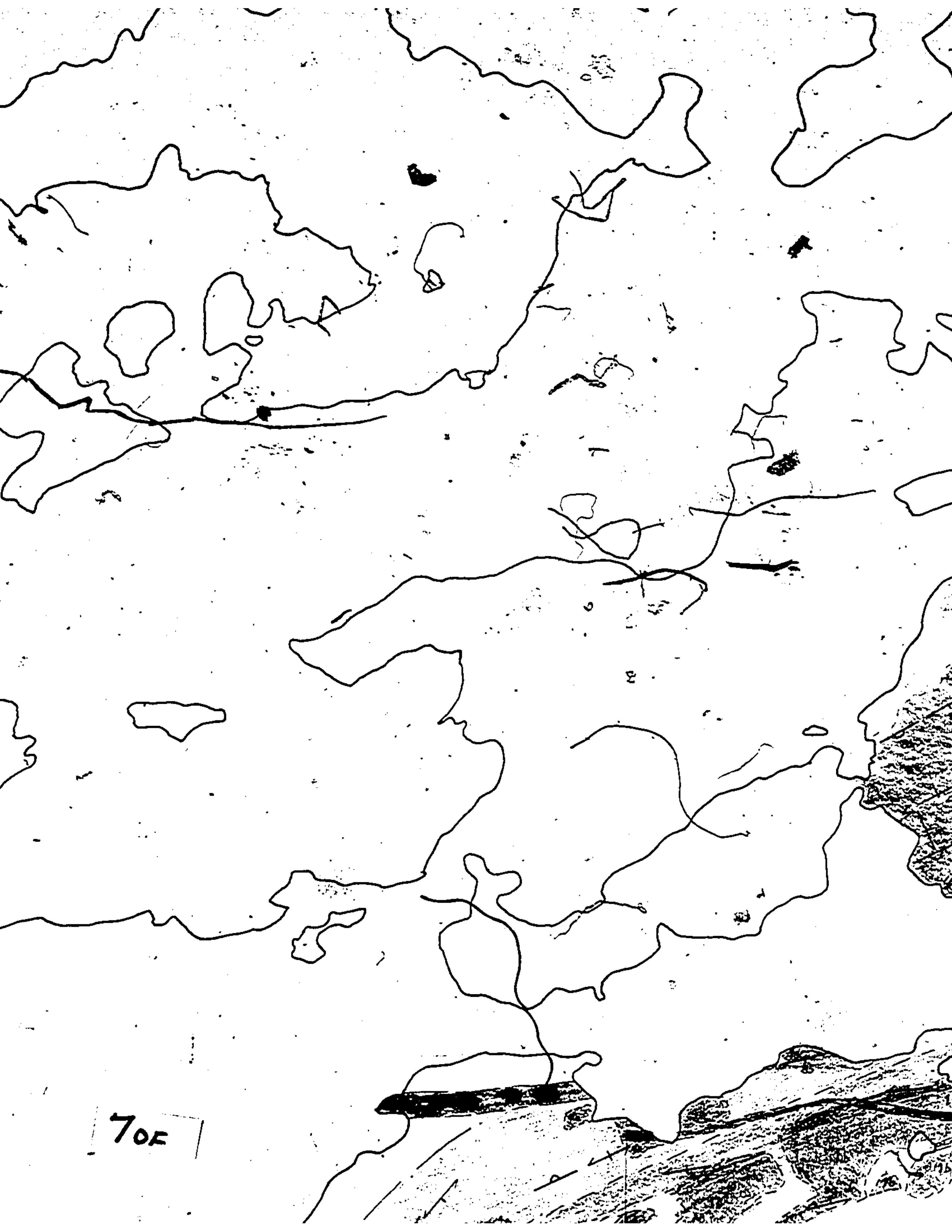



111 00
110 58
85
85

110 56

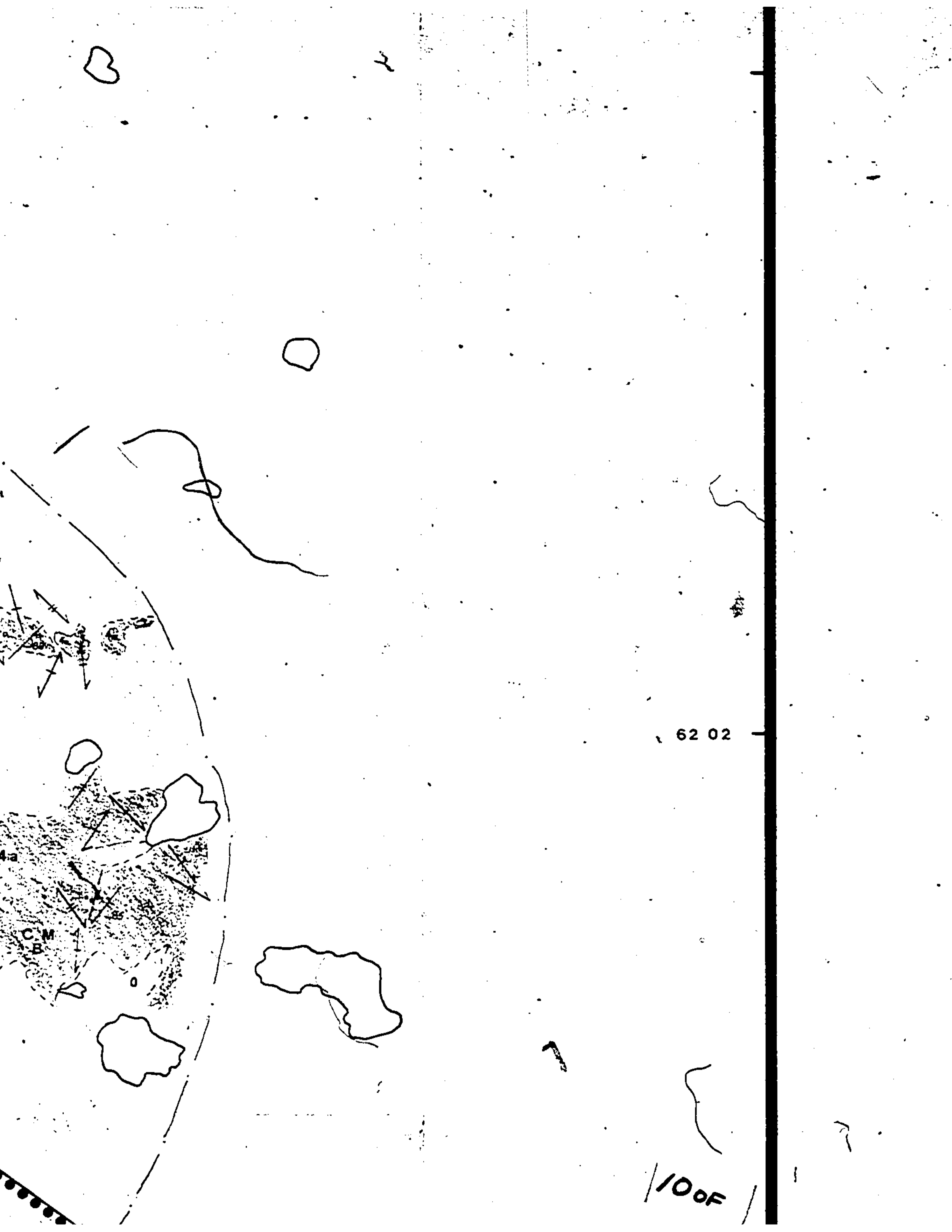
64 04

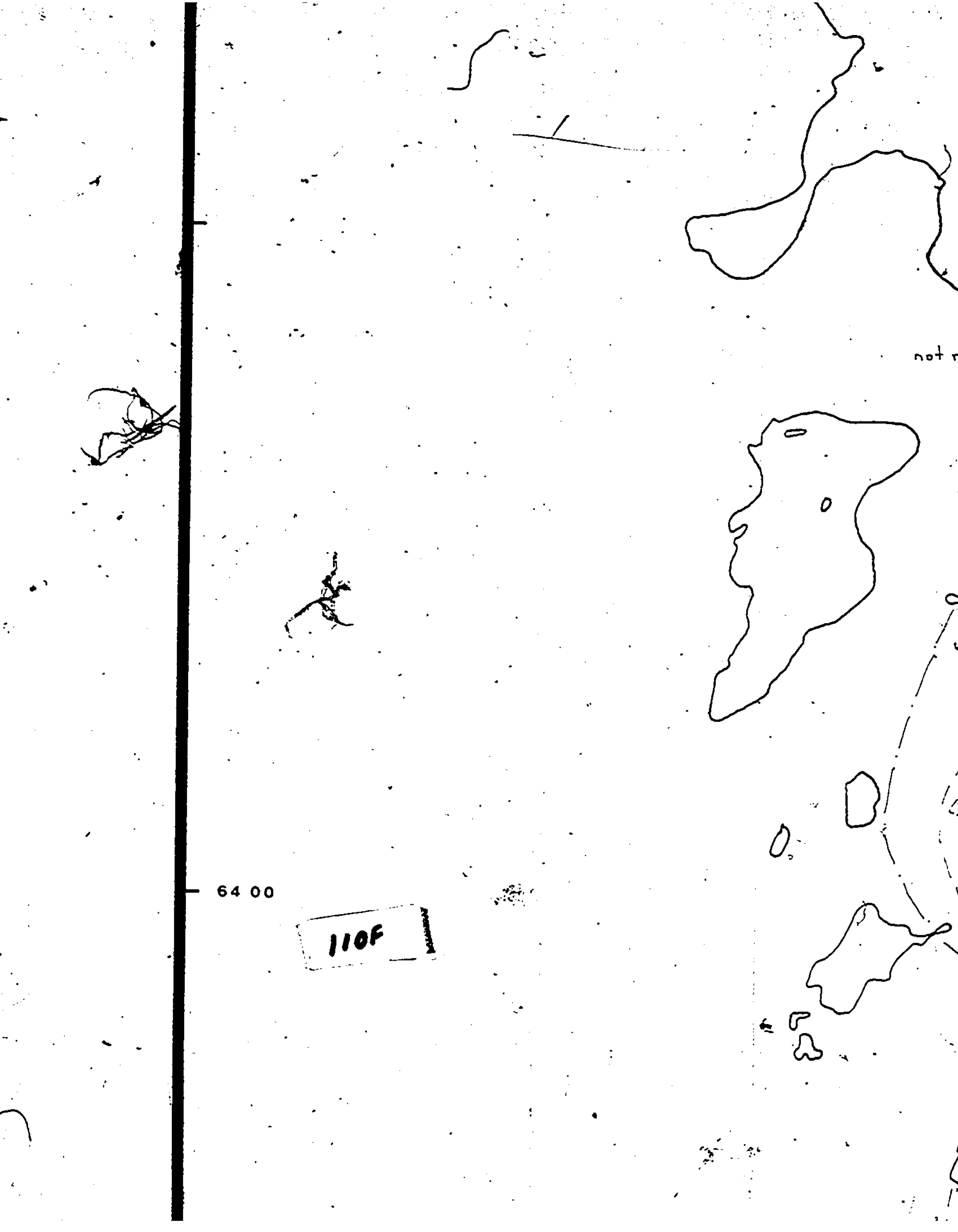

64 02
6 OF 1

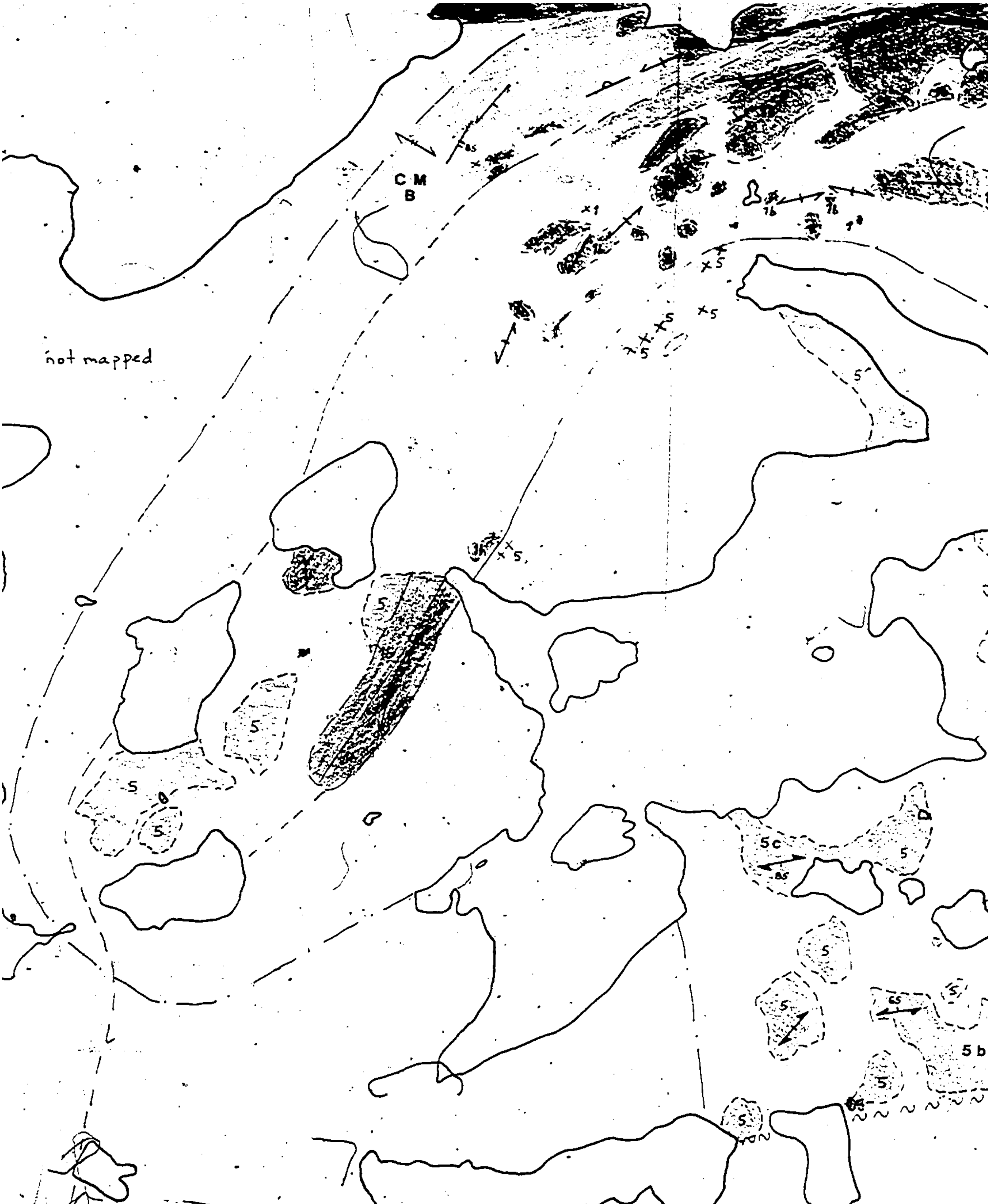

70F


not mapped
CMB
MB
C B
CM
B
4e
80
85
65
1a
1b
1
8oF

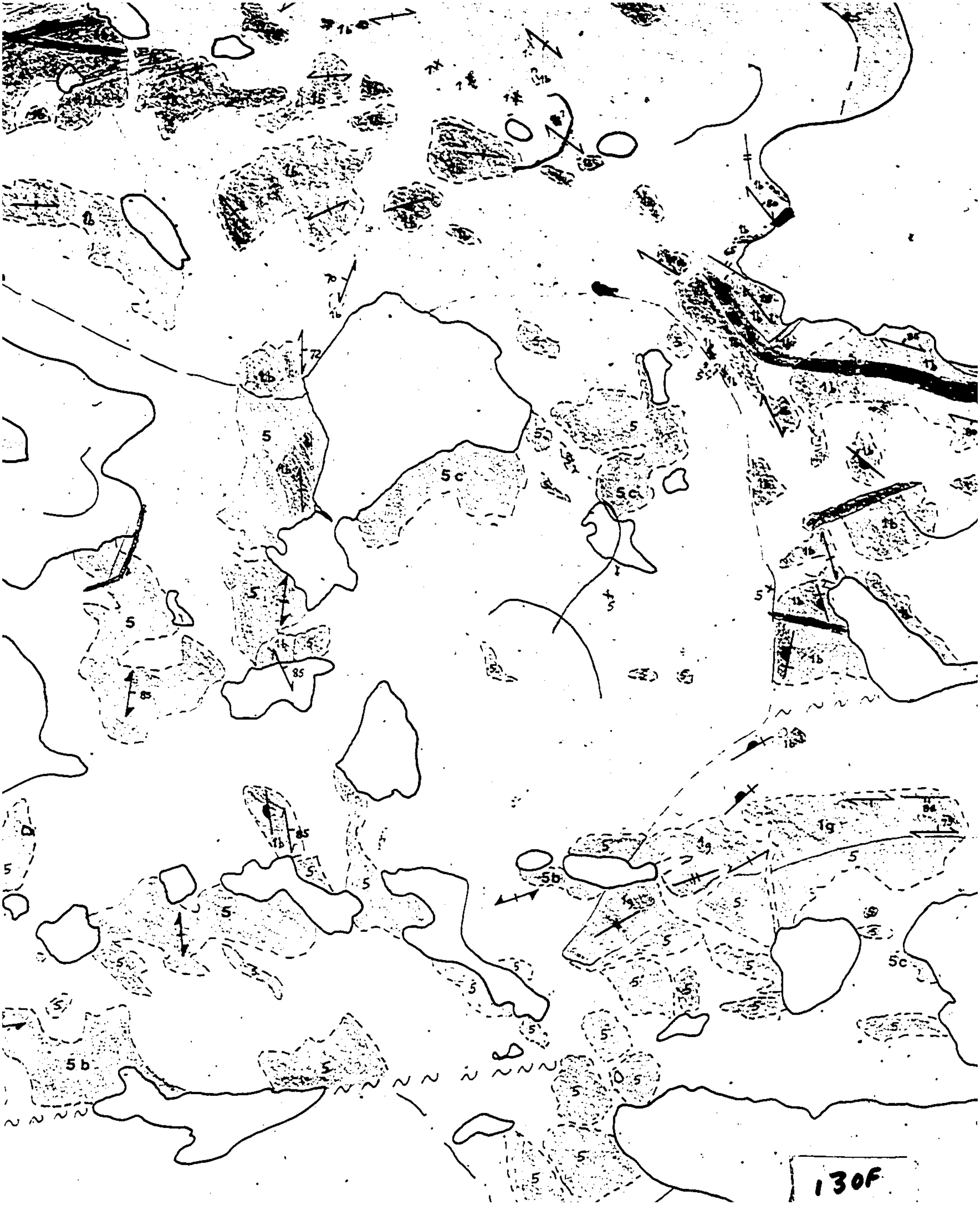
not mapped
C M B
C B
C M
B
4a
5b
5c
5
1b
4 a
C M
B
B C M CD


62 02
4a
C M
B
85
0
1 OF

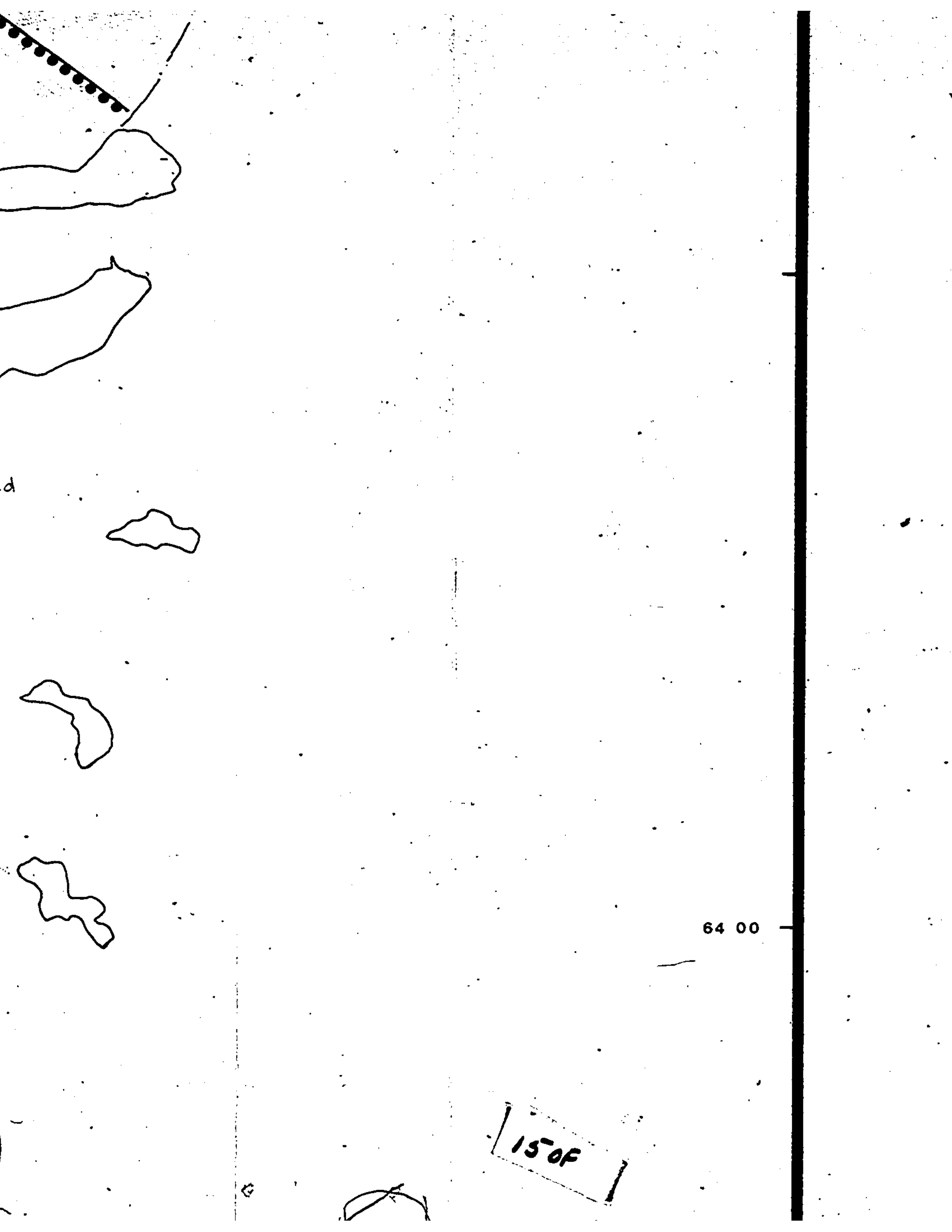

64 00
110F

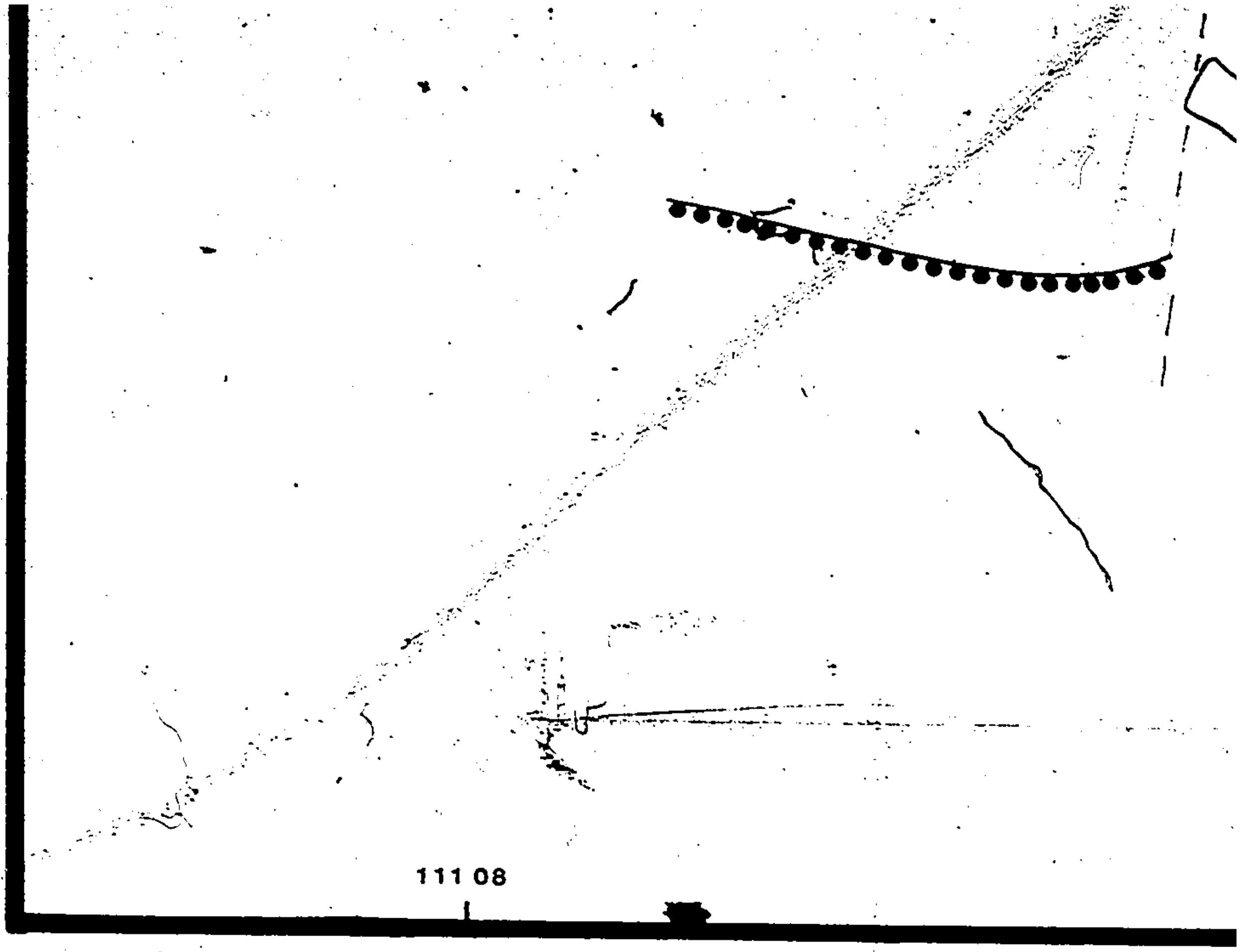


C M
B
not mapped
5
5c
5b


1b
72
5
5c
85
1g
5b
84
73
130F

not mapped
B C M
CD
1b
1a
1g
4d
5
140F


64 00
15 OF



LEGEND

INTRUSIVE ROCKS

PROTEROZOIC

Diabase: highly magnetic, steeply dipping dykes.

ARCHEAN

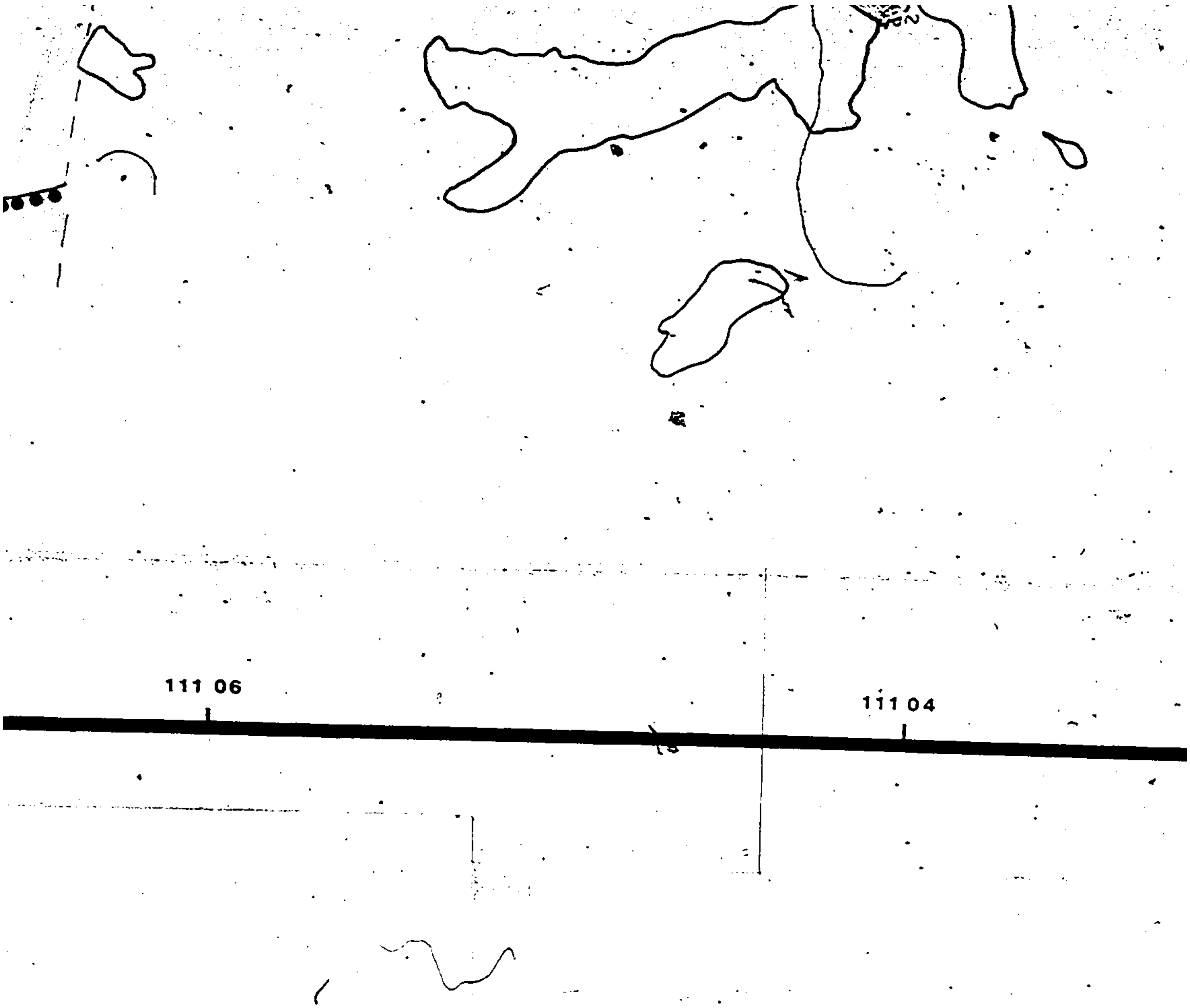
Pegmatite: biotite-muscovite pegmatite.

5

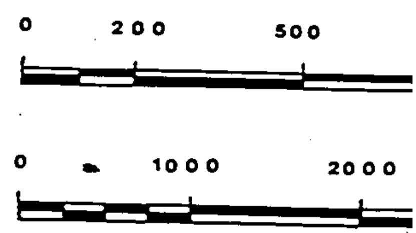
Granitoid rocks: 5a) biotite granite (synkinen granodiorite; 5c) biotite-hornblende tonalite; 5d) trondhjemite (synvolcanic to earlier?).

Metagabbro: feeder sills and dykes to the volcan subunit 4a and unit 6, crosscuts 5b. 3a, massive 3b, massive, feldspar-porphyritic.

160F 1



Scale – 1:12



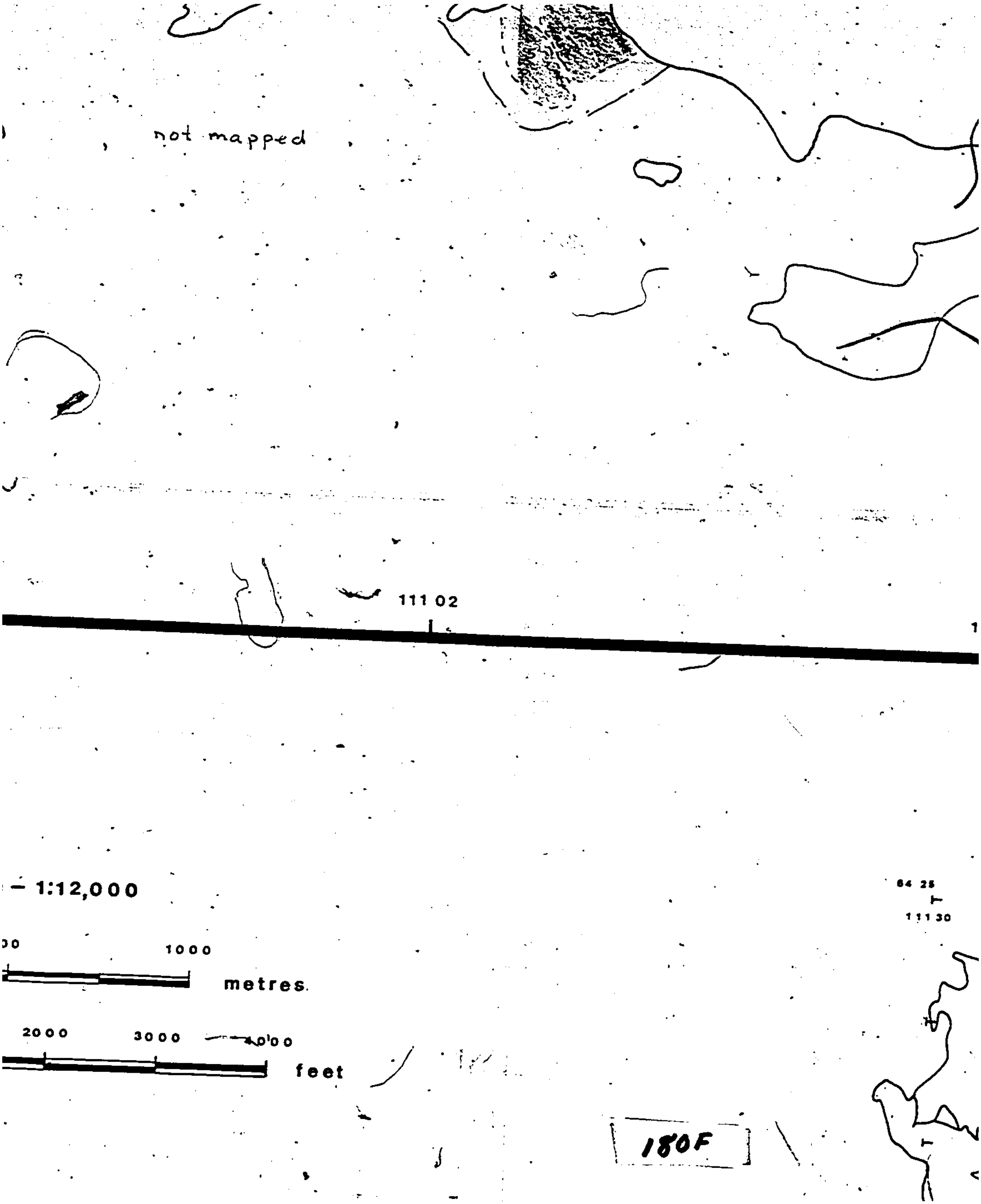
ıg dykes.

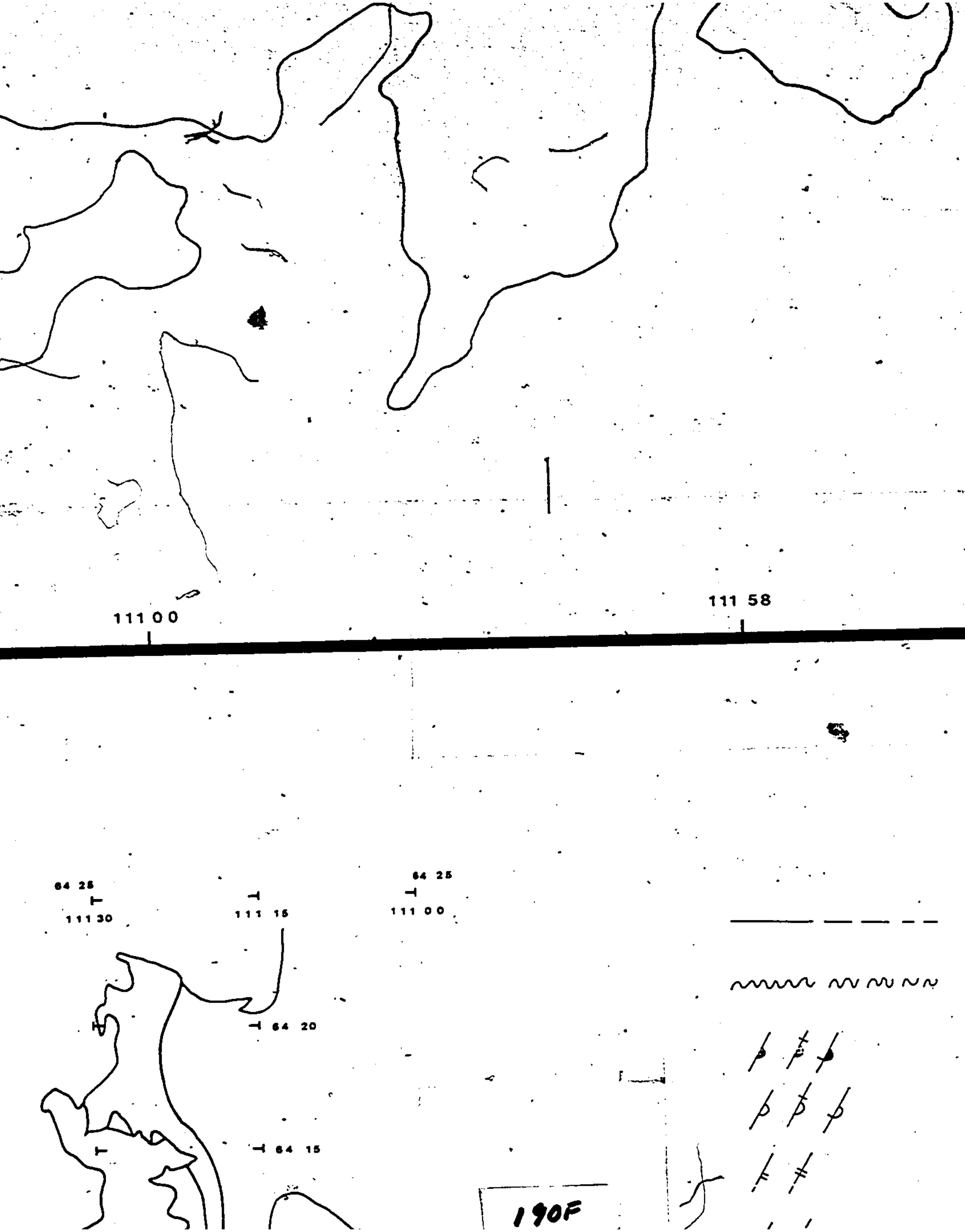
170F

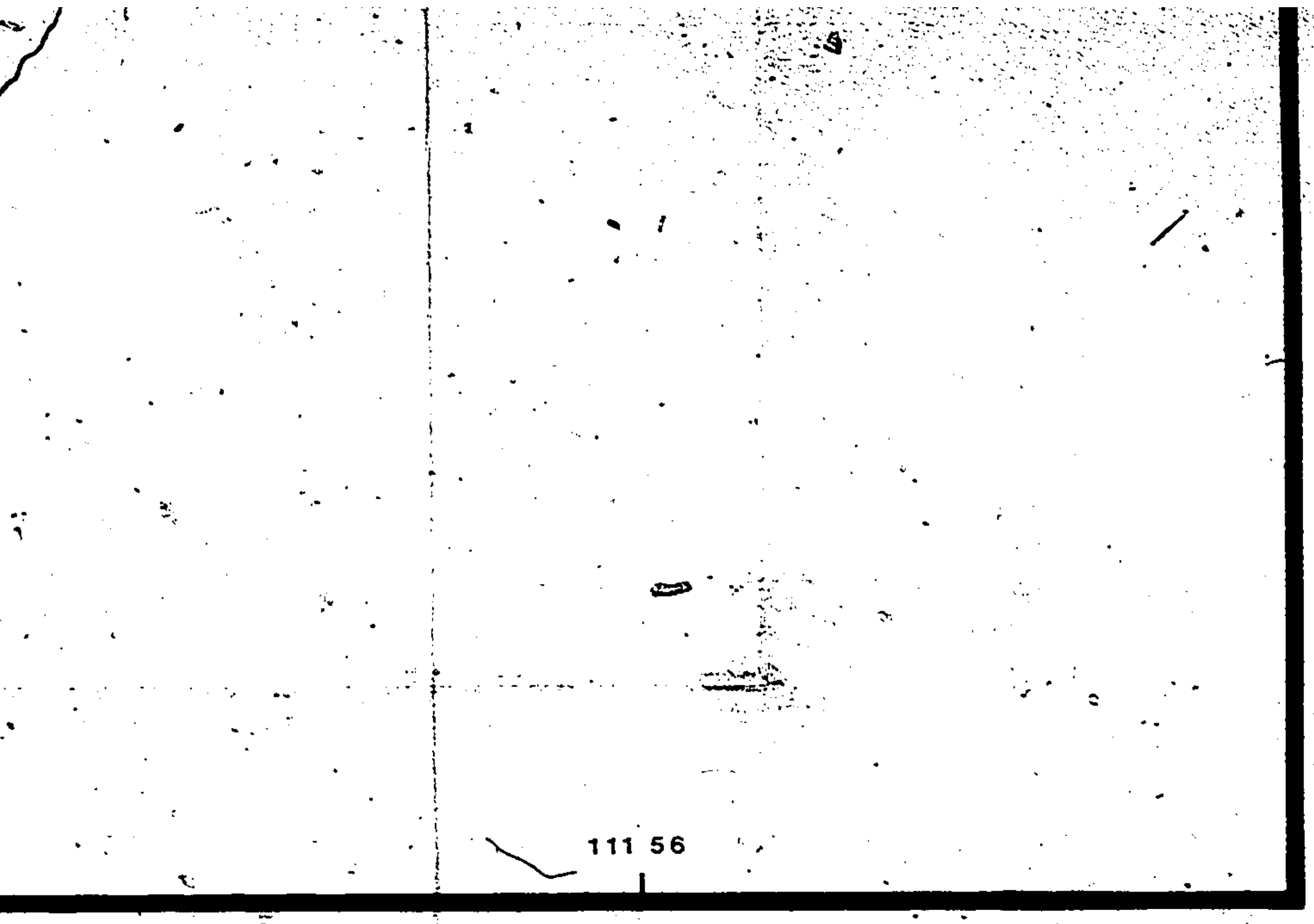
e.

(synkinematic); 5b) biotite
ıalite; 5d) biotite-hornblende

the volcanic pile, older than
3a, massive non-porphyritic;


not mapped
111 02
1:12,000
1000
metres
2000
3000
4000
feet
84 25
111 30
180F


111 00
111 58
64 25
111 30
111 15
64 25
111 00
64 20
64 15
190F



SYMBOLS

GEOLOGICAL BOUNDARY: DEFINED, APPROXIMATE, ASSUMED

FAULTS: DEFINED, APPROXIMATE, ASSUMED

PILLOW FACING: INCLINED, VERTICAL, OVERTURNED

BEDDING (GRADED TOPS): INCLINED, VERTICAL, OVERTURNED

BEDDING (TOPS UNKNOWN): INCLINED, VERTICAL

S_{1A} FABRIC: INCLINED, DIP UNKNOWN

20 of

PROTEROZOIC

Diabase: highly magnetic, steeply dipping dyke

ARCHEAN

Pegmatite: biotite-muscovite pegmatite.

Granitoid rocks: 5a) biotite granite (synk
granodiorite; 5c) biotite-hornblende tonalite;
trondhjemite (synvolcanic to earlier?).

Metagabbro: feeder sills and dykes to the vo
subunit 4a and unit 6, crosscuts 5b. 3a, ma
3b, massive, feldspar-porphyritic.

SUPRACRUSTAL ROCKS

YELLOWKNIFE SUPERGROUP

Metasediments: 4a) greywacke, arkose,
4b) intervolcanic argillite or phyllit
conglomerate; 4d) pyritic banded chert; 4e) g
conglomerate.

Cycle 2

2

Metarhyolite to metadacite: 2a) massive
block-breccia; 2c) rhyodacitic quartz-f
volcaniclastic; 2d) dacitic ash to lapilli
2f) massive quartz-feldspar phyric intrusive ro

Intermediate metavolcanics: 1c) massive,
flow; 1d) pillowed, amygdaloidal andes
1h) andesitic fragmental rock.

Mafic metavolcanics: 1a) massive basalt flo
flow; 1e) massive feldspar phyric basalt flow
phyric basalt; 1g) "banded" basalt (highly flatt

Note: volcanic units without inclined ruling
to a specific cycle.

Cycle 1

2

Metarhyolite to metadacite: 2c) rhyodacitic
sized volcaniclastic; 2d) dacitic ash to lapil
2e) rhyodacitic block-breccia (highly chloritic)

Mafic metavolcanics: 1a) massive basalt flo
flow.

Metamorphic assemblages: A - andalusite
B - biotite; C - chlorite; CD - cordierite;
CX - clinopyroxene; E - epidote; G - ga
K - potassium feldspar; M - muscovite; S - sill

m = carbonatized; s = sheared; n = silicified.

2 1 OF

dipping dykes.

ɡmatite:

ranite (synkinematic); 5b) biotite
ıde tonalite; 5d) biotite-hornblende
ier?).

ces to the volcanic pile, older than
s 5b. 3a, massive non-porphyritic;

OCKS

e, arkose, and slate turbidites;
or phyllite; 4c) intervolcanic
l chert; 4e) granitoid-volcanic clast

2a) massive rhyolite; 2b) rhyolite
quartz-feldspar lapilli-sized
to lapilli-sized volcaniclastic;
c intrusive rock.

c) massive, amydgaloidal andesite
ɡidal andesite flow:

ve basalt flow; 1b) pillowed basalt
: basalt flow; 1f) pillowed feldspar
(highly flattened).

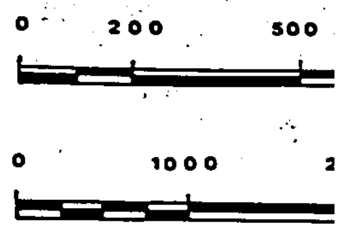
lined ruling have not been related

rhyodacitic quartz-feldspar lapilli-
ash to lapilli-sized volcaniclastic;
hly chloritic).

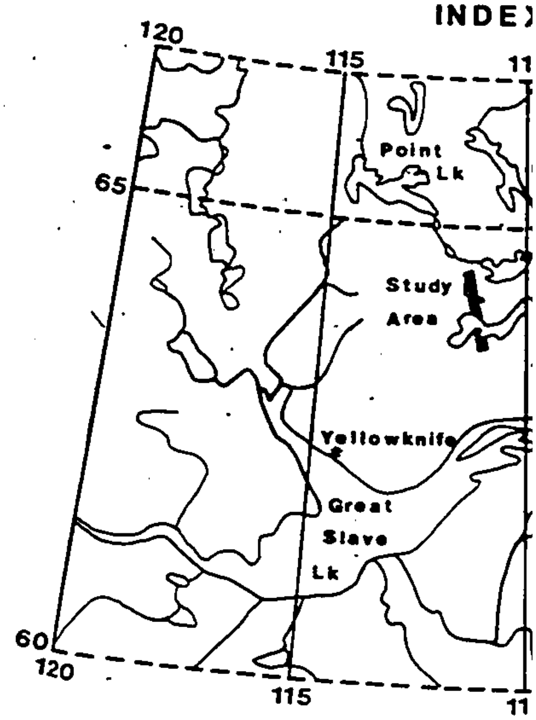
ve basalt flow; 1b) pillowed basalt

A - andalusite; AT - anthophyllite;
- cordierite; CM - cummingtonite;
te; G - garnet; KY - Kyanite;
ovite; S - sillimanite.

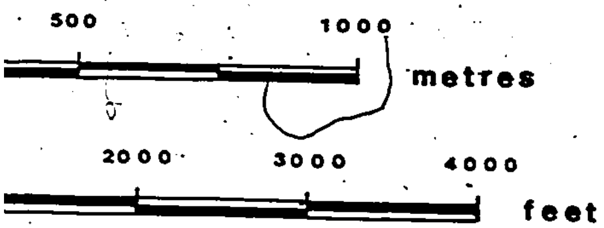
= silicified.



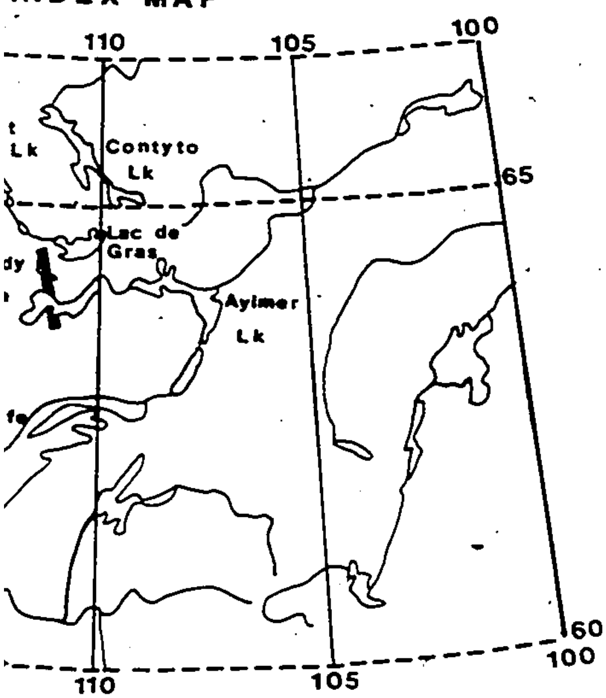
INDEX

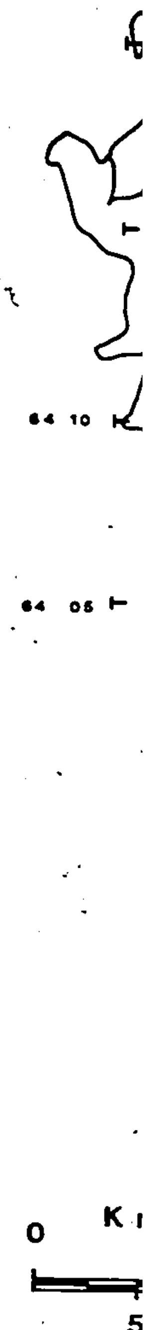


22 of

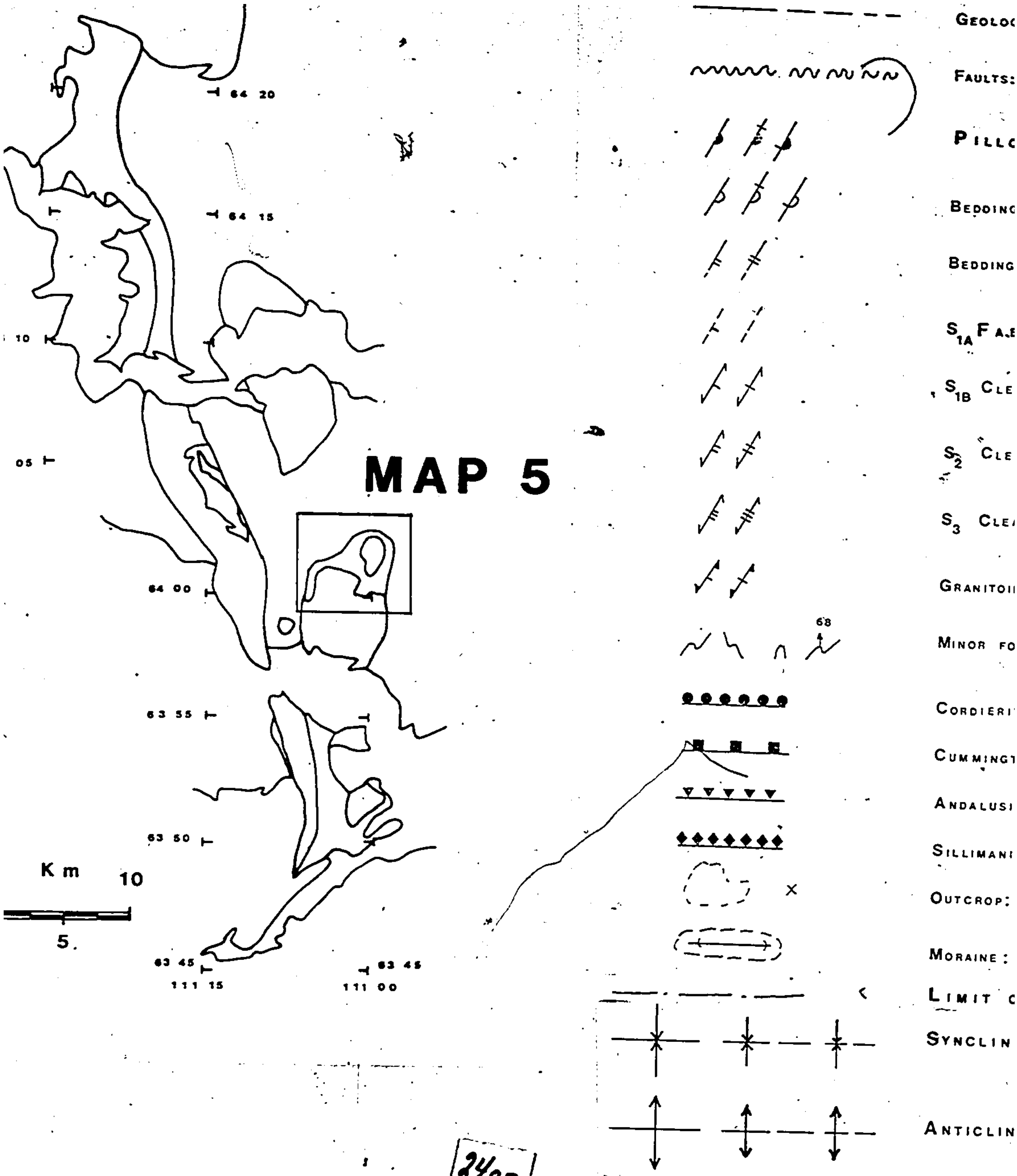


INDEX MAP





23 OF


MAP 5
64 20
64 15
10
05
64 00
63 55
63 50
63 45
63 45
111 15
111 00
Km 10
5.
68
GEOLOG
FAULTS:
PILLO
BEDDING
BEDDING
S_{1A} F A.
S_{1B} CLE
S_2 CLE
S_3 CLE
GRANITOI
MINOR FO
CORDIERI
CUMMINGT
ANDALUSI
SILLIMANI
OUTCROP:
MORAINE:
LIMIT C
SYNCLIN
ANTICLIN

24 of

GEOLOGICAL BOUNDARY: DEFINED, APPROXIMATE, ASSUMED

FAULTS: DEFINED, APPROXIMATE, ASSUMED

PILLOW FACING: INCLINED, VERTICAL, OVERTURNED

BEDDING (GRADED TOPS): INCLINED, VERTICAL, OVERTURNED

BEDDING (TOPS UNKNOWN): INCLINED, VERTICAL

S_{1A} FABRIC: INCLINED, DIP UNKNOWN

S_{1B} CLEAVAGE: INCLINED, VERTICAL

S_2 CLEAVAGE: INCLINED, VERTICAL

S_3 CLEAVAGE: INCLINED, VERTICAL

GRANITOID GNEISSOSITY: INCLINED, VERTICAL

MINOR FOLD SYMMETRY: 'Z' SENSE, 'S' SENSE, SENSE UNKNOWN, FOLD PLUNGE

CORDIERITE ISOGRAD

CUMMINGTONITE ISOGRAD

ANDALUSITE ISOGRAD

SILLIMANITE ISOGRAD

OUTCROP: AREA, SINGLE OUTCROP

MORAINE: ICE DIRECTION UNKNOWN

LIMIT OF MAPPING

SYNCLINE: DEFINED, APPROXIMATE, ASSUMED

ANTICLINE: DEFINED, APPROXIMATE, ASSUMED