SOME GEOMORPHIC FEATURES AND AN ATTEMPT AT MORPHOLOGIC MAPPING IN THE FALCON LAKE-WEST HAWK LAKE AREA, MANITOBA.

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A thesis submitted to the Department of Geography in partial fulfillment of the Degree of Master of Arts.

Acknowledgement

Thanks are due to Prof. W.J. Brown for his help and encouragement without which the completion of this thesis would not have been possible.

Contents

GENERAL INTRODUCTION

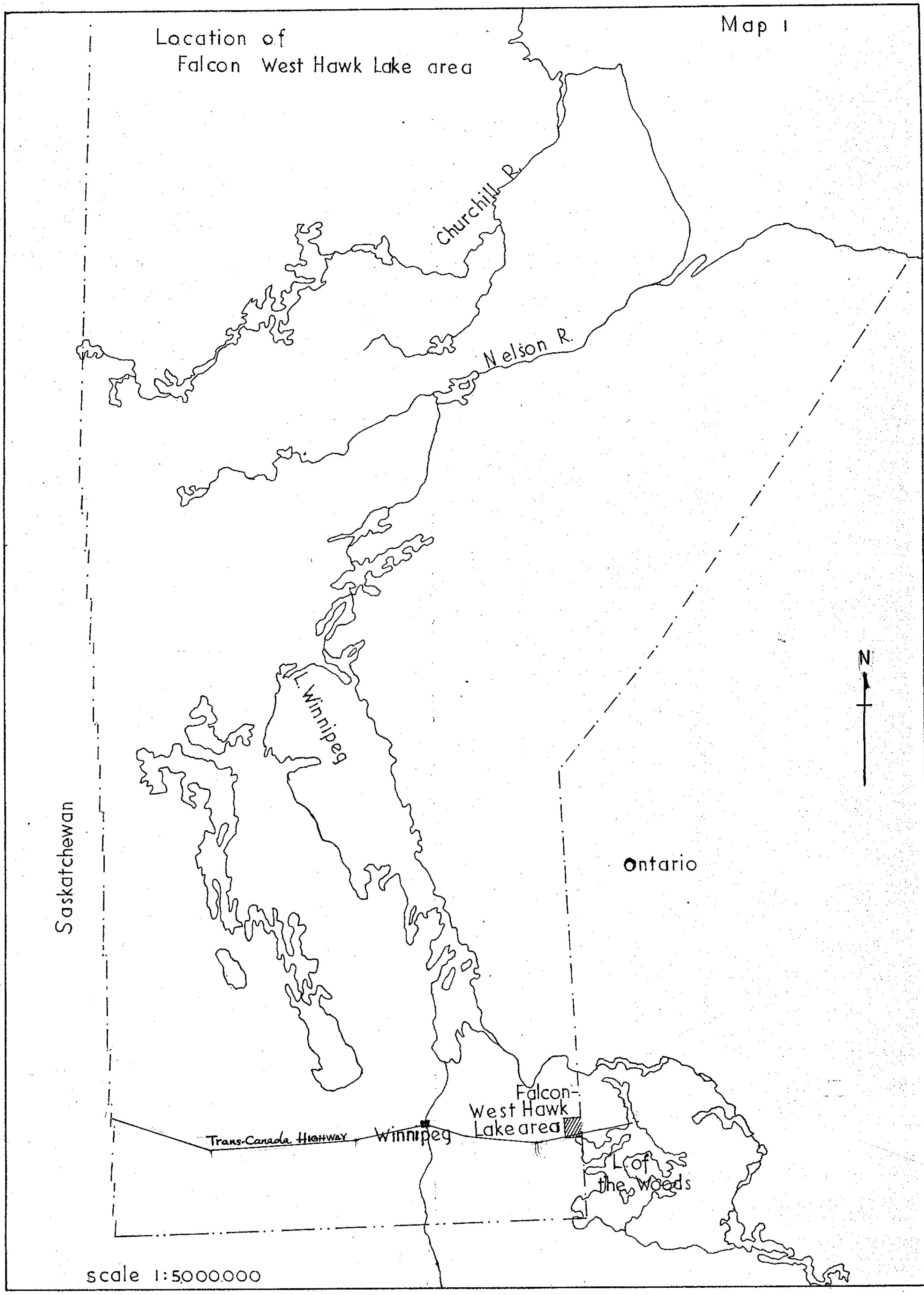
LOCATION

The Falcon-West Hawk field area for this study extends from longitude 95^{o} 09'W to longitude 95^{o} 20'W, and from latitude 49^{o} 40'N to latitude 49^{o} 50'N. The total area is approximately 100 sq. miles.

The area is traversed by railway and by the all-weather Trans-Canada Highway. Formerly a gold mining district, and now part of the Whiteshell Provincial Park, this area possesses gravel pits and branch roads, which greatly facilitated access and data compilation. This area, approximately 90 miles east of Winnipeg (map 1), is now a summer and winter holiday resort.

TOPOGRAPHY

Most of the Falcon-West Hawk area displays an irregular surface of low relief so characteristic of the western edge of the Canadian Shield. Extensive rock outcrops are interrupted by muskegs. Rock outcrops are smooth and usually occur as elongated ridge forms. The tops of hills are generally about 100 feet or less above the level of nearby lakes. In a few places, local relief up to 200 feet occurs, usually where a massive rock outcrop stands boldly above the general level. The Falcon-West Hawk area is approximately 1,100 feet above sea level.



Map 1
Location of
Falcon West Hawk Lake area
Churchill R.
Nelson R.
L. Winnipeg
Saskatchewan
Ontario
N
Falcon-
West Hawk
Lake area
Trans-Canada HIGHWAY
Winnipeg
L. of
the Woods
scale 1:5000000

The area is underlain by volcanic, intrusive igneous rocks and metasedimentaries which are generally resistant to weathering. Even when weathering does take effect, the weathered material is often removed by mass wasting and fluvial processes. Hence soils are absent from areas of exposed bedrock. Till deposits are usually located along troughs between successive ridges.

The drainage of the area was deranged by glaciation. Some old channels were blocked by the deposition of drift, giving rise to lakes. The discontinuous and hummocky bare rock surface which is the result of differential glacial erosion also leads to the formation of a large number of small lakes, largely remnants of the glacial age. The only notable river in this area is the Falcon River, which flows through muskegs and swamps southward from Falcon Lake to Shoal Lake. Elsewhere there are channels of already disconnected streams, each now occupied by a swamp. The eastern part of the area is relatively high and well drained. West Hawk Lake drains northwestward to Whiteshell River, and thence to Winnipeg River.

GENERAL GEOLOGY

Due to the discovery of gold and other valuable minerals in the Falcon-West Hawk area, pioneer geologists were working in this area as early as 1886, when A.C. Lawson mapped a considerable area around the Lake of Woods district in Ontario and a small part in Manitoba.[1] More geological work were done on the area since then. However, most articles written on this area were centred on certain particular aspects of economic geology, and supplied only piecemeal information about the general geology of the area. Moreover, geologists might hastily draw up a report after a visit to the area that was too brief even to call a reconnaissance survey. The report "Molybdenite, near Falcon Lake, Manitoba" by E.L. Bruce was drafted after a meagre three days' stay in the area.[2]

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1. A.C. Lawson (1886) Report of the Geology of the Lake of Woods Region, with special reference to the Keewatin (Huronian?) Belt of the Archaean Rocks. Geol. Surv. Can. Ann. Rep. 1885, part cc.
2. E.L. Bruce (1918) Molybdenite near Falcon Lake, Manitoba. Geol. Surv. Can. Sum. Rept. 1917, pt. D, p. 22-25.

The first large-scale systematic geologic investigation of the area was undertaken by G.D. Springer in 1952 who ran a series of traverses and later drew up a detailed geologic map embracing about 395 square miles around West Hawk Lake.[1] Later, as more gold-bearing quartz veins were uncovered in the Falcon Lake Stock, J.F. Davies (1954) carried out a more substantial survey for a larger scale map around the Falcon-West Hawk area.[2] The following account of the general geology of this area is based largely on these two reports.

The hard rocks of the area are predominantly of volcanic and sedimentary origin. The volcanics are mostly tufaceous and volcanic flows. The sedimentary strata are largely metamorphosed and sheared to the extent that their original composition, texture, and structure could no longer be detected. Davies states that "it is possible that many of the so-called quartzites and allied rocks are silicified basic tuffs."[3]

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1. G.D. Springer (1952) Geology of the Rennie-West Hawk Lake Area, Manitoba. Man. Mines Br. Publ. 50-6.
2. J.F. Davies (1954) Geology of the West Hawk Lake-Falcon Lake Area. Man. Mines Br. Publ. 53-4
3. Ibid p. 6

All these rocks in the area are of Precambrian age. The oldest ones are a group of volcanics intermixed with some metamorphosed sedimentaries which have been designated as belonging to the Keewatin Series, a term first brought into being by Lawson (1886) in his report of the Lake of Woods district. Into these greenstones[1] were intruded, probably at different times, large stocks and batholiths of pink pegmatite, quartz-porphyry and granodiorites. The relative ages of the various intrusives are difficult to determine, in view of the complexity of the geologic structure, especially where 'greenstone' is found intermingled with fresh rock resulting from earth movement. The Falcon Lake Stock, made up of a gabbro-diorite rim and a quartz-monzonite core, as designated by G.M. Brownell (1941)[2], posed ambiguity in its age determination. Springer and Davies placed the age of the stock at different ages in the region's chronology.

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1. Greenstones is a common term for the Keewatin Series.
2. G.M. Brownell (1941) Geology of the Falcon Lake Stock, Southeastern Manitoba. Trans. Can. Inst. Min. and Met. v. 44 p. 230-250.

The accompanying table, Table 1, based on Davies' report, shows the classification and possible sequence of rock formations within the region.

A fold of the Keewatin sedimentaries can be traced south of West Hawk Lake though the distinct axis has been obscured by later intrusions. The south limb of this east-west trending anticline can be recognised north of Indian Bay, about 10 miles south of Falcon Lake. West of Star Lake, the trend of the Keewatin rocks changes to south-west and takes the form of a series of small folds. The above structures were reported by Davies, and were based on strike, dip and plunge readings.[1] Most of the altered granitic rock has foliations that follow the bedding planes of the older sedimentaries.

Dominant shear zones, developed between West Hawk and Falcon Lake, trend east and north-east. They have steep shear planes but the relative movement along the plane is unknown.

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1. J.F. Davies (1954) Geology of the West Hawk Lake-Falcon Lake Area. Man. Mines Br. Publ. 53-4 p.20.

Table 1

Table of Formations of Rocks in

Falcon-West Hawk Area.

ARCHAEAN OR	PROTEROZOIC	Quartz-feldspar porphyry Pink porphyritic granite Grey gneissic granite Auartz monzonite Gabbro, diorite, grano- diorite, syenodiorite	) Falcon) Lake Stock

Intrusive Contact

ARCHAEAN	KEEWATIN	Mixed Keewatin rocks and pegmatite Silicified andesite and tuff Clastic sedimentary, and related, rocks Basic tuff Basic agglomerate Slate Andesite, basalt

After Davies 1954

Leaf blank to correct numbering.

PART I

THE GEOMORPHOLOGICAL SIGNIFICANCE OF THE BARE ROCK RIDGES

(A) PREVIOUS LITERATURE

Bare rock ridges are both macro (large scale) and micro (small scale) features and are very common in the Canadian Shield. There has been little attempt made to carry out a systematic study of them. Geological survey reports possess general descriptions of areas studded with ridges which run more or less parallel to each other. The literature cited below provides a few examples when geologists encountered this low hard rock ridge topography and yet paid scant attention to its origin.

C.S. Lord (1942) reported the extent of bare rock ridges in the Northwest Territories, "The surface of the Precambrian area ranges in elevation from 495 feet at the south edge of Snare River area to about 1,350 feet near the northeast corner of Ingray Lake area. It is rugged in detail. In southern Snare River bare rocky ridges commonly rise abruptly from 50 to 100 feet above the innumerable intervening muskegs and lakes, but in Ingray Lake area, they commonly rise 150 feet or more."[1]

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1. C.S. Lord (1942) Snare River and Ingray Lake Map areas, N.W.T. <u>Can. Geol. Surv. Memoir</u> No. 235 p. 4.

J. Kalliokoski (1952), in northern Manitoba, wrote on what he thought was the controlling factor of the configuration of rock ridges. "The shape and size of individual hills are governed by both the number and attitude of regional joints, and by the resistance of the bedrock to glacial scour. Consequently, areas of granitic rocks stand in higher relief than those underlain by volcanic rocks."[1]

J.C. McGlynn (1959) reported on the probable effect of foliation in controlling the trend of the rock ridges in Manitoba. "The 'grain' of the country is characterized by low ridges which are approximately parallel to the regional trend of foliation in the underlying rocks."[2]

Apart from sporadic references such as these, which only touch on the topic of bare rock ridges, the latter do not appear to have been an object of study. This part of the thesis, therefore, is devoted to a study of them in the West Hawk -- Falcon Lake area.

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1. J. Kalliokoski (1952) Weldon Bay Map Area, Manitoba. Can. Geol. Surv. Memoir No. 270 p. 2.
2. J.C. McGlynn (1959) Elbow-Heming Lakes Area, Manitoba. Can. Geol. Surv. Memoir 305 p. 2.

Several geomorphologists and geologists have reported on parallel flutings in glacial deposits and also parallel ridges or grooves created from bedrock erosion. G. Hoppe and V. Schytt (1953)[1], explaining the parallelism of flutings on morainic deposits, postulated that "The ridges may therefore have been formed by the great weight of ice pressing water-soaked ground moraine at the pressure melting point up into hollows formed in the lee of boulders." C.P. Gravenor and W.A. Meneley (1958)[2] attributed the parallel straight flutings in Alberta to the occurrence of subglacial alternating high and low pressure zones.

H.T.U. Smith (1948)[3], assessing the significance of the giant grooves in an area of the Mackenzie Valley, came to the conclusion that the trend of these features was not governed by structure or topography, although their depth seemed to be related to lithology. Their orientation appears to indicate the true direction of ice flowage.

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1. G. Hoppe and V. Schytt (1953) Some observations on fluted moraine surfaces.
2. C.P. Gravenor and W.A. Meneley (1958) Glacial Flutings in Central and Northern Alberta.
3. H.T.U. Smith (1948) Giant glacial grooves in Northwest Canada. Am. J. Sci. v.246, p.503-514.

However, S. Aronow (1959)[1], commenting on the mode of formation of the drumlins and related streamline features in the Warwick-Tokio area of North Dakota, conceded that these features were moulded by some mechanical means of the ice now still unknown to us, because the streamline features were found only in a small area which bears no significant difference in terrain or material from the surrounding area.

(B) BARE ROCK RIDGES IN FALCON-WEST HAWK AREA.

Bare rock ridges occur throughout the Falcon-West Hawk study area.

Ridges of different sizes and forms are found in areas of exposed bare rock outcrops. They appear in groups, as well as in single ridge forms. Those in groups are located generally on higher relief. They tend to align with their long axes parallel to each other, forming successive series of troughs and crests. In some of the deeper troughs can be found thin layers of till deposits.

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1. S. Aronow (1959) Drumlins and related streamline features in the Warwick-Tokio area, North Dakota. Am. Journ. Sci. v.257 p.191-203

The scale of the ridges varies in length from several hundred yards to short ones of fifteen to twenty feet. Long ridges have a width ranging from 50 to 200 feet and short ones about 5 to 10 feet.

Small ridges can be readily recognised on the ground and some of the large scale ridges can be seen on aerial photographs.

In the Falcon-West Hawk area, there is good evidence that the streamlined rock ridges are glacial erosional features. The reasons are :

(1) The surface of the ridges shows clear evidence of having been polished and scoured. Abrasion is indicated by pressure striae and friction cracks.

(2) There are numerous crescentric gouges in the bedrock surface that cannot be accounted for except by glacial excavation. These crescentric gouges are formed as a result of shear strain acted upon the bedrock by the force of the ice movement. This produces a cone of fracture which are crescentric and are concave upstream.

R.F. Flint (1957)[1] regarded such streamline moulded features as the "products of the streamline flow of glaciers."

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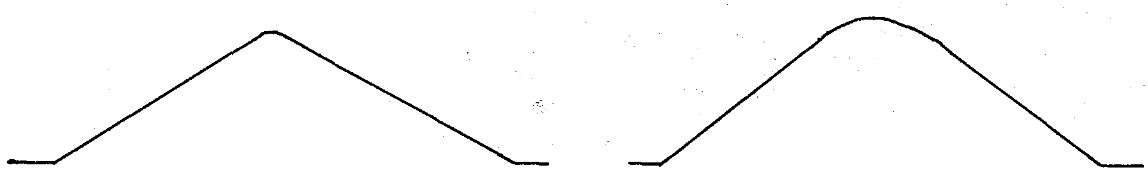
1. R.F. Flint (1957) Glacial and Pleistocene Geology, New York, John Wiley and Sons, Inc. p. 66

The mechanism by which a glacier erodes is uncertain. Yet it is generally agreed that glacial plucking as well as abrasion, are the dominant processes. Plucking herein is defined both as frictional drag as ice passes over bedrock and also the release of pressure immediately downstream from a bedrock outcrop, thereby actuating the release of stress inherent in the rock with consequent cracking, and removal of debris. A slight reduction of pressure due to a change in the motion or the occurrence of an obstruction may affect the efficiency of these processes. However, we must bear in mind that glacial erosion cannot occur unless there are erodible materials to pick up. Plucking supplies the glacier with these materials, therefore, it might have played an essential preliminary role in moulding the rock ridges.

(C) MORPHOLOGICAL CLASSIFICATION OF ROCK RIDGES

Not all bare rock ridges in the Falcon-West Hawk area assume the same shape and characteristics, although they seem to trend essentially in the direction of former glacial movement. (See section F) Varying resistance to erosion and, more often, different structures, such as joint sets, shear planes, and faults appear to have effected distinctive forms.

Bare rock ridges in the area reach different heights. Often massive ridges have a relief of as much as 100 feet, but seldom do they exceed this. Ridges 20 to 30 feet high are most common. They usually assume a uniform cross section, with a concavity at each side of the ridge that often makes an approximately 30° angle with the surrounding flattish surface. Sometimes, the basal slopes on both sides are gentler than this, ranging from 10° to 20°. There are two forms of ridge profile (Figure 1). The one has a narrow crest, with sharp lateral changes in gradient. (See 'h', Morphological map A) The other is a continuous crest-curvature, in which the gradient changes gradually. (See 'a', Morphological map B)



Angular ridge-crest Profile

Blunt ridge-crest Profile

Figure 1

There is probably no single reason for the existence of these two different crest-forms. Usually the sharp crest line occurs on ridges that are narrow and quite short, while the blunt form is usually found on broad and long ridges.

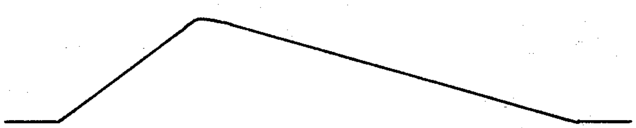
Some other ridges do not have such a regular profile curvature. Slopes may be stepped, with several identifiable microfacets. (Figure 2) On the morphological map, slope of this kind is represented by the "irregular slope" symbol (See section C of Part II, and also morphological maps A and B)

Stepped ridge profile.

Figure 2

Yet another cross-sectional form is an asymmetric one (Figure 3) which one of the slopes may be steep or even cliff-like, assuming the shape of a small-scale escarpment. (See Plate I)

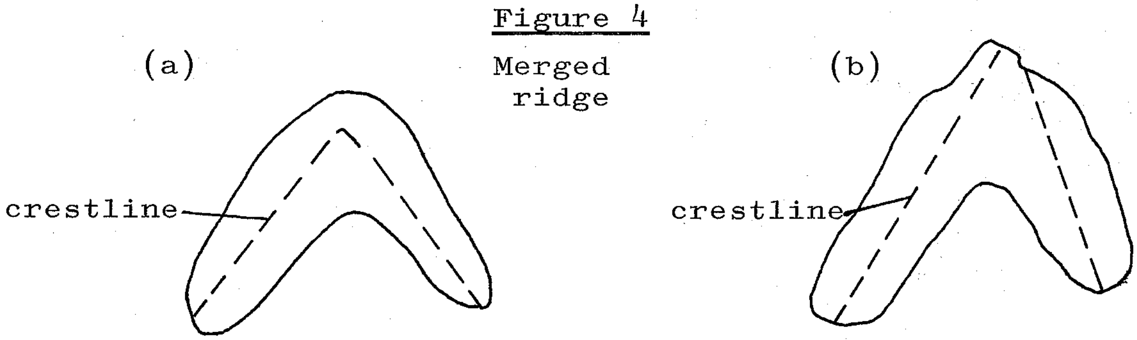
Figure 3



Asymmetrical ridge profile

When two rock ridges are merged together, there may be one continuous curved crest line (a) or two separate ones (b). (Morphological Map A, 'C')

Figure 4



The plane of bare rock ridges vary tremendously. Most common ones are in the form of an ellipsoid, with two sharp ends and flattened body. A good example is provided by "a" in morphological map B.

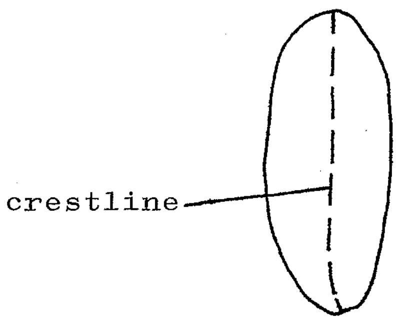


Figure 5
Streamlined ridge form

However, many bare rock ridges in Falcon-West Hawk area possess shapes that are different from the ellipsoidal ones, which represent about 40% of the ridges found. Some ridges are approximately as broad as they are long. Some have blunt ends, not sharp ones. Some also have rather irregular plans. (Figure 6)

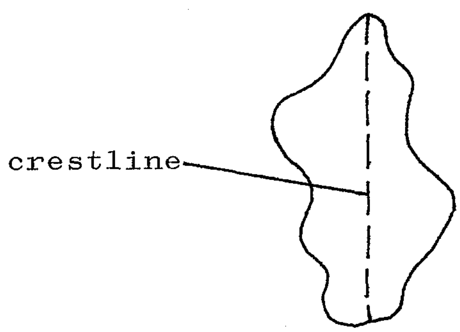


Figure 6
Ridge with irregular limits

(D) A CLASSIFICATION OF RIDGE FORMS

Fundamentally, each bare rock ridge possesses a form that the bed rock should assume, given its own resistance of erosion, its preglacial surface expression, and its structure under a particular set of subglacial conditions. The variety of lithologies and structural controls in the Falcon-West Hawk area therefore result in many types of ridge forms. The following is a systematic presentation of these forms. Some of the bigger forms can be recognised on aerial photographs.

(a) Single streamlined rock ridges (Fig. 7) are those that assume an streamline form. The ridges apparently were eroded by ice to such a form that their external surfaces offered a minimum amount of resistance to scouring. The long axis of each ridge, usually represented by the crest line, conforms very closely to the direction of striae and pebble orientation. One example of this ridge form can be found on morphological map (B), indicated by (a).

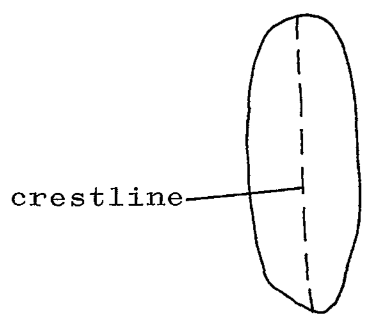


Figure 7

Single streamlined rock ridge.

(b) Broken rock ridges are those that, due to unknown factors, have a broken end. Often, these ridges exhibits a broken or apparently quarried end, which indicates a tremendous amount of localized plucking (see Plates II & III). The broken part usually stands out boldly as a cliff, with screes of rock fragments fannling out from the base. Examples can be found in morphological map (A) indicated by (b).

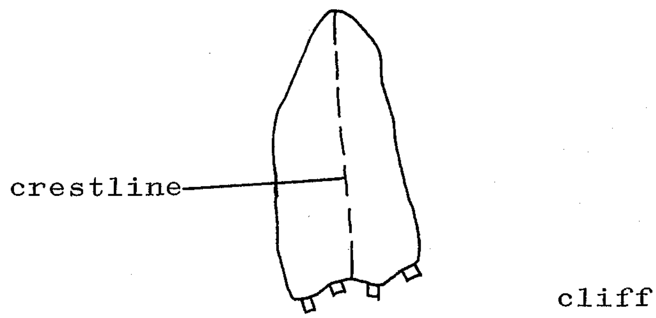


Figure 8

Broken rock ridges

(c) Merged rock ridges are formed when two roughly subparallel ridges are joined to one another at one end. This form can further be classified into two forms, depending on the configuration of the crestlines. In some forms there is a single continuous crestline along the two ridges (Figure 9a); in others, there are multiple crestlines that are straight and parallel (9b). The latter may give the impression of three small ridges that are joined to each other. One example of merged ridges can be found in morphological map (A) indicated by (c).

(a)

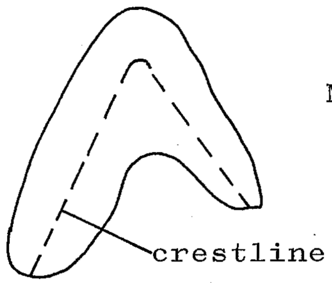
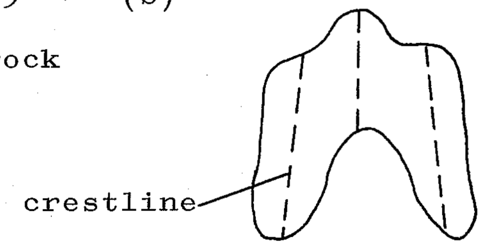


Figure 9

Merged rock ridges

(b)



(d) Cross ridges are those which intersect each other at more or less 90°. (Figure 10) A good example of cross ridges can be seen on morphological map (A) indicated by (d).

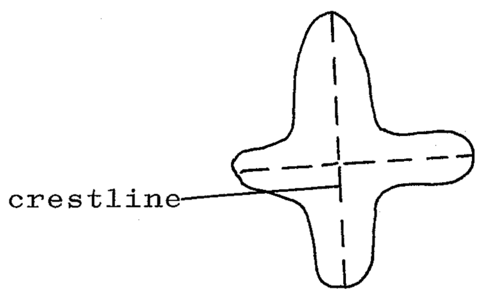


Figure 10

cross ridges

(e) Diagonal ridges resemble cross ridges, but they join each other at an acute angle. (Figure 11)

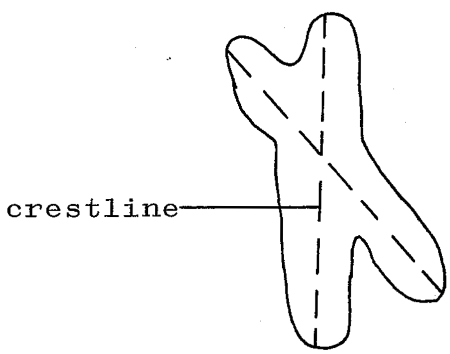


Figure 11

Diagonal ridges

(f) Arcuate ridge. Some of the ridges area are arcuate in plan and have a curved axis. If the ridge crest appears to be made up of two approximately straight lines, it should be classified as a merged ridge. A good example of an arcuate ridge is on morphological map (B) indicated by (f).

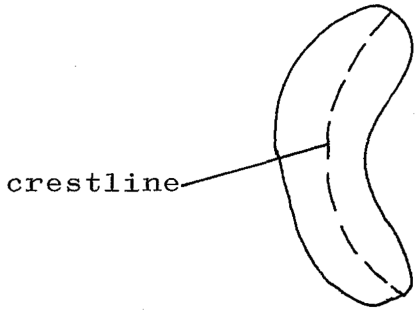


Figure 12

Arcuate ridge

(g) Composite ridges (Figure 13) are formed when three or more parallel or sub-parallel ridges are united in elevated bedrock feature. An example can be found in morphological map (B) indicated by (g).

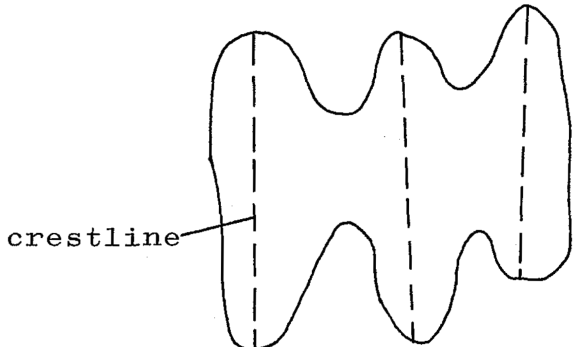


Figure 13

Composite ridge

(h) Echelon ridges (Figure 14) are, another type of composite ridge, but here the individual ridges occur en echelon.

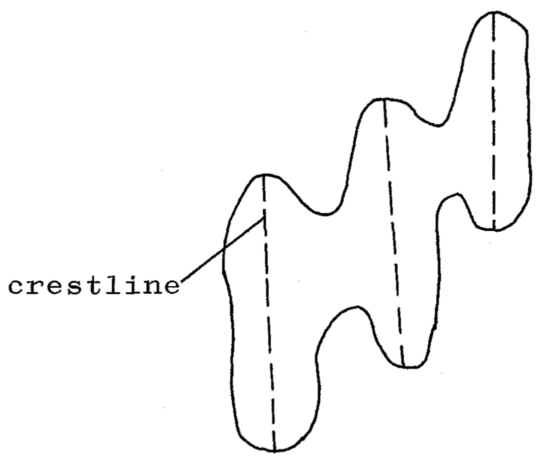


Figure 14

Echelon ridge

(E) ORIENTATION OF RIDGES

Streamlined Ridges (Fig. 7) with definite crestlines and sharp ends provide convenient means to indicate the direction of glacial movement. The ridge form offers two ways by which the directionof ice movement can be measured, first by measuring the direction of the creatline and second by measuring a line joining the two sharp ends.

Broken Rock Ridges (Fig. 8), on the other hand, are also good indicators of the direction of ice movement. The long axis of the ridge as well as its plucked end, which is invariably at the leeward downstream direction of ice movement, are usually reliable indicators.

Merged Rock Ridges, however, on account of its form and curved crestline, usually pose difficulties in inferring orientation of ice movement. The one form of Merged Rock Ridge, shown in Figure 9(a), with curved crestline, may give a rough estimate of the direction by bisecting the angle made by the curved crestline; a more reliable indicator, moreover, is provided by another form of Merged Ridge, as in Fig. 9(b), whose straight and parallel crestlines give clear indications as in the case of Streamlined Ridge.

Cross Ridges (Fig. 10) are not good means in inferring the direction of glacial movement. The trend of glacial movement is measured by taking the compass bearing of the axis of each ridge. The ridge that possesses a larger mass and henceforth usually a longer axis is then employed as indicator of the trend. Where two ridges were about the same length, they could not be used in the determination of ice movement direction.

To infer the direction of glacial movement with Diagonal Ridges (Fig. 11), the same criterion was employed as in the case of Cross Ridges. That is the orientation of the longer axis is used. For those that cross each other at extremely acute angles, an approximation of ice direction cab be obtained by bisecting the angle that the two ridges subtend.

It is difficult to obtain a meaningful direction reading from a curved crestline, such as in the case of Arcuate Ridge (Fig. 12). A reading is first taken by joining the two ends of the ridge, which is to be compared with the reading from the tangent line taken at the middle of the crestline. The two lines should be parallel to each other but if they are not, they should be extended until they intersect. A bisector of the angle made by these two lines then provides the most objective evaluation of the compass bearing of glacial movement.

The long axis of the Composite Ridge (Fig. 13) does not reveal the direction of glacial movement; it is the creatline of each ridge that enables the inference of direction to be accurately made.

As for Echelon Ridges (Fig. 14), the actual trend of glacial movement is measured along the long axis of each individual ridge forming the complex.

Based on the criterion of axis or crestline orientation described above, compass bearings of ridges in Falcon-West Hawk area were measured. Only those whose ridge forms and crestlines provide definite indications for objective results are used. A total of 98 ridge orientation readings were taken. These were subsequently plotted on nine rose diagrams, each representating ridges in a different area (map 3). A cumulative rose diagram was drawn on the map to depict ridge orientations for the whole area. The mode of the readings plotted as a histogram (Figure 15) shows that most ridges trend at 40-220°, that is, north 40° east to south 40° west. The mean of this statistical sample is 225.5°, and its standard deviation is 24°, It is interesting to note that not even one of the readings made falls into the northwest and southeast quadrants.

Plate I A ridge with a crest curvature resembling an escarpment.

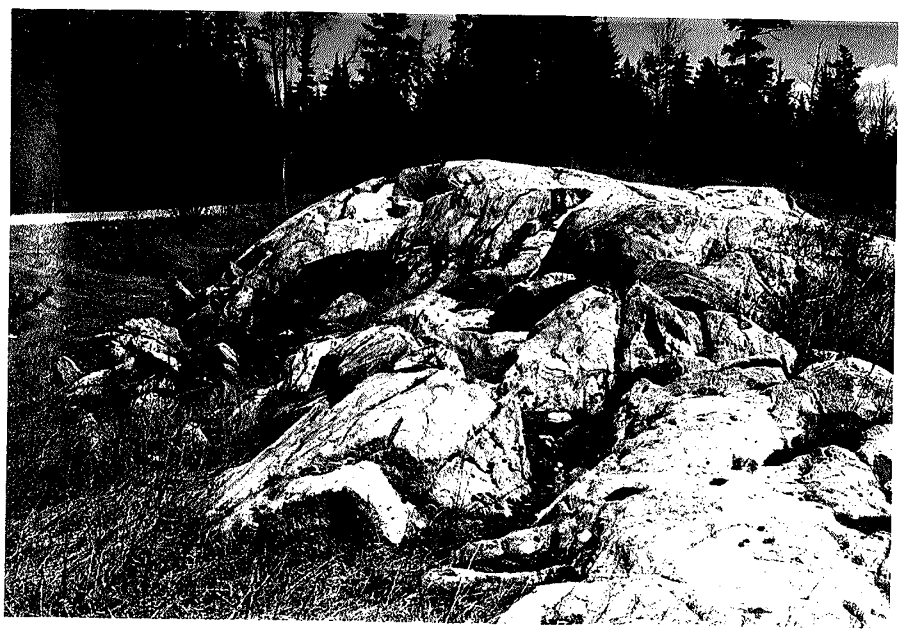


Plate II The broken end of a ridge.

(a) JOINTING AND RIDGE ORIENTATION

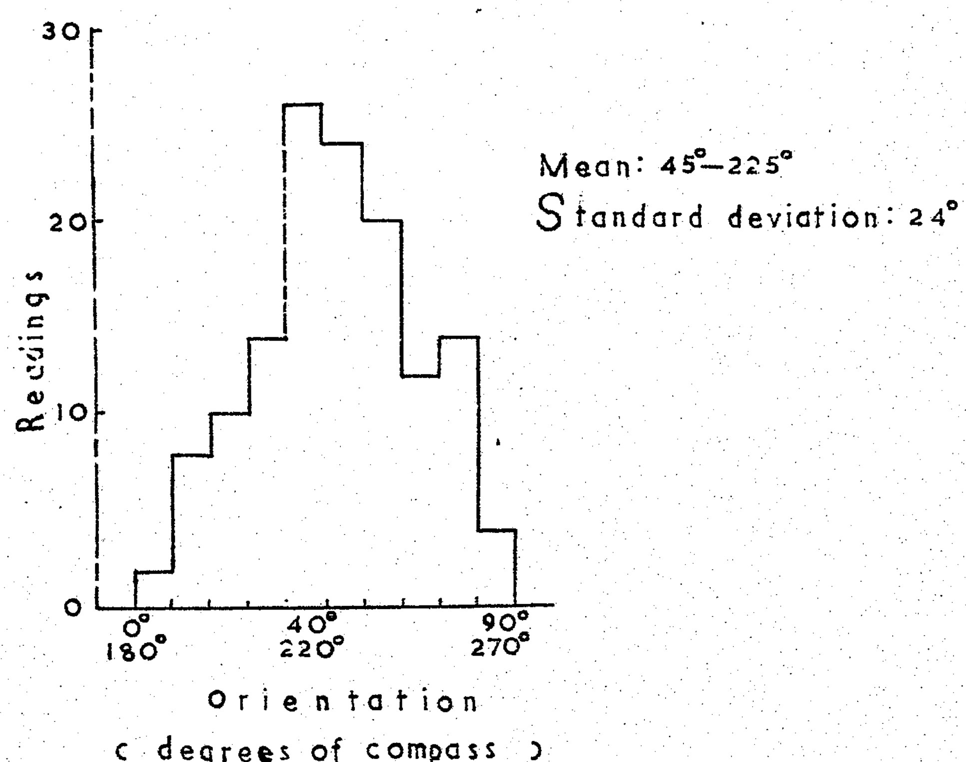
In analysing the joint patterns and their relation to ridge orientation, a total of about 600 joint readings were taken and plotted on stereographic equal area nets (Appendix I). The joint strikes were plotted as rose diagrams (map 2), so enabling joint systems to be compared with ridge orientations and an assessment to be made of the extent to which joints determine the orientation of the ridges.

South and southeast of Caddy Lake joints have very prominent north-northwest -- south-southeast but a second set trends northwest-southeast. A third set is oriented northeast-southwest. These trends are discordant with the ridge orientations of the same locality (map 3) which are dominantly north-northeast -- south-southwest.

West of West Hawk Lake joints trend marked by west-northwest -- east-southeast, with less important sets trending northwest-southeast and north-northeast -- south-southeast. However a notable discrepancy exists between the ridge and joint strike orientation. Immediately north of Star Lake bedrock ridges are essentially aligned east-northeast -- west-southwest and further west the dominant orientations are northeast-southwest and north-northeast -- south-southwest.

Fig 15

Frequency distribution of ridge orientation



Between West Hawk Lake and the eastern end of Falcon Lake, joints trend mainly northwest-southeast and east-northeast -- west-southwest. However, the few ridges with clearly defined orientations trend northeast-southwest in this locality.

Joints south of Falcon Lake tend to fall into two sets, with north-northwest -- south-southeast and west-northwest -- east-southeast trends respectively. There is a less prominent set at north-northeast -- south-southwest. A unequivocal disparity exists between these trends and ridge orientations, that are dominantly northeast-southwest.

Northwest of Falcon Lake, on the Falcon Lake Stock, two prominent joints sets, with northwest-southeast and northeast-southwest trends, exist. Bedrock ridges essentially conform with the northeast-southwest joint set.

Consequently, comparing the rose diagrams of maps 2 and 3, there is a general disparity between dominant joint sets and ridge orientations. The joints can be only a very minor control of the orientation of the ridges. In one or two localities, where there is accordance of orientations, there may have been preferential erosion by ice along clsely-spaced major joints. If we assume that ridge orientation manifests the actual direction of ice movement and that the joint strike is the line of weakness along which preglacial erosion was initiated, we can crudely estimate, the amount of work ice erosion performed to reorient the 'topographic grain' to the path of ice movement. The two rose diagrams produce the same result of topographic grain reorientation as C.A. Chapman and R.L. Rioux (1958) brought out in their study of granite jointing in Maine.[1]

Most of the joints in this area are high angle joints, with a dip angle usually between 70° to 80°. Joints with medium angles are rare. Sheet joints or low angle joints are frequently found, lying at angles of about 15 degrees or less. These joints with different dip angles can be easily distinguished on the stereographic nets (Appendix I). In north Falcon Lake area for example (Appendix I(a)) the net shows clustering of joints at its south eastern edge, meaning joints dipping 80° to 85° with a strike of about N60°E. -- S60°W. These are unquestionably high angle joints.

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1. C.A. Chapman and R.L. Rioux (1958) Statistical Study of Topography, Sheeting and Jointing in Granite, Acadia National Park, Maine. Am. Journ. of Sci. v. 256 p.111-127.

Medium angle joints can be recognised in Penniac Bay area, in western West Hawk Lake (Appendix I(c)). The stereographic net shows a dispersion of points throughout the net. Those points beyond the edge of the net but also away from the central axis represent joint planes dipping at a moderate angle. Low angle joints, or sheet joints are represented on the stereographic net of southeastern West Hawk Lake area (Appendix I(d)). There the points tend to cluster around the central axis, showing low angle joint planes dipping at about 15° or less. The stereographic net of southern West Hawk Lake (Appendix I(e)) shows all three kinds of joints.

The presence of more high angle joints might have facilitated more intense ice erosion, and this could have been the case in the Falcon-West Hawk area.

Sheeting is found in the granitic area, suggesting a recent release of load upon the disappearance of the ice. Sheeting inclinations are to a large extent controlled by topography.[1] This is exemplified where the outer sheet joints follow very closely the ridge surface configurations (Plate III & IV). Some sheets even approximate the curvature of the ridge. It can be inferred, therefore, that the sheeting only developed after the actual ridges had been formed.

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1. C.A. Chapman (1958) Control of Jointing by topography. Journ. of Geol. v.66 p.552-558

Plate III Side view of a massive streamline ridge.

Plate IV A single streamlined ridge with exposed sheet jointing system.

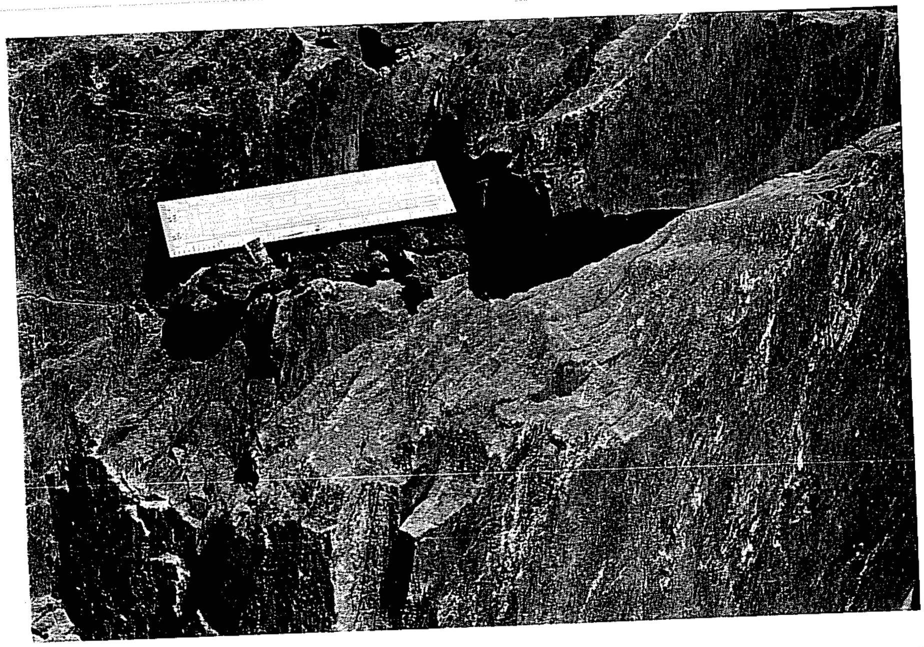

Plate V Shear Planes.

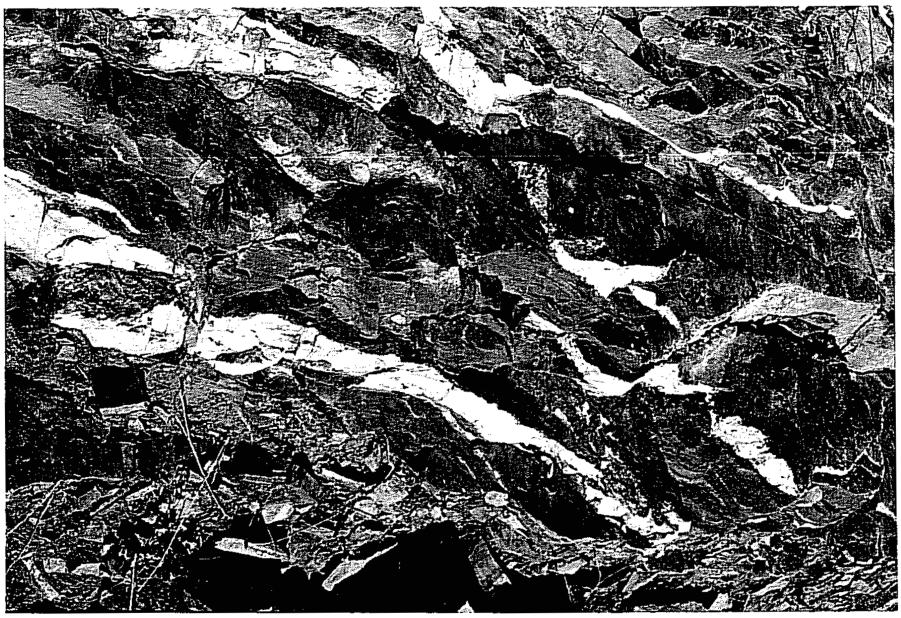

Plate VI Shear Planes with embedded quartz veins.

(b) SHEAR PLANES AND RIDGE ORIENTATION

Shear planes may prove to be another type of weakness exploited by ice as it eroded the area. They are most numerous in the greenstone formations of the area. It has been suggested[1] that in this area shear folding has occurred because of the intrusion of the granites into the greenstones. Vertical movements produced numerous shear planes at close intervals (Plate V & VI). Shear planes in the area, dip at very high angles, usually around 80°. A total of 130 shear plane readings were taken; these were plotted on stereographic nets (Appendix II). The shear plane strike trend dominantly at two directions, one east-west and another east-northeast -- west-southwest (see Figure 16). This bimodality can be explained by two periods of shear folding, each producing a set of shear planes with a slightly different strike orientation. The variation in their strike orientations is so great that it is obvious that, at most, shear planes could only have influenced the direction of rock scouring by ice. Furthermore, although there are few shear planes in the granitic intrusive areas, the ridges found here have almost the same trends as those in the greenstone area. Shear planes may have had some effect in the ice moulding of the ridges in the greenstone area. However, neither they nor joint planes were the main determinant of the orientation of the ridges.

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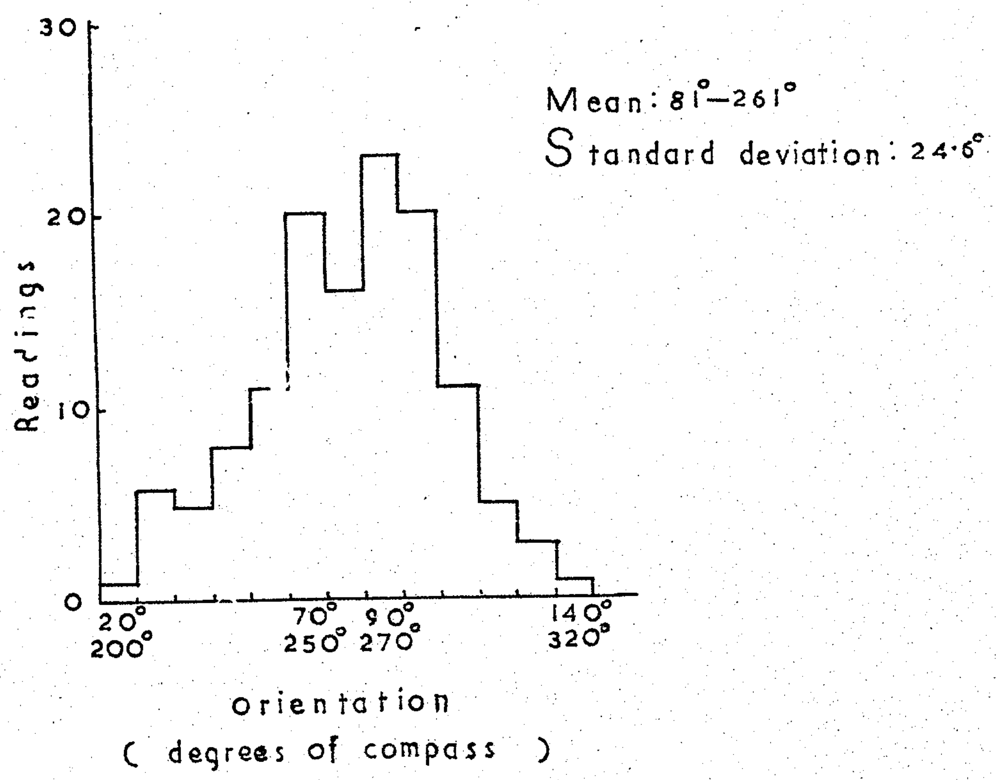
1. Personal communication, Prof. Brisbin of the Dept. of Earth Sciences, University of Manitoba.

Fig 16

Frequency distribution of shear plane strike orientation



(F) DIRECTION OF LOCAL GLACIAL MOVEMENT

1. A BRIEF OUTLINE OF THE GLACIAL HISTORY OF THE AREA

Several geologists have worked on the history of Glacial Lake Agassiz. One of the more acceptable hypothesis in explaining LakeAgassiz's history was put forward by J.B. Tyrrell[1] and supported by W.A. Johnston[2]. Both workers' interpretations of Lake Agassiz have strong bearing on the glacial history of the Falcon-West Hawk Lake Area. Recent work in the area around Falcon and West Hawk Lakes has provided information that fits well the findings of Tyrrell and Johnston. It is the intention of the writer to outline very briefly the evidence of the movement of ice movement around the Falcon-West Hawk Area and describe how the tills encountered correlate with the findings of Johnston and Zoltai (1961)

Johnston (1916)[3] working in the Rainy River District, Ontario, pointed out that the striations there trend northwest-southeast and west-east.

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1. J.B. Tyrrell (1896). The Genesis of Lake Agassiz. <u>Journ. of Geol</u>. v. 4 p. 811-815.
2. W.A. Johnston (1917) Records of Lake Agassiz in Southeastern Manitoba and adjacent parts of Ontario, Canada. <u>Bull. Geol. Soc. Amer</u>. v. 28 p. 145
3. W.A. Johnston (1916) The Genesis of Lake Agassiz, a confirmation. <u>Journ. of Geol</u>. v. 24 p.625-638.

At the same time, he stressed that since the striations occurred on bedrock underlying the younger calcareous till of the area, it is probable that an ice readvance did reach this area. He wrote, "It seems evident, therefore, that the calcareous till was deposited by a lobe of the Keewatin glacier and that the area in which the calcareous till occurs was not overridden by an advance of ice from the northeast at that time."[1]

Later, Johnston claimed that there was proof that glacial Lake Agassiz was not created immediately after deposition of till in the Red River Valley, as Upham envisaged, for a marked depositional break or unconformity at the base of the lacustrine sediments indicates an episode of erosion of the new moraine along the Greater Winnipeg Water District Railway just south of the Falcon-West Hawk area.[2] The actual ponding of the lake must have occurred as a consequence of a readvance of the ice sheet at a later time during the Wisconsin stage of glaciation.

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1. W.A. Johnston (1916) op. cit. p. 630
2. W.A. Johnston (1917) op. cit. p. 145

E. Antevs (1931)[1] suggested that during the Wisconsin stage, ice sheets from the Patricia and Keewatin centres must have transgressed the Ontario and Manitoba region and that "In Southern Manitoba the boundary between the Keewatin and the Patricia ice sheet may have run northwesterly from Lake of Woods to Lake Winnipeg and thence along the axis of this lake, for the striae to the east of this line have a south-westerly direction, whereas those to the west of it have a south to south-easterly trend."[2]

S.C. Zoltai (1961)[3] noted that there are four till sheets in the area. The oldest, a calcareous drift deposit found in the Rainy River District was highly oxidized and was about 6 feet thick. The 2nd oldest till was termed the Patrician red drift and carried twice as much sand as rocks. It was made up of mostly granitic material that derived from the granite outcrop of Northern Ontario over which the glacier passed. In general, the till is thin.

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1. E. Antevs (1931) Late glacial correlations and ice recessions in Manitoba. Canada Geol. Surv. Memoir No. 168
2. E. Antevs (1931) Late glacial correlations and ice recessions in Manitoba. Canada Geol. Surv. Memoir No. 168 p. 43
3. Zoltai, S.C. (1961) Glacial History of Part of N.W. Ontario. Proc. Gepl. Assoc. Can. v. 13 p.61-83

The third till sheet was believed to be deposited by the Keewatin Ice Lobe and was named by Elson the Keewatin grey drift. In this till, clay and silt are most abundant, while stones only constitutes 15% of the total volume of the till. The presence of carbonate is especially conspicuous.

The youngest drift of the area was deposited during Valders Substage of the Wisconsin Glaciation. This younger Patrician lobe overrode the older Keewatin grey drift and deposited another layer of red drift, made up predominantly of granitic materials, and containing only minor amounts of limestone.

In the Falcon-West Hawk area, surveys by the writer have recognised 3 till sheets, differentiated on the basis of their stone content and the size of the stones. These three till deposits are : sandy till, sandy-stony till, gravelly till.

The sandy till is chiefly found around the southern part of West Hawk extending to Camp Lake in the south, while its east and west extent is limited. The till is thin, rarely exceeding 15' in thickness. However, in a small valley near Camp Lake, it is found to be 30 feet thick. Stones were plentiful, but their size is rarely larger than 1.5 inches in diameter.

The composition of stones constitutes about 30%[1] of the volume. The composition material making up this till seem to fall into Zoltai's description of the Patrician Red Drift considered as the second oldest till of the area.

The sandy stony till covers a substantial part of the area. The till consists mostly of granitic fragments, which are well rounded due probably to excessive wear by ice. The stone content is usually higher than that in the sandy till, ranging from 40% to 60%. The stones are also much bigger. Stones with a diameter of 2.5 inches are found. The thickness of the till also varies. In north-eastern Falcon, the till is as thin as 5 feet. However, at the eastern end of Toniata Beach, the till material is more than 50 feet deep. The till is also found at higher altitude covering pockets of sandy till described earlier. On account of its high grantic content the till correlates well with Zoltai's youngest red drift which is considered to have been lodged by the younger Patrician lobe.

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1. This percentage is estimated by visual judgement. No mechanical analysis has been done on these deposits. The size boundaries of various granular materials are set according to the Wentworth Scale :

boulder	256 mm.
gravel	64 - 256 mm.
stone and pebble	2 - 64 mm.
sand	2 mm.

The main exposure of the gravelly till is found at south-eastern Caddy Lake, southeast of West Hawk Lake, central north Falcon and at some scattered locations south of Falcon Lake. The till is characterized by its stone content. Large rocks were usually seen. By acid test (dilute HCL) this till is found to be calcareous. Limestone boulders were also recognised. Evidence suggested that this till seem to fit well into Johnston's upper till[1] in his work at Whitemouth River which he described as calcareous. It is probably that this till was brought by the Keewatin Ice lobe from the north-west, which was commonly called the Keewatin grey drift (Elson 1961)[2]. The till is grey in colour, probably due to its high carbonate contents. Its average thickness is about 15 feet, but in southeast West Hawk, it is as thick as 30 feet. In comparison, the grey till, though having larger stone size, seems to contain more silt and clay than that of sandy-stony till. This supports Elson's conclusion that "the Patrician Red Drift is a sandy non-calcareous drift, and the Keewatin Grey Drift is a sandy to clayey calcareous drift".

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1. Johnston, W.A. (1921) Winnipegosis and Upper Whitemouth River Areas, Manitoba, Pleistocene and Recent Deposits. Geol. Surv. Canada Memoir 128
2. Elson, J.A. (1961) Soils of Lake Agassiz, in Soils of Canada edited by R.F. Leggett. Royal Society Canada. Sp. Publ. 3 pp. 51-79

With the drift data and the striation direction, S.C. Zoltai (1961) deduced the broad outlines of the glacial history of north-western Ontario and the adjacent part of Manitoba. He came to the conclusion that this part of the Precambrian Shield had been glaciated by two ice lobes, each affecting the area twice. The first discernible intrusion was by the Old Keewatin ice sheet from the northwest. This was succeeded by a period of glacial retreat north of the area under study. The Old Patricia ice-sheet then invaded the area from the northeast, and in turn was followed by the Young Keewatin sheet from the west. The last ice sheet to enter this area was the Young Patricia from the northeast during the second stage of Lake Agassiz.

Zoltai attempted to correlate the time and deposits of Northwestern Ontario as follows :

	Time	Moraines	Origin of drifts	Lakes
WISCONSIN	Valders	Trout-Basket Hartmann Eagle-Finlayson L. of Woods and Rainy Lake	Young Patrician	Lake Agassiz II
				Lake Agassiz I
	Makato		Young Keewatin	
	Cary		Old Patrician	
	Iowan(?)		Old Keewatin	

After Zoltai, S.C. (1961)

From the literature cited above, we can safely conclude that the Falcon-West Hawk area, being in the territory of the Patrician ice sheet at the second stage of Lake Agassiz, was affected at least twice by ice from the northeast. The existing evidence in the Falcon-West Hawk Lake area supports this conclusion.

2. STRIATION DIRECTION

Striations are supposed to be one of the most conspicious small scale features of glacial erosion. They are usually fine grooves, generally on the bedrock surface, which have been etched by rock particles held in the base of the glacier. Striae found on granite in the Falcon-West Hawk area are small fine markings. Since the directions of striae may vary a great deal according to local topography, for example at a step or obstruction, or within trenches[1], great caution must be taken when recording and evaluation striae orientations. Only those striae on flat level surfaces, and possessing no obvious evidence of having been deflected, were recorded. The writer was able to obtain only four new striae direction readings; the rest were recorded by Springer[2] in his geological report of the same area. The present striation map (Map 4) was compiled partly from information obtained from his map. Though their orientations vary, all the striations trend roughly southwestwards. With compass bearings ranging from S10^{o}W to S65^{o}W, most striae trend approximately N45^{o}E to S225^{o}W, except to the northwest of Falcon Lake.

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1. P.W. Demorest (1938) Ice flowage as resolved by Glacial Striae. Journ. of Geol. v.45 p.700-725.
2. G.D. Springer (1952) Geology of the Rennie-West Hawk Lake Area, Manitoba. Man. Mines Br. Publ. 50-6.

These trends should be compared with striae recorded in an adjacent area. E.M. Burwash (1923)[1] reported a striation direction of 235° at the Ontario-Manitoba border. In the Rainy Lake area, E.S. Moore (1940)[2] recorded striae trending at 200°, while Zoltai (1961) observed that a 210° azimuth was prevalent in the Lake of Woods Area.[3] Apart from the southwest trending striation, no southeast-trending striae markings could be found to support Zoltai's claim that this area probably had been invaded twice by the Keewatin ice sheet from the northwest. Two explanations for this are feasible. Either the Keewatin ice sheet had never reached this area, or it had invaded the area but the markings it produced were completely erased by later glacier movements. The fact that old striae trending southeast were observed by Burwash in the Kakagi Lake area[4] and by Zoltai at the western shore of Wabigoon Lake[5], near Dryden, proved that the Keewatin ice sheet did extend well into Ontario but old striations must have been obliterated in the Falcon-West Hawk area by the later Patrician sheet.

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1. E.M. Burwash (1923) Geology of Ontario-Manitoba Boundary. Ont. Dept. of Mines v. 32 pt. 2
2. E.S. Moore (1940) Geology and Ore Deposits of the Atikokan Area. Ont. Dept. of Mines v.48 pt. 2
3. S.C. Zoltai (1961) Glacial History of Part of Northwestern Ontario. Geol.Assoc.Can. Proceedings v.13 p.63
4. Burwash, op. cit.
5. Zoltai op. cit. p. 63.

3. PEBBLE ORIENTATION

C.D. Holmes (1941), (vol. 255) in his important paper on till fabric orientation[1], came to the conclusion that the bottom of a glacier behaves plastically and obeys, in general, the laws of fluid mechanics. Stones carried by the ice are subjected to rotation, generally about their long axes, in a plane of uniform shear and normal to the direction of glacier flow. However, those stones in contact with the sole of the glacier are moved by sliding. Glen, Donner and West (1959)[2] explained that preferred orientation to direction of ice flow is produced by free flow in ice, collisions of oblate stones and dragging on a stationary layer whereas preferred orientation in the traverse direction is produced by protracted flow in ice and collisions of prolate stones.

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1. C.D. Holmes (1941) Till Fabric <u>Bull. Geol. Soc. Am.</u> v. 52 p. 1299-1354.
2. J.W. Glen, J.J. Donner & R.G. West (1959) on the mechanism by which stones in till become oriented. <u>Am. J. Sci</u>. v.255 p.194-205

To corroborate the local evidence of direction of ice movement obtained by striation readings, the writer performed a number of pebble orientation measurements of till deposits in the Falcon-West Hawk area. The choice of sample sites was undertaken with the utmost care. Each of the locations was chosen so that possible biased data could be eliminated. To safeguard against variations of data due to different terrain, sites were chosen at approximately the same height and on essentially level ground, where there is no obvious feature that could have deflected the moving ice. The sites were freshly exposed by the writer, and had apparently not been disturbed by any erosional processes. Sites were mostly around 1150 feet, obviously higher than the depositional break between Agassiz I and Agassiz II as envisaged by Johnston.[1] Only the top portion of each deposit was sampled, in order to ensure that the pebbles belonged to the till laid down by the Patricia Ice Sheet. This is important, in order to test the hypothesis that the bare rock ridges in the area were moulded by the Patricia Ice Sheet. If the hypothesis is true, the trend of the ridges should conform with the preferred orientation of the till pebbles.

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1. W.A. Johnston (1917) Records of Lake Agassiz in Southeastern Manitoba and adjacent parts of Ontario, Canada. Bull. Geol. Soc. Am. v.28 p.145.

A modification of W.C. Krumbein's[1] method of measuring pebble orientation was employed. Each pebble was carefully taken out of a deposit and held in space with its orientation being preserved. The long and short axis were immediately defined on the pebble surface. A properly oriented compass was placed on top of the pebble and the orientation of the long axis was read. The long axis was defined by visual judgement where possible and by comparative measurements of length when the former was not readily identifiable.

More than three hundred pebble orientation measurements were taken, and these are depicted by the rose diagrams of Map V. Most of the diagrams show a distinct northeast-southwest trend as expected. However the preferred orientation at the site north of the western end of Falcon Lake is markedly east-west. This orientation is also at variance with the north-northeast -- south-southwest striation observed in this locality. This deviation may be due to the fact that the site where the samples were taken was a platform at a low altitude (1132') close to Falcon Lake and that erosional agents might have affected the orientation of these deposits.

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1. W.C. Krumbein (1939) Preferred orientation of pebbles in sedimentary deposits. Journ. of Geol. v. 47 p.673-706.

Computing all the orientation frequencies and plotting them on a histogram (Fig. 17) reveals that there are two principal modes. Many pebbles either orientate at 210^{o} (primary) or 235^{o} (secondary) azimuths. As shown in Table 3 local preferred orientations accord with the striation readings and there is some directional accordance with the ridges. It would appear that the last ice movement of this area was towards the south-west, as suggested by the earlier workers and now verified by these findings.

4. BARE ROCK RIDGE ORIENTATIONS AS AN INDICATION OF THE DIRECTION OF GLACIAL MOVEMENT

It has been shown that, in the Falcon-West Hawk Lake area, bare rock ridges do trend basically in the same general direction as striations and till pebbles. The applicability of these bare rock ridges as an indicator of the direction of glacial movement, and the importance of structural controls on them, should now be assessed.

A comparison is made below between the modes of the statistical occurrences of orientations of ridge axes, shear planes, and joint strikes. This is done in view of the possible variability of joint plane and shear plane directions in each locality, thereby altering the orientations of ridge directions should these structures be important controls of topography.

Fig. 17.

Frequency distribution of till pebble orientation

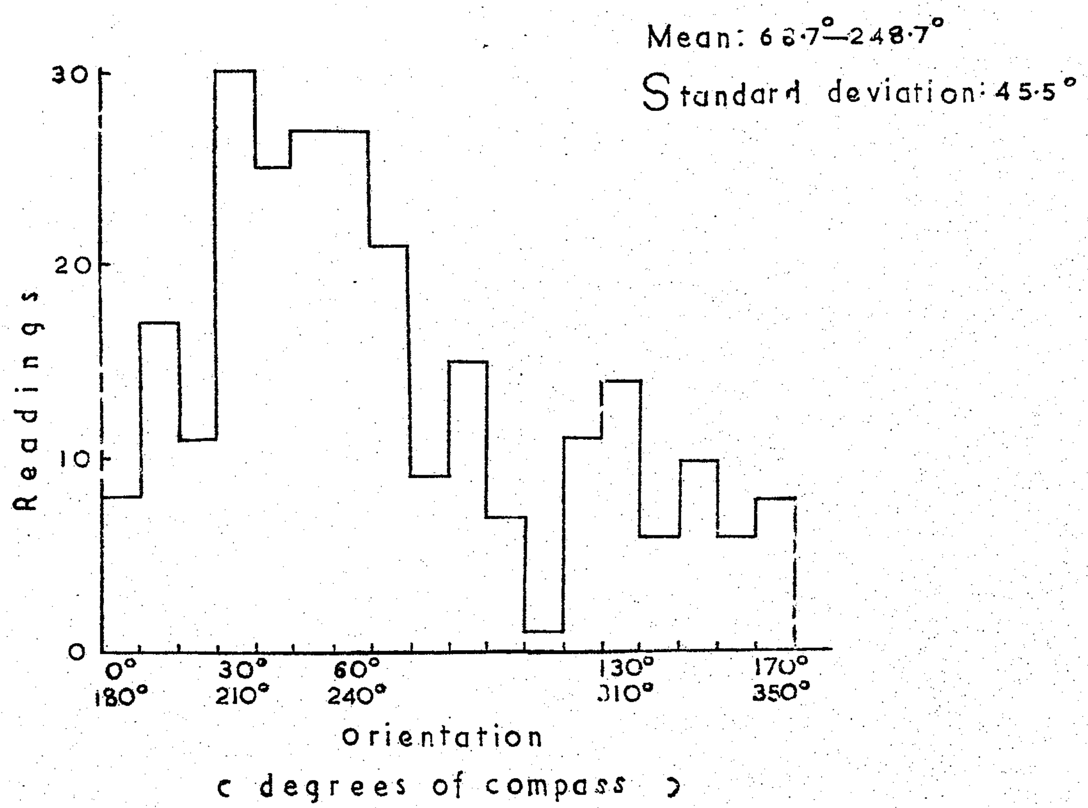

Table 2

Principal Modes of occurrences of Shear Plane Strike Orientations, Joint Strike Orientations, and Ridge Orientations at different Localities of Falcon-West Hawk Area

Locality	Mode of			
	shear plane strike	joint strike		ridge
Central N. Falcon	250	230	320	210
S. Falcon		230	340	230
N.E. Falcon	270	230	330	220
W. Caddy		190	310	240
Star Lake		290	210	220
S. West Hawk	280	260	290	220
S.E. West Hawk		250	290	210
Penniac Bay	240	340	310	260
Caddy Lake South		220	330	200

To the nearest 10 degrees

If we take the 'mode' as a reliable indicator of the most frequently occurring orientation, we find that there is a large discrepancy in the directions of shear plane strikes and joint plane strikes respectively with ridge orientations. At various localities where shear planes have been measured, the mode of strike orientations deviates from that of ridge orientations by at least 20°. The presence of shear planes in this respect could, at best, serve as an initial guide to ice flow and direction erosion. The idea that ridge orientations are controlled by shear plane direction is, therefore, obviously ungrounded.

The same appears to hold true with regard to the joint strike directions. Their histogram reveals a basically bimodal distribution, suggesting that there are two or even more prominent joint sets in the area (page31). Of the different major joint sets, one usually trends approximately northeast-southwest, approximately corresponding with the ridge directions. However, there are great discrepancies. Apart from the readings in southern Falcon, where both ridge and one set of joint strike directions are found to coincide, the other readings have a difference that varies from 10 to 50 degrees. Such a large disparity in orientation could hardly lead to conclusions that the ridge trends are controlled by joint sets.

Since no dyke, sill nor any other geologic structure significant enough to affect ridge directions was found in the Falcon-West Hawk area, it is safe to assume that the latter trends are apparently independent of any endogenetic control, and that they are accordant with the direction of movement of the erosive agent.

Since the alignment of hard rock ridges is attributed to the erosive movement of the ice sheet, there should be an azimuthal relationship between these topographic features, the long axes of till pebbles, and striations in each locality of the survey area. The modes of the sampled populations of such orientations are tabulated and analyzed below.

Table 3

Modes of Occurrences of Pebble Orientations, Striae Azimuths, and Ridge Orientations at various Localities of Falcon-West Hawk area

Locality	Mode of		
	stria direction	till pebble orientation	ridge orientation
Central North Falcon	210	210	210
South Falcon	230	220	230
N.E. Falcon		235	220
W. Caddy	235	240	240
Star Lake		210	220
S. West Hawk	235		220
Caddy Lake South		220	200

Figures to the nearest 5 degrees

The readings for striae were obtained by averaging the data recorded by both the writer and Springer. The reading 235° for West Caddy emerged from taking an average of the three striae found there. The result of this comparison is striking. In the Central North Falcon area, where the terrain is extremely flat, striation reading and pebble orientation data could be obtained. As a result, the orientation readings recorded for each of these features are identical. Very similar situations apply at Western Caddy Lake and the southern part of Falcon Lake. Differences in orientation of 15 degrees occur south of West Hawk Lake and 20 degrees south of Caddy Lake.

Judging from the potential sources of inconsistency and irregularity of the orientations of striations, pebbles and ridges, the concurrence of trends in these localities is indeed remarkable. Striae direction is subject to variations in local topography. Pebble orientation could be disturbed by subsequent erosional, mass movement, or even frost processes. If these two criteria are reliable indicators of the direction of glacial movement, ridge direction might also be employed as a tool for the same purpose. The cumulative rose diagram of ridge orientations (Map 3) provides a fairly reliable estimate of the general direction of glacial movement in the area.

The most frequently recorded ridge orientation is 40-220 degrees, which accords with many of the striae trends and preferred till pebble orientation data at different localities. This direction of glacial movement can be related to the last incursion of the Patricia Ice Sheet into this locality.

(G) FORMATION OF BARE ROCK RIDGES

The bare rock ridges in the Falcon-West Hawk Lake area are oriented in the direction of most recent ice movement. Structural control of their orientations seems to be minimal. It appears, therefore, that these ridges are glacial erosional features. We must now attempt to envisage the conditions under which these bare rock ridges were produced. To begin with, according to O.D. Von Engeln (1938)[1] several conditions should prevail during their sculpturing. These conditions are :-

(1) A rather thick ice sheet with a steep gradient whereby the margin of ice travelled fast.

(2) An ice margin composed of rigid ice.

(3) The existence of numerous prominent joints in the bedrock to facilitate the eroding processes, especially quarrying.

(4) A thin cover, so that glacial erosion of bedrock occurred soon after ice invasion.

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1. O.D. Von Engeln (1938) Glacial Geomorphology and glacier motion. Am. Journ. Sci. v.35 p.426-460

O.D. Von Engeln (1938) suggested that hard bare bedrocks should not be regarded as rigid resistant masses but as an erosion-receptive materials, and that preglacial topographic terrain as well as rock structure do not control the final form of the features.

Given that the bare rock ridges in the Falcon-West Hawk Lake area are the result of ice erosion under the conditions described above, their different stages of formation might have been as follows :-

(1) A fast moving thick and rigid ice sheet, probably the Patrician Ice Sheet, moved into this part of the Precambrian Shield.

(2) Pre-existing joints and topographic irregularities, especially elevated rock features, regardless of trend, became the places where intensive ice erosion first occurred.

(3) The subglacial fragments transported by the glacier began a concerted scouring of these regions.

(4) As the joints were widened and deepened, the scouring action was localized.

(5) Scouring began to affect the joint blocks that did not conform with the direction of ice movement. Plucking and scouring operated simultaneously, gradually producing depressions, and leaving bare rock ridges in intervening areas.

(6) These ridges were streamlined by lateral and superjacent smoothing and abrasion by the overriding ice.

(H) CONCLUSION

In addition to till pebble orientation, striations, and occasionally drumlinoid features, streamlined bare rock ridges can be a useful guide in the estimation of the general direction of ice movement. Bare rock ridges may be especially useful and reliable in those parts of the Precambrian Shield where the preglacial topography was rolling and would, therefore, have affected the striation directions, and where the till deposits are usually thin, if not non-existent. The data obtained from the ridges in the Falcon-West Hawk area have proved a reliable indicator of ice directions, probably more so than have the two more common criteria. The intrusive stock and anticline structure of the area do not seem to have affected the orientation of the ridges, nor have the joint sets and shear planes. If the measurement of orientation of streamline ridge features is undertaken in an area, the results may be much more satisfactory than the dependence on sporadic striae.

PART II

MORPHOLOGICAL MAPPING

OF

FALCON-WEST HAWK LAKE AREA

(A) USE OF MORPHOLOGICAL MAPS

Geomorphology is, by definition, primarily concerned with the form of land features. Particular emphasis, especially in classical geomorphology, has been placed in the past on qualitative landform descriptions. However, few landforms, especially in terms of their spatial attributes, can be adequately described by words. The use of a mapping method to represent three dimensional landform features becomes necessary.

Morphological maps are basically cartographic expressions of the areal distributions of land surface features. They contain the boundaries of supposedly morphologically indivisible units of which all landscapes are composed. To provide basic data for planning and potential land use, and to assess the relationships of cultural phenomena to landforms, the morphological map is an indispensable tool to geographers. Suffice to say, it may also be very useful to geologists, pedologists and hydrologists.

(B) TECHNIQUES AND DIFFICULTIES IN FIELD MORPHOLOGICAL MAPPING IN THE FALCON-WEST LAKE AREA

The major purpose of modern morphological mapping is to produce a morphological map which contains certain geometrical and dimensional landform data. R.A.G. Savigear[1] was able to relate slopes angles to different types of lithology, while E.M. Bridges and J.C. Doornkamp[2] made use of the morphological map in the study of soil patterns. The mapping, for these purposes, involves substantial field survey and use of surveying instruments. Clinometer, ranging rod and tape may suffice for detailed work, while for very precise mapping a theodolite and tacheometer should be used. Large-scale base maps or vertical aerial photographs are indispensable in a well-coordinated survey.

A morphological map is a two-dimensional representation of assemblages of landform constituents, termed morphological units, which are defined in terms of changes or breaks of slopes. It is a very laborious task, because of the land surface complexity and the required precision, to measure and record each of the morphological units, on the map.

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1. R.A.G. Savigear (1965) A Technique of Morphological Mapping. <u>Ann. Amer. Assoc. Geog</u>. v.55, p.514-538
2. E.M. Bridges & J.C. Doornkamp (1963) Morphological Mapping and the Study of Soil Patterns. <u>Geog</u>. v.48 pp. 175-81.

Tremendous difficulties were encountered in field morphological mapping in the Falcon-West Hawk area, with its rolling terrain studded with numerous ridges too small to be mapped true to scale. The area is thickly covered with trees, and is punctuated by impassable swamps and muskegs, rendering some localities impenetrable.

The field problems encountered in the survey of this area are presented systematically in the following discussion.

(1) Choice of scale

R.A.G. Savigear (1965) comments that most standard geomorphological features can be represented on a base map of scale 1/10560. This scale just allows a morphological unit whose ground horizontal equivalent is 110 feet to be mapped true to scale.[1] However many of the ridge features in the area of Falcon-West Hawk are smaller than this. A map at this scale simply cannot portray accurately the extremely rolling pattern of echelon or composite ridges that occur within parts of the survey area. Savigear suggested an optimal scale at approximately 1/7,500. In this case, the minimum ground horizontal equivalent is about 75 feet. This scale is inadequate for mapping micro features, such as terracettes, but is reasonably good for reconnaissance mapping with air photos in an area such as Falcon-WestHawk Lake.

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1. R.A.G. Savigear (1965) A Technique of Morphological Mapping. Ann. Amer. Assoc. Geog. v.55 p.530

The scale of mapping used in the Falcon-West Hawk Lake survey was 1/6,336, with a ground horizontal equivalent of about 65 feet for the smallest feature represented true to scale. However, this scale proved to be inadequate with regard to ridges composed of several microfacets ranging from 10' to 20' in width. If these minor units are not mapped, the map will be too generalized. Yet when they are mapped in terms of constituents, the map becomes an almost undecipherable mass of symbols.

(2) Identification of morphological discontinuities.

A margin of error always exists when an attempt is made to define the location of morphological discontinuities. A break of slope (angular slope angle change), and a change of slope (gradual slope angle change) may run obliquely or vertically down a slope, and are not always perceived by the surveyor, especially where there is only a slight change in gradient.

Any person with the experience of feeling the rough surface of a 'broken off' piece of granite could conceive the inherent difficulties of drawing a demarcation line along each change or break of slope. In the Falcon-West Hawk Lake Area especially, where granitic outcrops are dominant, discontinuities often exist only for short distances.

The errors of the location of the discontinuities of a slope can be cumulative, and may confuse a ground surveyor in a morphological survey.

(3) Inaccessibility

Owing to thick undergrowth, and sporadic swamps, it was impossible to survey some parts of the field area. Gradients of these impenetrable areas were estimated by viewing angles of slope of the tree crowns at vantage points, as most trees in the area are approximately uniform in height. Yet by doing this, many of the significant ground surface microfacets are not apparent.

(4) Field instrument use.

An improperly handled instrument, such as tilting the clinometer when taking a reading, will give incorrect data. On slopes heavily covered by vegetation, a ranging rod is initially necessary to insure correct reading. Field experience leads, however, to increasingly reliable estimates of distances and heights above ground level.

(5) Recognition of true slope

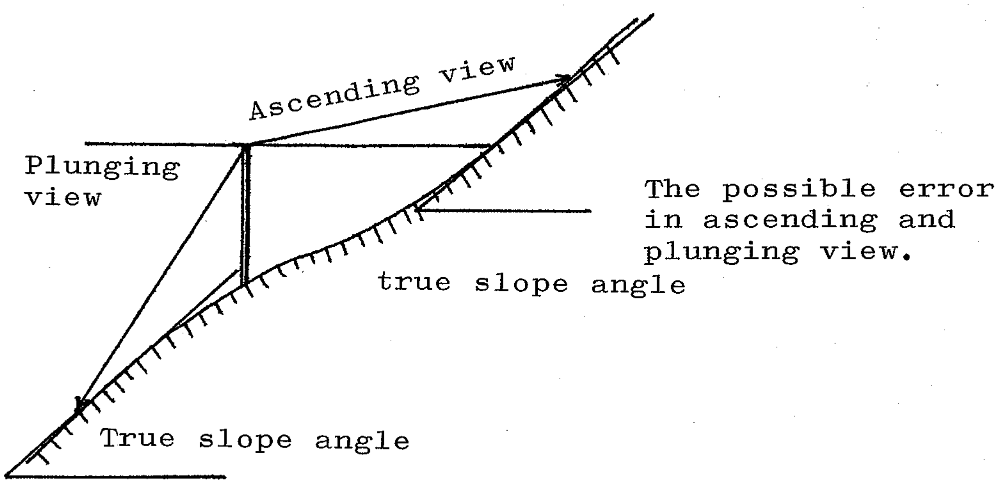
True slope is the maximum angle of slope that exists on that part of the morphological unit that is measured, while apparent slope is the angle measured in any other direction.

Unless the line of slope measurement is predetermined, it is not always easy to get the maximum slope angle. To measure several angles and take the maximum value makes the work very laborious and time-consuming, but it is the only guarantee of accuracy.

(6) Problem of perspective

Misjudgement due to perspective views always give an over-estimation or under-estimation of a slope angle. The error so produced is usually inversely proportional to the length and steepness of the slope.

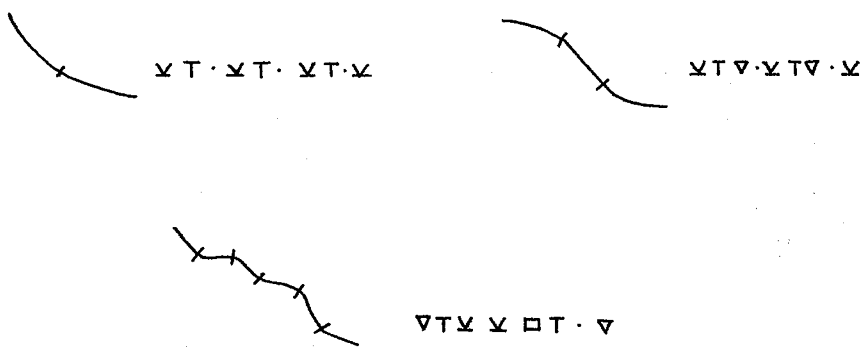
According to D.R. MacGregor (1957)[1], the difference in ascending and plunging views so produced could be as big as 5^{o} to 10^{o}.



1. D.R. MacGregor (1957) Some observation on the Geographical Significance of slope. Geog. 45 p.167-173

(7) Problem of field recording

The most difficult part of morphological mapping is that of the field recording of micro-features. There is always the problem of determining which features should be represented on the map to provide maximum information without the destruction of clarity. R.A.G. Savigear (1965)[1] suggested the use of composite symbols to represent micro-features that cannot be depicted by associations of separate symbols. Three of Savigear's symbols are, for example, as follows :



After R.A.G. Savigear (1965)[1]

These symbols, with a width of about one eighth of an inch, may be capable of representing their mutual relationship and the character of association with the units above and below.

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1. R.A.G. Savigear (1965) A Technique of Morphological Mapping. Ann. Amer. Assoc. Geogr. v.55 p.526

However, the problem in the Falcon-West Hawk area is that many morphological units are microfeatures. Employment of Savigear's method would result in a mass of composite symbols, rendering the map extremely complex to interpret. Hence, different microsymbols have been devised for use in this area.

(C) SYMBOLIZATION

R.A.G. Savigear (1965)[1] has carefully defined several terms that are used in the description of the morphology of terrain: the following definitions are essentially those of Savigear's.

A <u>flat</u> is a surface area which is horizontal, or is inclined at an angle of less than two degrees.

A <u>cliff</u> is a surface area which is vertical or is inclined at an angle of forty degrees or more.

A <u>slope</u> is a surface area inclined at two degrees or more but less than 40^{o}.

A <u>facet</u> is a plane, horizontal, inclined, or vertical surface area.

A <u>segment</u> is a smoothly curved concave (negative) or convex (positive) upwards surface area.

An <u>irregular facet</u> or an <u>irregular segment</u> is a facet or segment which possess distinct surface irregularities that are too small to be represented at the scale of the field map.

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1. <u>Ibid</u> pp.517

A <u>micro-facet</u> is a facet whose boundary discontinuities are too close together to be represented separately at the scale of the field map.

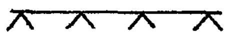
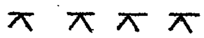
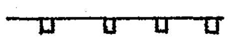
A <u>micro-segment</u> is a segment whose boundary discontinuities are too close together to be represented separately at the scale of the field map.

A <u>morphological unit</u> is either a facet, a micro-facet, a segment or a micro-segment.

A <u>break of slope</u> is a discontinuity of the ground surface.

An <u>inflection</u> is the point, line, or zone, of maximum slope between two adjacent concave and convex segments.

The symbols employed by R.A.G. Savigear(1965)[1] for these slope units are :

	Angular convex break of slope
	Angular concave break of slope
	Smoothly convex change of slope
	CLIFFS (40° or more)
	Smoothly concave change of slope

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1. R.A.G. Savigear (1965) A Technique of Morphological Mapping. <u>Ann. Amer. Assoc. Geog</u>. v.55 p.518

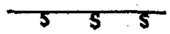
In the morphological maps of Falcon-West-Hawk that were drawn based on field information and air photographs, these symbols are closely followed, except that because changes and breaks of slope cannot be differentiated on the photos in this area, they are generally referred to as a 'discontinuity of slope' and only one convex and one concave symbol are used.

However, in as far as the mapping in Falcon-West Hawk Lake area is concerned, the above set of symbols, is still incomplete. For certain composite micro-features, there must be generalized symbols which present a good mental impression of the recurrent micro forms a particular segment possesses. It is necessary, therefore, to put forth two symbols to supplement Savigear's. These micro features are usually associated with bare bedrock ridges and they can be classified as :-

(1) Wavy segment

(2) Rugged & irregular segment

When two or more small parallel or subparallel undulations occur on a larger morphological units, such as a ridge side, Savigear's composite symbols are inadequate for representations.



wavy segment

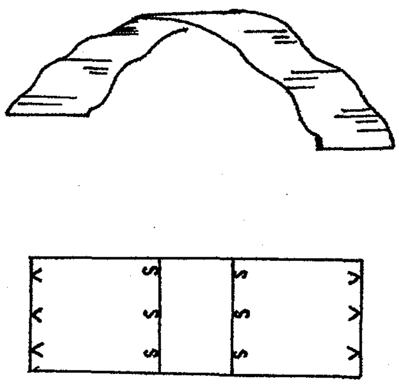
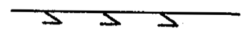


Figure 18

Symbolization of two wavy segments on a ridge

Instead of being smooth, some morphological facets and segments are fragmented, with many breaks of slope being traceable only for a few feet. Since the details of the micro-facets on the units are impossible to map, the terrain can be represented by employment of a discontinuity symbol defining its limits.

The symbol for a rugged and irregular segment or facet will be :-



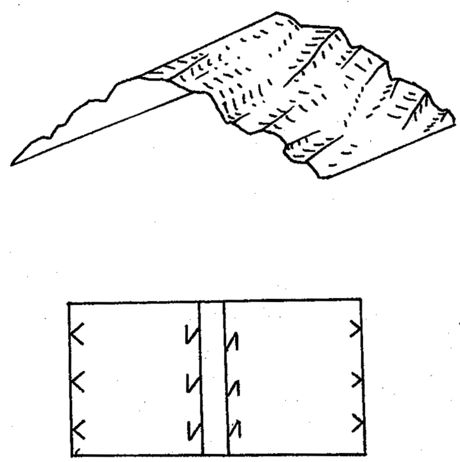


Figure 19

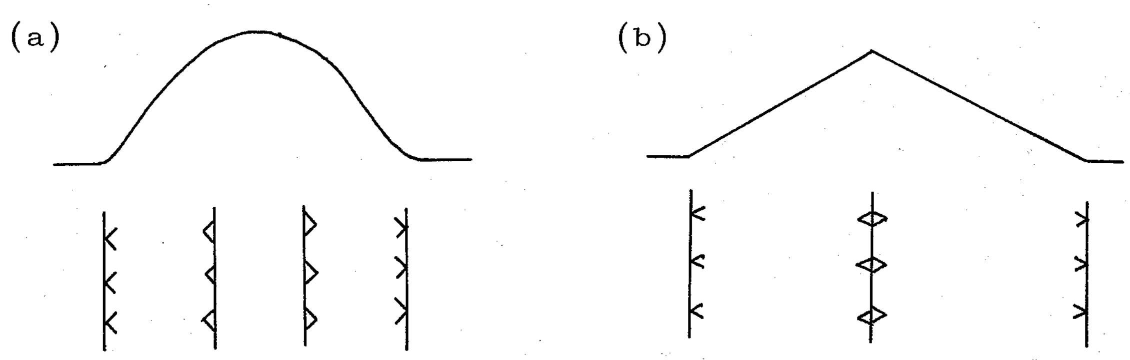
Symbolization of two irregular segments or facets on a ridge

These symbols can be drawn in the smallest possible space and yet ensure clarity. The symbols are almost pictorial of the ground surface itself. They appear to be necessary in order to map the particular terrain in the Precambrian Shield, and presumably in other parts of the world of similar topography.

(D) MORPHOLOGICAL MAPPING OF BARE ROCK RIDGES

Bare rock ridges are relatively small features. To represent them as units by single details would require a large scale map which is usually not suitable for regional mapping. Here it can again be manifested that by means of morphological mapping a small scale landform can be illustrated. Block diagrams can show adequately a sequence of the process of formation of a landform; a large scale contour map can show the general shape and form, but it does not reveal in detail the different morphological associations which make up that particular feature. This is one of the prime tasks that morphological map is designed to serve and in this respect, it is unique.

Following different cross-sections of the bare rock ridges, there are several combinations of morphological units. A ridge with a sharp crestline curvature would have fewer morphological facets than that of a 'blunt' or rounded ridge. Their differences on a morphological map are readily detectable.



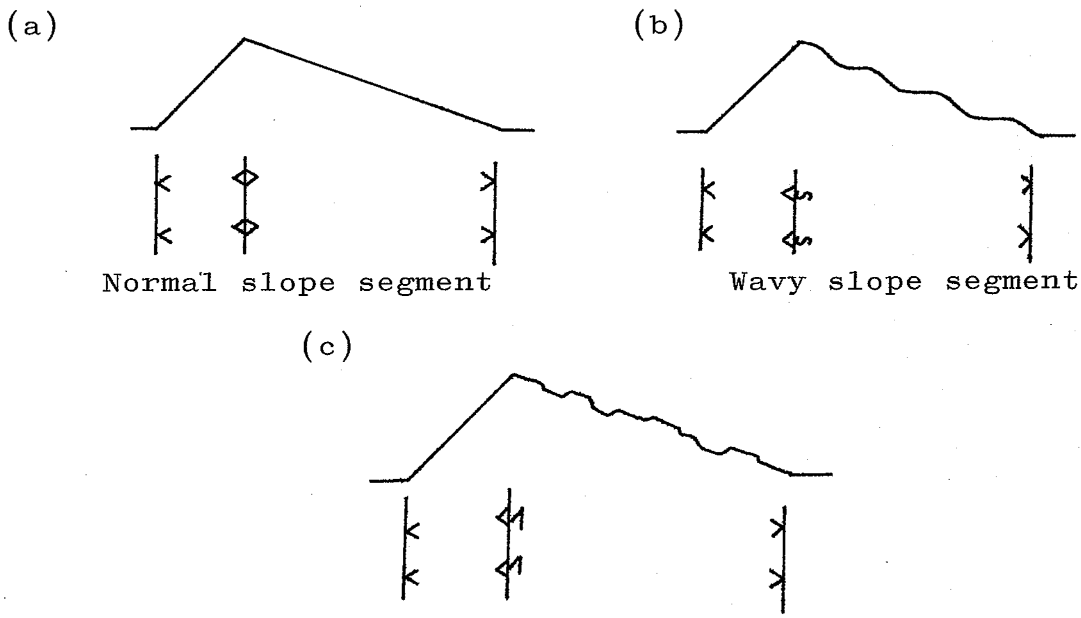
Ridge with 'blunt' crest curvature

Ridge with sharp crest curvature

Figure 20

Some ridges having a cross section resembling that of a cuesta, with both an escarpment and a 'dip' slope, the gentle slope often possessing a wavy, hummocky or broken irregular surface, in which case, the 'new' symbols should be utilized in mapping.

Figure 21



(a) Normal slope segment

(b) Wavy slope segment

(c) Irregular slope segment

The mapping of an entire bare rock ridge feature requires care in locating boundaries of each morphological segment and interpretating morphological relationships. Very often, the differentiation between a change or break of slope is disputable. Workers may map the same feature in a different way, although the difference may be a minor one. Morphological mapping is essentially a rather subjective operation, it needs more training, practice and experience before the operator's variance can be kept to a minimum.

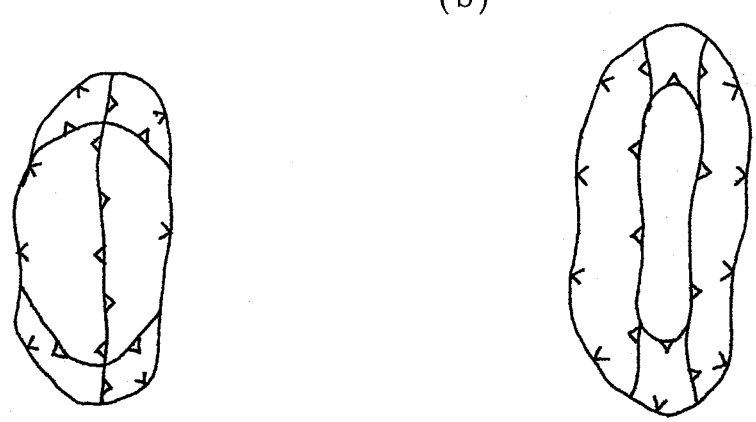
Morphological mapping techniques can present a visual model of a feature, complete with the best possible detailed morphological units, such as the examples below. Scales are not used.

(a) Single streamline ridge

The profile of the crestline curvature largely decides the final cartographic expression of the bare rock ridge. A sharp crestline would give a break of slope symbol at the middle part of the ridge, while a 'blunt' crest curvature would have two lines each representing a change of slope from its downslope direction, and the area within the discontinuity symbol is a separate morphological unit, the equivalent of a crestline.

Figure 22

(a) (b)



Single streamline ridge with sharp crest curvature.

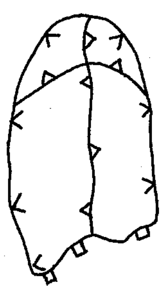
Single streamline ridge with blunt crest curvature.

(b) Single broken streamline ridge

The 'broken' ridge poses an additional problem. Since this type of ridge feature is broken off at one end, a cliff feature usually exists, at either end. So instead of having a complete oval basal outline, the 'broken' ridge will appear as :

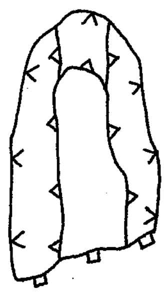
Figure 23

(a)



Broken Streamline ridge with sharp crest curvature

(b)



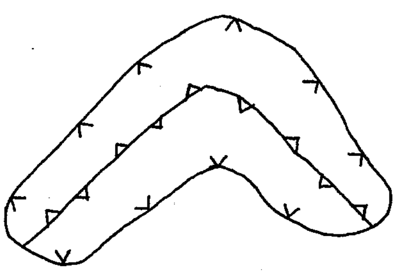
Broken Streamline ridge with blunt crest curvatur

(c) Combined ridge

As combined ridges are formed by two ridges merged at one end, the way they are represented is essentially similar to a streamlined ridge.

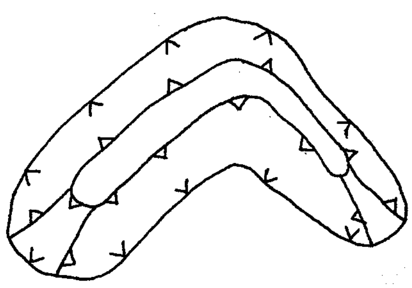
Figure 24

(a)



Combined ridge (sharp crest curvature)

(b)

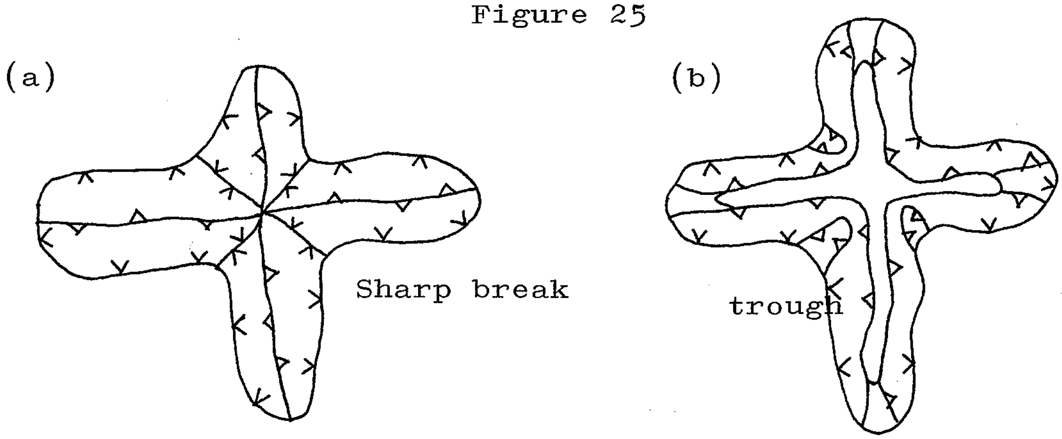


Combined ridge (bluntcrest)

(d) Crossed ridge

Crossed ridges usually have sharp breaks at the junction where the two single ridges join. These areas always have troughs which present some micro-morphological units.

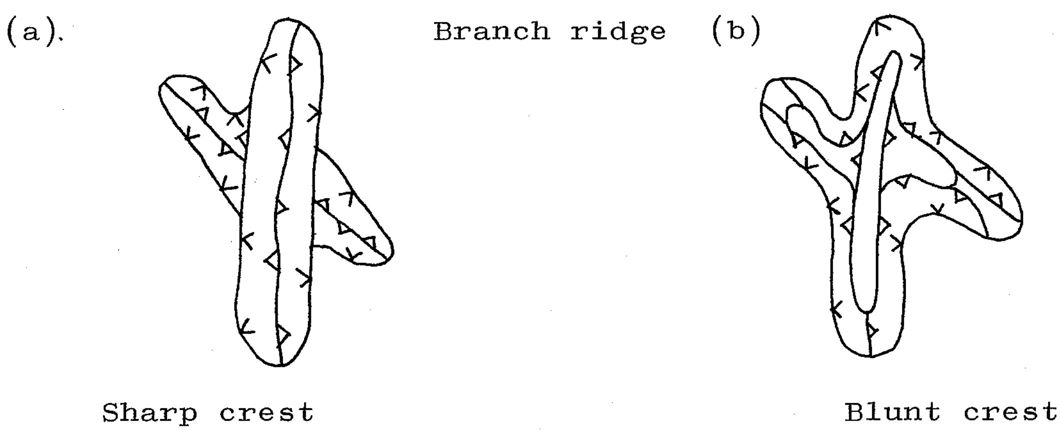
Figure 25



(e) Branch ridge

Branch ridges present the same problems and complexities as cross ridges. An additional difficulty may be from the size of the branch ridge. Very often the crestline of the shorter and smaller branch ridge is lower in height than that of the major ridge, yet by cartographic means, this can be well brought out.

Figure 26



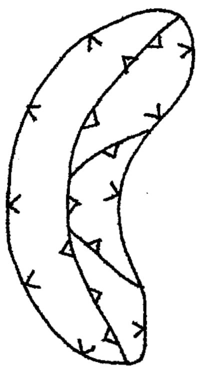
(f) Arcuate ridge

Apart from its plan, an arcuate ridge can be distinguished from a streamline ridge by the usually multiple facets that the arcuate ridge possesses. Especially at the 'inner bend', more morphological planar units are usually found.

Figure 27

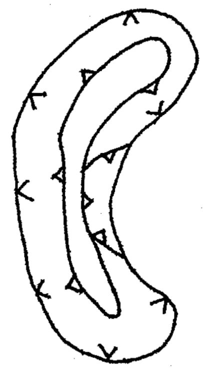
Arcuate ridge

(a)



Sharp crest

(b)



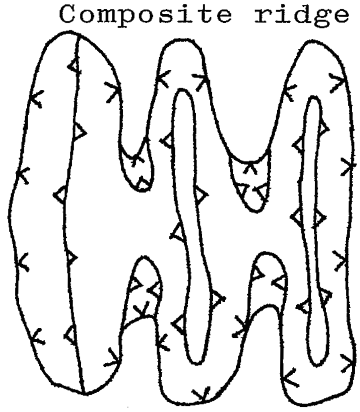
Blunt crest

(g) Composite ridge

Composite ridges are composed of distinct individual parallel ridge units. Each unit is separated from the other by an elongated trough. When the crestlines of each small ridge are not prominent, those wavy and hummocky symbols can be used to represent fused surfaces of this sort.

Figure 28

Composite ridge



Regular crest feature

(E) ELEMENTS OF AERIAL PHOTOGRAPHY IN MORPHOLOGICAL MAPPING

Faced with the great practical difficulties in actual ground mapping of the morphology of the Falcon-West Hawk area, air-photo interpretation and mapping afforded a convenient supplemental supply of information. Aerial photos are used extensively nowadays in topographic mapping, and their value in morphological mapping should not be overlooked. Photo mapping reduces the amount of field work and economizes on the survey budget. Photo survey, in many cases, turns out very good results.

The prime difficulty with air photo mapping is the actual recognition and interpretation of the morphology of features on the photo. R.N. Colwell (1954)[1] defined photo-interpretation as "the act of examining photographic images of objects for the purpose of identifying the objects and deducing their significance." Keeping in mind that our task is not only to recognise the landforms but also to delineate each morphological unit, the difference between ordinary aerial mapping with aerial morphological mapping stems from the fact that the former requires an overall consideration of the whole area, perhaps leading to identification of main landform features, while morphological mapping must, where possible, divide each of these features into morphological units.

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1. R.N. Colwell (1954) A Systematic analysis of some factors affecting photographic interpretation. Photogram. Eng. v.20 No. 3 p.433

Of course, in the latter case, the three dimensional image that stereo-pairs of photos give under a stereoscope is of great assistance. Aerial photo interpretation, more often than not, is a result of deductive and inductive reasoning based on the principle of cause and effect. It can be considered as a two stage process. The first includes recognition, observation, and measurement of shape, a fact-gathering process, while the second step involves the mental process of deducing the mode of origin of each feature and hence giving it a morphological term.

The elements that interpretation can be based upon are :

(1) photographic tone
(2) texture
(3) pattern
(4) association of features
(5) shape

Each of these elements will be discussed below :-

Photographic tone

Tone is a measure of the relative amount of light reflected by an object and actually recorded on a black-and-white photograph; it is fundamental to all other recognition of features. Tones on photos are usually shades of grey, sometimes black or white. Variation in steepness of morphological units will usually give off different degree of tonal reflection, thus helping a great deal in the delineating of morphological facets.

Texture

Texture was defined by R.N. Colwell (1952)[1] as "the frequency of tone change within the image ... and ... produced by an aggregate of unit features too small to be clearly discerned individually on the photograph." In this case, the scale of photo also has considerable bearing on the determination of texture. Texture has been described in terms of coarse, fine, rough and fluffy. But these terms have not been properly defined and there is therefore considerable confusion in their usage. Usually an area with a fine texture means a closed interaction of morphological facets. Falcon-West Hawk area, with its numerous small rock ridges, is an example of fine texture.

Pattern

Pattern refers to the orderly spatial arrangement of geological, topographic or vegetation features.

Patterns are usually made up by an assemblage of curves, lines and circles, which represent structural features such as joints, faults, bedding, or geomorphological features, such as eskers, kames and kettle-holes.

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1. R.N. Colwell (1952) Photographic interpretation for civil purpose, in Am. Soc. Photogrammetry, Manual of Photogrammetry, 2nd ed., p. 538

Relation to associated features

Recognition of an isolated feature or a morphological unit may not be representative. It may not be distinctive enough to permit definite identification and delineation. The significance of a unit's relation to its associated features may be spatial or genetic.

Photograph scale again is important in this respect. The size of a morphological unit in relation to another may determine whether it be mapped or not.

Shape

Shape is especially significant for geomorphological interpretation in recognizing constructional landforms such as drumlins and eskers which have highly distinctive shapes that are readily identifiable. The shapes of depressions and outcrop patterns can also be employed to recognise fault features and contact zones. The shape of shadows of the features provide a valuable sideview which can greatly aid their identification. The shape of each feature will in turn affect the shape of the morphological unit found on them.

(F) TRANSFERENCE OF DATA

The actual morphological mapping from air photo contact prints was a time-consuming task, and the resultant work may not be as accurate as the ordinary topographic contour map, yet it brings out reasonably well the landform and morphology of the area.

The first stage of the map making involves the collection of aerial photos of the Falcon-West Hawk area. A total of eleven flight lines were collected but because of the time factor only a small portion of them were finally utilized.

Each flight line of photos were first put in order. Their principal point is located at the centre of each photo while conjugate principal points are transforms of principal points of the adjacent photos. Each photo therefore should have at least one principal point and two conjugate principal points. (The overlapped area of two adjacent photos being at least 60%). A line joining the principal and conjugate principal points will show the flight line of that strip of photos. Flight line may not necessarily straight, most of them are zig-zag lines converging on each photo at the principal point. These flight lines were to be used as the reference lines when data are transferred from the photo to the base map.

A coordinate system then is set up with its X and Y axes orientated along the north-south and east-west azimuth direction. In this way, the X and Y axes are perpendicular to each other while the point of origin falls on the principal point of the photo.

The flight line can also be used as a reference line when the same coordinate system is reproduced on the base map, since the flight line can be drawn on the base map with a fair amount of accuracy.

The next stage is the reproduction of the same coordinate system on to a prepared base map. Here care should be taken with the scale. In the case of the Falcon-West Hawk Lake area, the photos available were at a scale of 4 inches to 1 mile, while the base maps prepared were 10 inches to a mile. The base map therefore is 2.5 times larger. The flight line of each strip of the photos are conveniently set down on the map, having fixed beforehand the locations of each principal points. The X and Y axes are put down the same way as they are on the photos. On the photos, the X and Y axes were calibrated into intervals of 1 cm. and then further subdivided into 10 subdivisions. On the base map, the X and Y axes are divided into divisions of 2.5 cm. and subdivisions of 2.5 mm. So a point on the upper right hand corner of the photo, for example, may read 3254, meaning 3.2 unit distance along X axis from the origin and 5.4 units along Y axis from the origin. The same point, therefore, with considerable amount of accuracy can be transferred onto the base map.

In order to avoid inaccuracies and inconsistencies of the location of a morphological facet because of distortion, only the zone immediately adjacent to the point of origin (principal point of the photo) of each photo is processed and the data transferred. For areas outside this zone, it is left to the cate of another photo of the flightline or another photo of the next flight line.

(G) WEAKNESSES OF MORPHOLOGICAL MAPS PRODUCED BY AERIAL PHOTOGRAPHS

In spite of the convenience and simplicity of the method, aerial morphological mapping is not without deficiences. Inaccuracy may cumulate with over-generalization of the map, distortion of the photo and inconsistency with its interpretation. Readers must therefore be cautioned that a map of such kind aims primarily at giving an overall correct visual and cartographic image of the morphology of the area, while its accuracy is not very great. The following apparent weaknesses should be taken into consideration :

(1) Generalization -- the scale of the aerial photos on which the mapping is based is 1:15,840. Such a scale can by no means, even under the stereoscope, give the full and complete details of the morphology marked with distinct boundaries, though it is obvious that the photo can present a fairly accurate model of the ground morphology. In demarcating the units, there very often exists a certain amount of interpolation. Nonetheless, though some minor details may thus be discarded, the general picture still holds good.

(2) Distortion -- distortion of each photo increases to a maximum at its outer edges. Every point is radially displaced from the principal point. The amount of distortion is now minimized with theuse of overlapping photos so that the exact position of a point can be accessed. When a point appears on two overlapping photos, it may be transplanted to two slightly different positions on the base map because of the effect of radial displacement. This, however, can be minimized by shifting to the 'bisector point' of the line joining the two points. The 'in-between' point is the nearest location of the transferred point.

Despite all kinds of corrections, the distortion on the derived map can only partially be offset, resulting in a degree of inaccuracy.

(3) Recognition of morphological units and actual slope angles.

Under a stereoscope, it is sometimes rather difficult to differentiate between a change and a break of slope. Again, apart from careful examination and reexamination of the photo, certain amount of speculation is inevitable, leading sometimes to inconsistencies and inaccuracies. More often than not, a very slight change of slope is overlooked.

In areas with forest cover, recognition of morphological units is done by observing the change of tree heights. Again, many of the minor features are not detected.

Varying trees height has not been a problem. The height of trees observed in the field are generally uniform, with a variation of not more than five feet, which is insignificant in the interpretation of morphological units.

(H) SUMMARY

On the two sheets of morphological maps (back flap) produced by the writer, the same method of interpretation, symbolization and actual transference of data as described in the preceding pages are used. The result seems quite satisfactory. The maps show the actual ruggedness and 'broken' surfaces of the Precambrian Shield, and also many of those ridge features, large and small, which are common in that area.

It has also been attempted to represent the different forms of bare rock ridges in Falcon-West Hawk area by delineating the ridges into morphological units.

Methods of symbolization is discussed. Two generalization symbols are suggested for the rugged and wavy morphological segments commonly found in this area.

Morphological field mapping has encountered tremendous difficulties chiefly because of the thick forests and impassable swamps. Attempt was thus made to map the area morphologically with the help of airphotos, and it is found that if the demand of a morphological map is not for precision of location or absolute gradients, then it can be produced, fairly satisfactorily by a combination of field survey and aerial photos interpretative mapping.

GENERAL CONCLUSION

Bare rock ridges occurred in Falcon-West Hawk Lake area had their long axis orientated in such direction that they conform with pebble orientation and striation direction of the area. It was found that the bedrock geology and the structure of the area had no effect on the orientation of these ridges, and it was suggested that bare rock ridges can be a reliable indicator of general ice movement in the area.

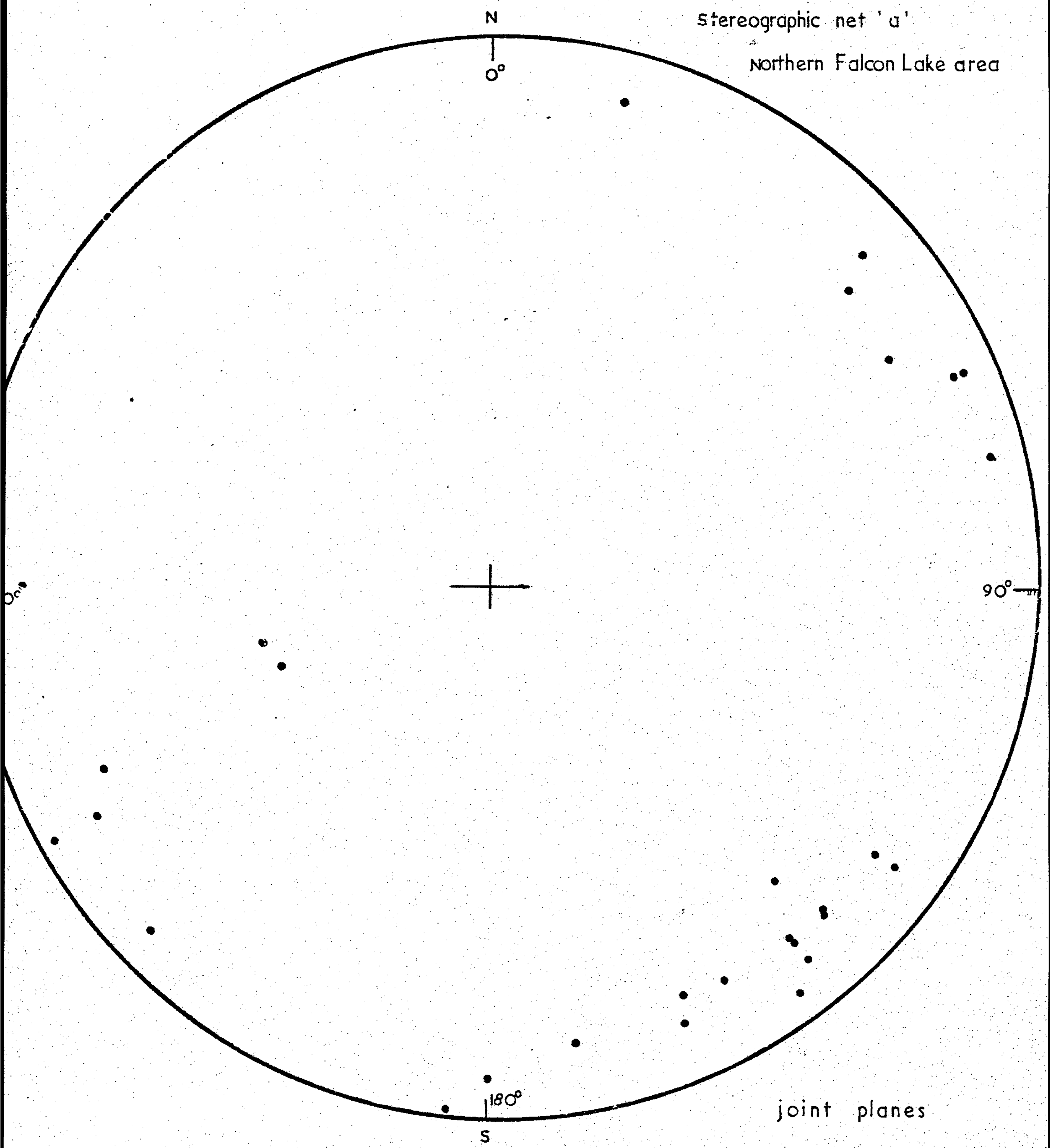
The forms of the ridges are classified and a morphological mapping of the area with the help of air photos attempted. The difficulties with field mapping were tremendous, ranging from possible error in perspective views when taking a reading, to the improbability of locating morphological units and mapping an area of dense forest cover.

APPENDIX I

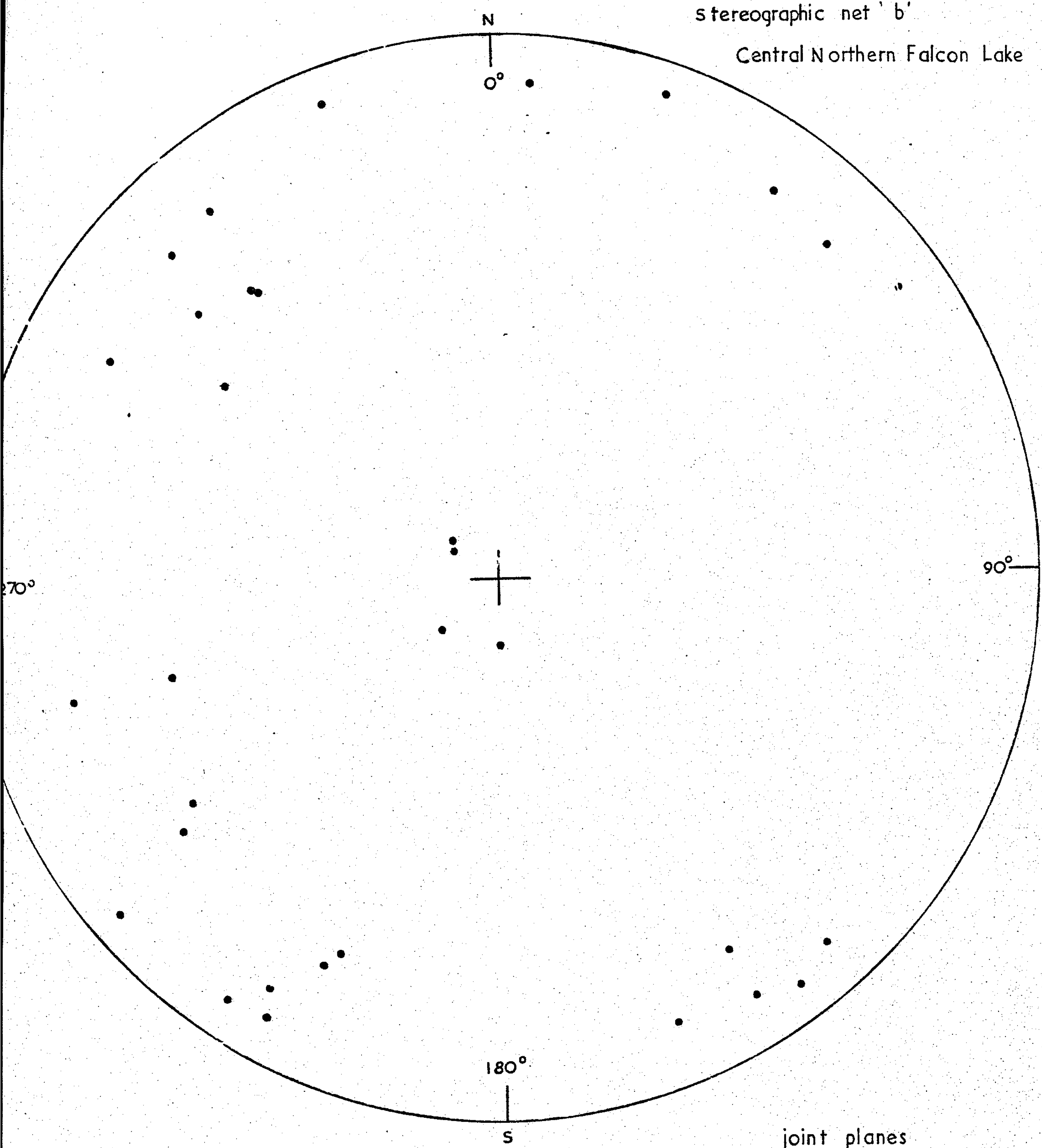
JOINT SYSTEMS PLOTTED ON A STEREOGRAPHIC NET

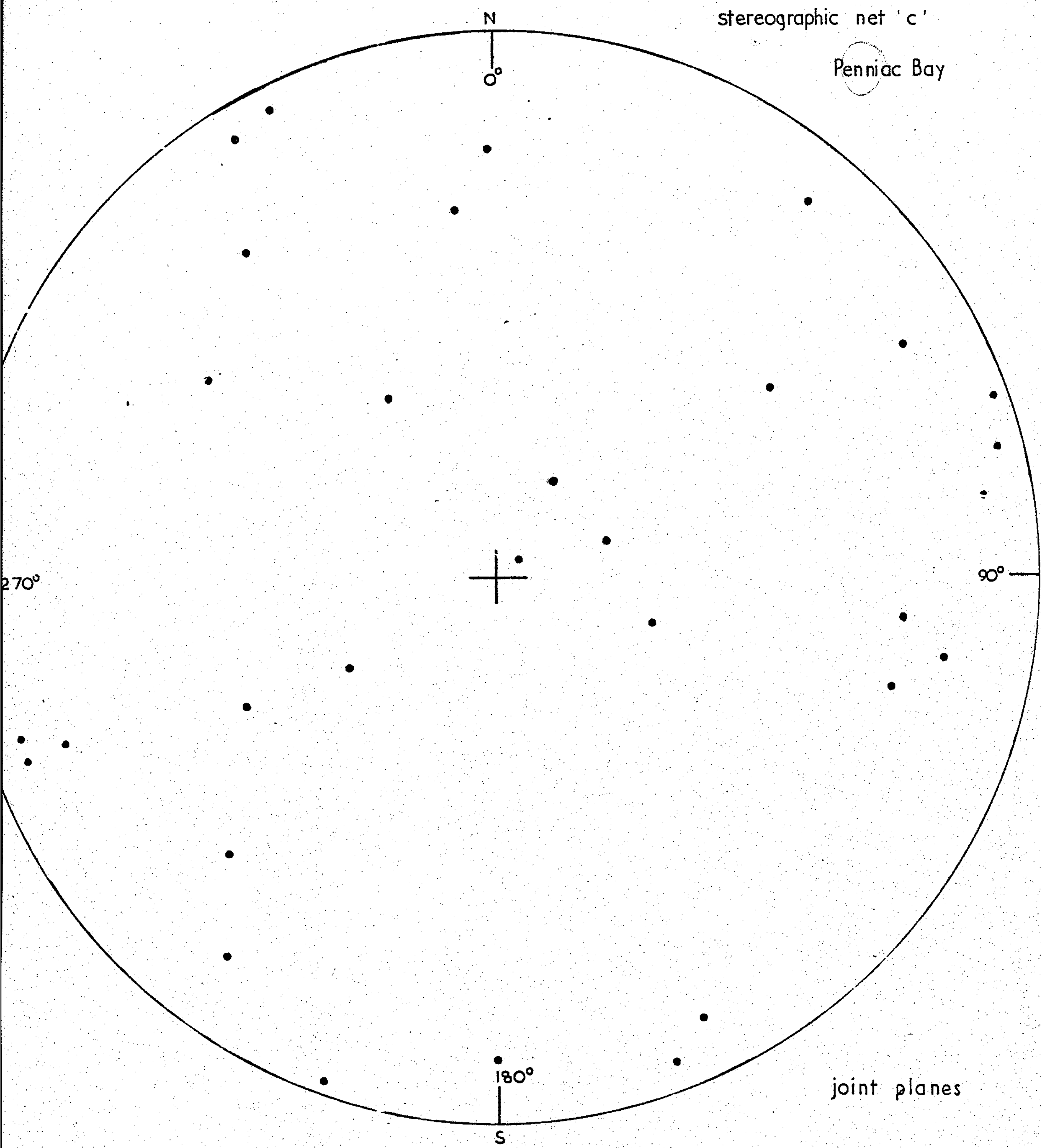
The stereographic projection is a simple method usually employed to demonstrate a preferred orientation in mineralogy and in structural geology.

A plane with known dip angle and strike direction is put at its proper orientation on top of an imaginary lower half sphere. The central point of the plane, which can be pierced through by a line joining the pole and the centre of the sphere, can be projected according to its dip and strike direction on to the surface of the sphere. The stereographic net indicates the dip and strike of the plane. An extra-ordinary clustering of many points on a certain portion of the net means a preferred orientation of the planes.



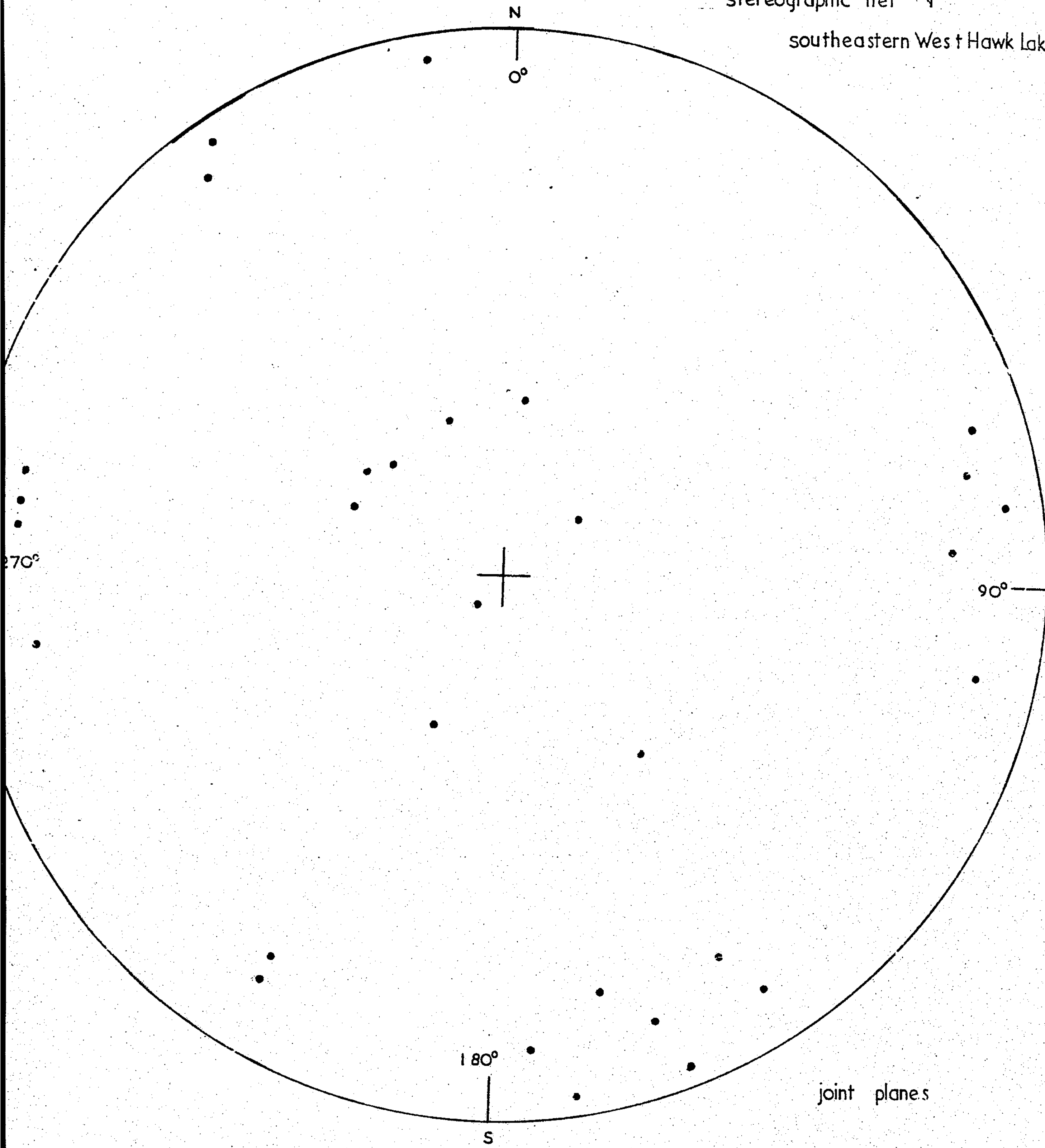
Stereographic net 'a'
Northern Falcon Lake area
N
0°
90°
180°
S
joint planes


Stereographic net 'b'
Central Northern Falcon Lake
N
0°
90°
270°
180°
S
joint planes


stereographic net 'c'
Penniac Bay
N
0°
90°
180°
S
270°
joint planes

stereographic net '4'

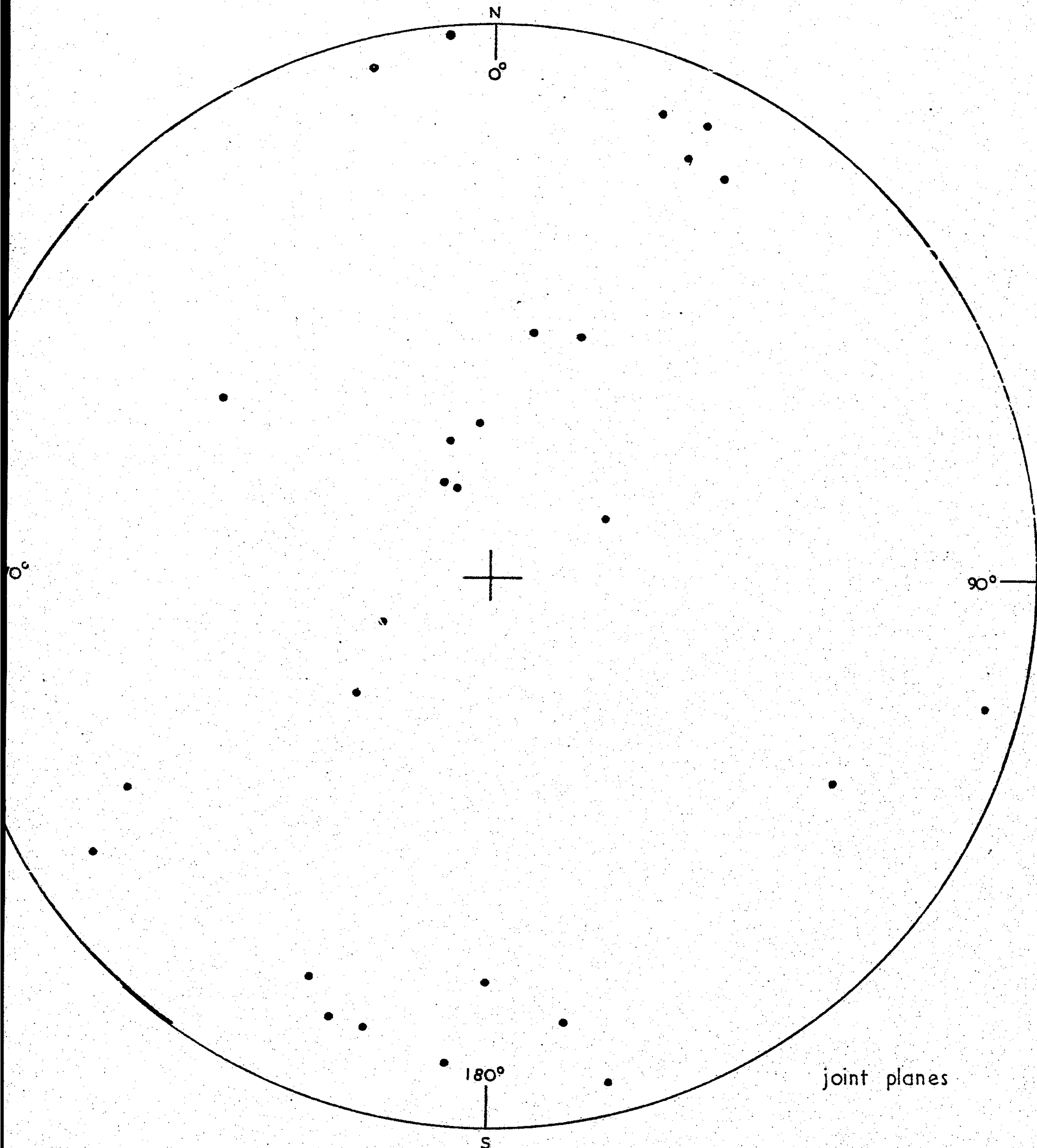
southeastern West Hawk Lake



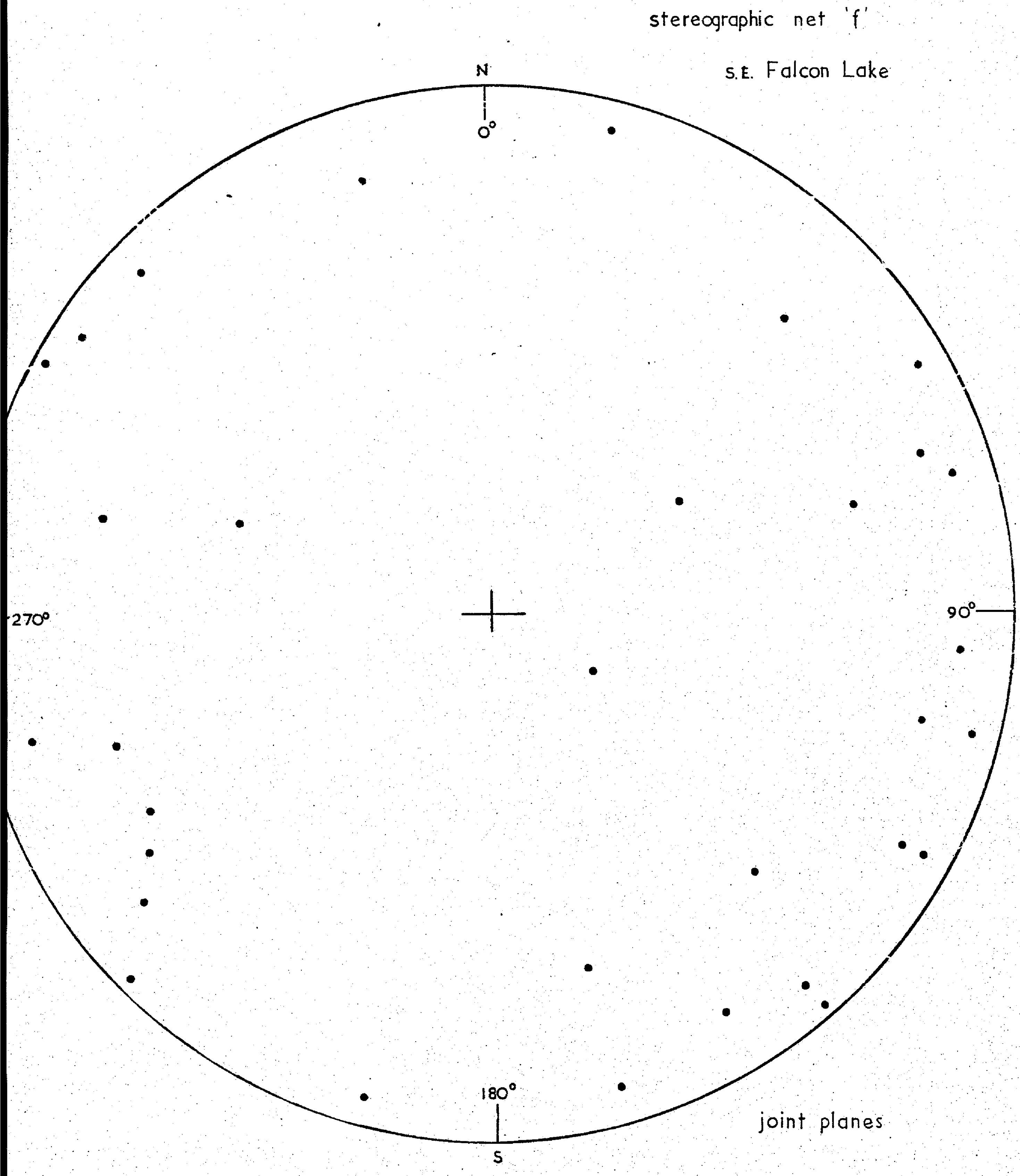
joint planes

stereographic net 'e'

southern West Hawk Lake

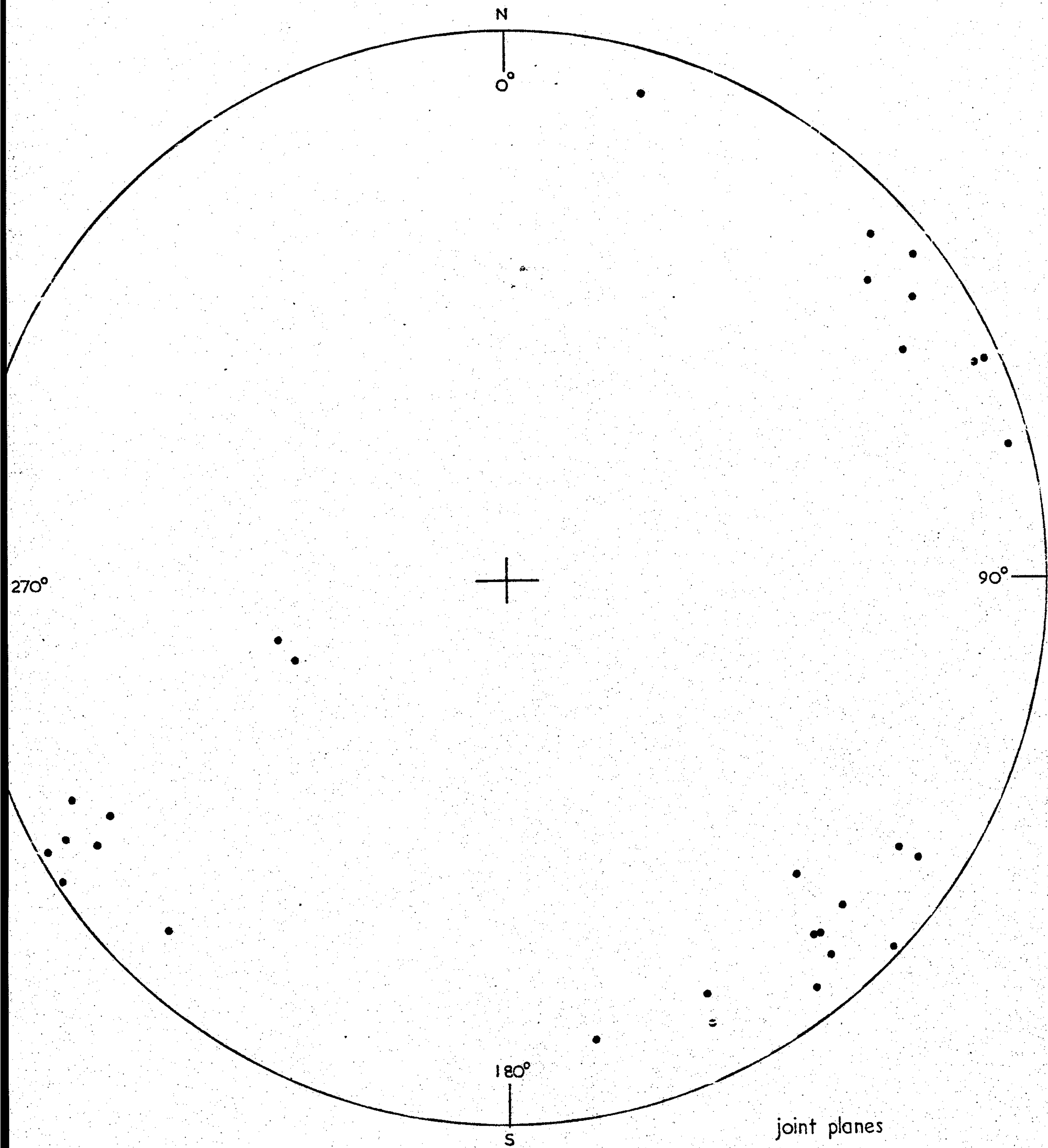


joint planes


stereographic net 'f'
S.E. Falcon Lake
N
0°
90°
180°
S
270°
joint planes

stereographic net 'g'

N.W. Falcon Lake



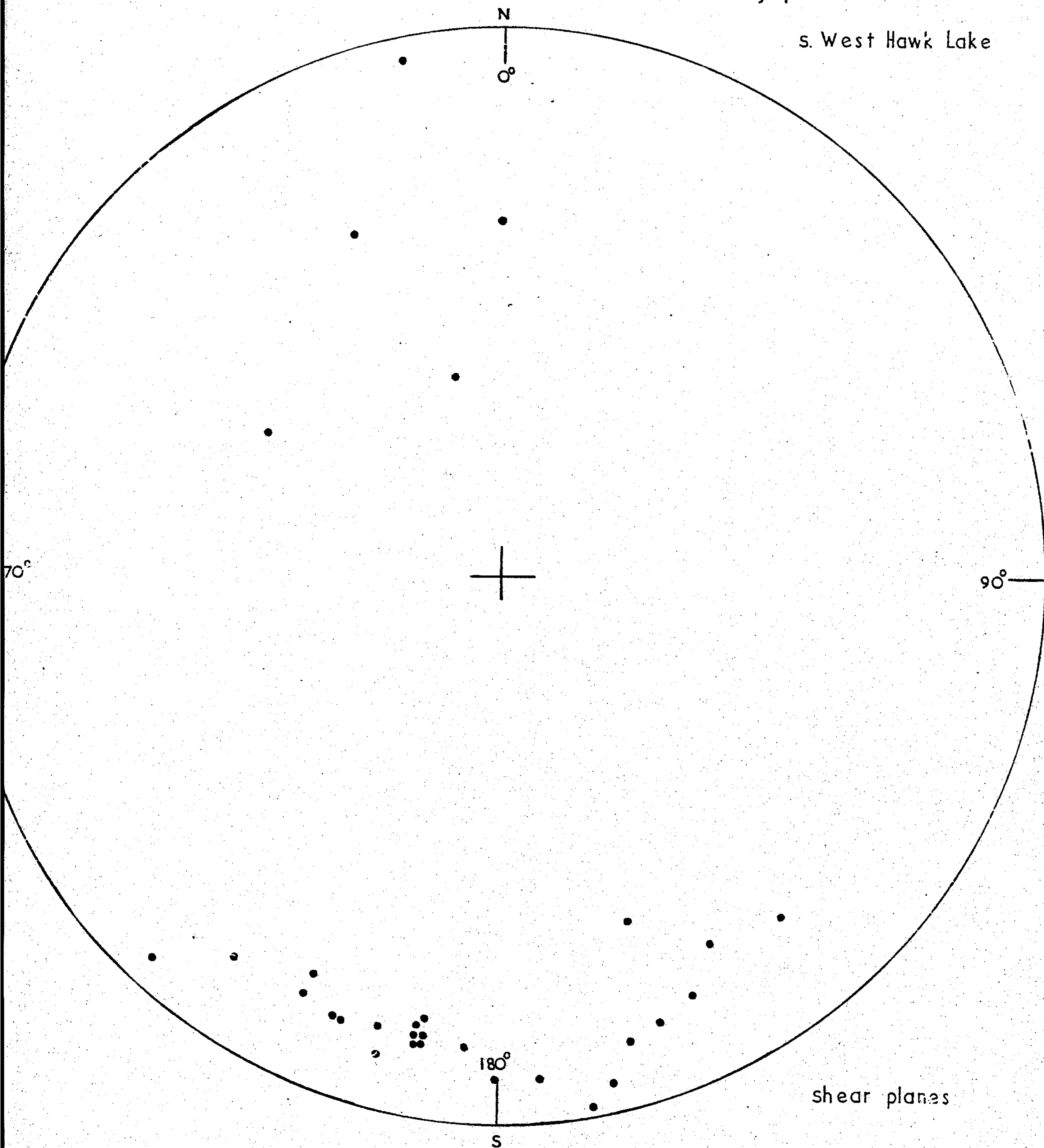
joint planes

Appendix II

SHEAR PLANE SYSTEMS PLOTTED ON STEREOGRAPHIC NET

Stereographic net 'h'

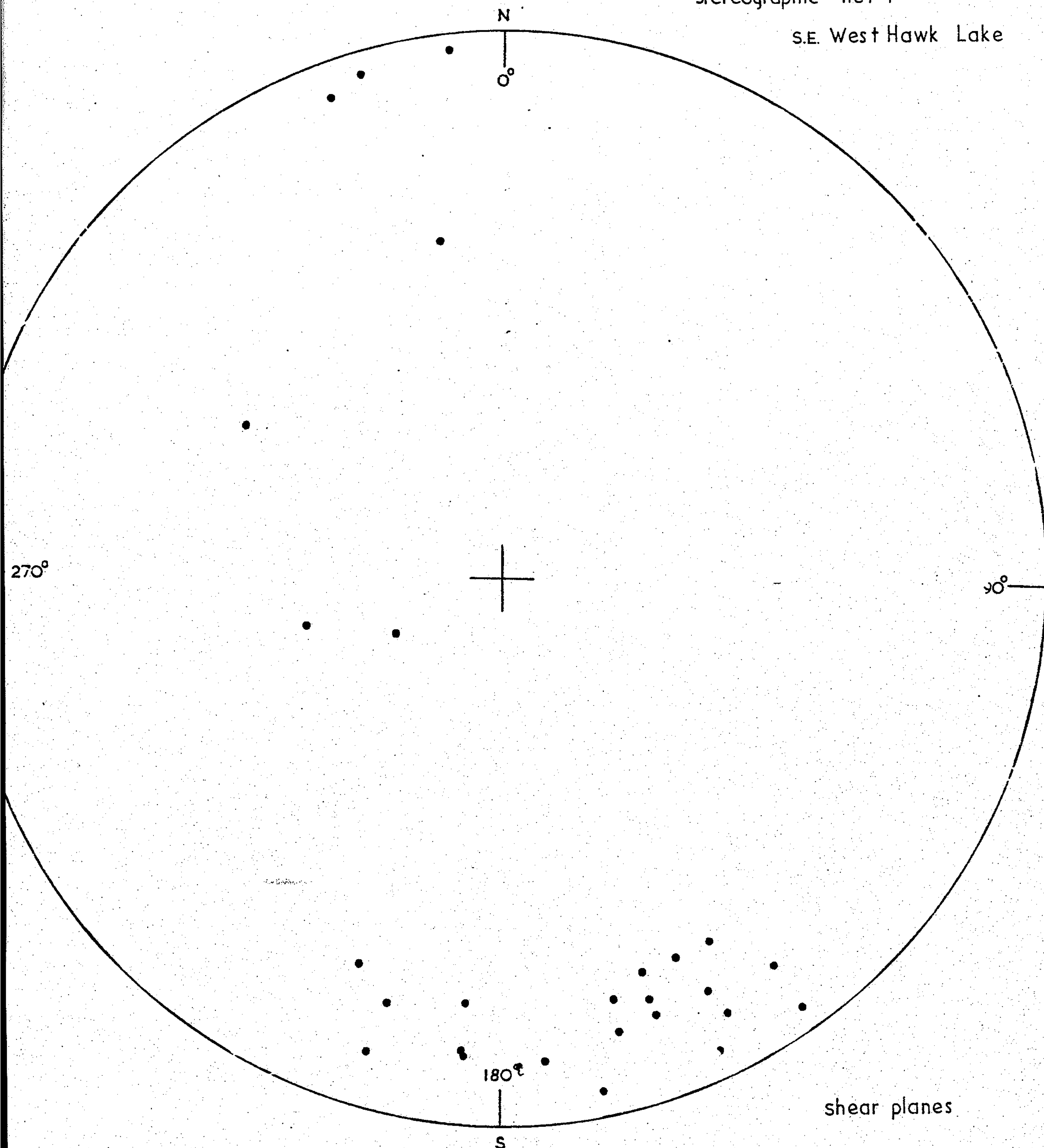
S. West Hawk Lake



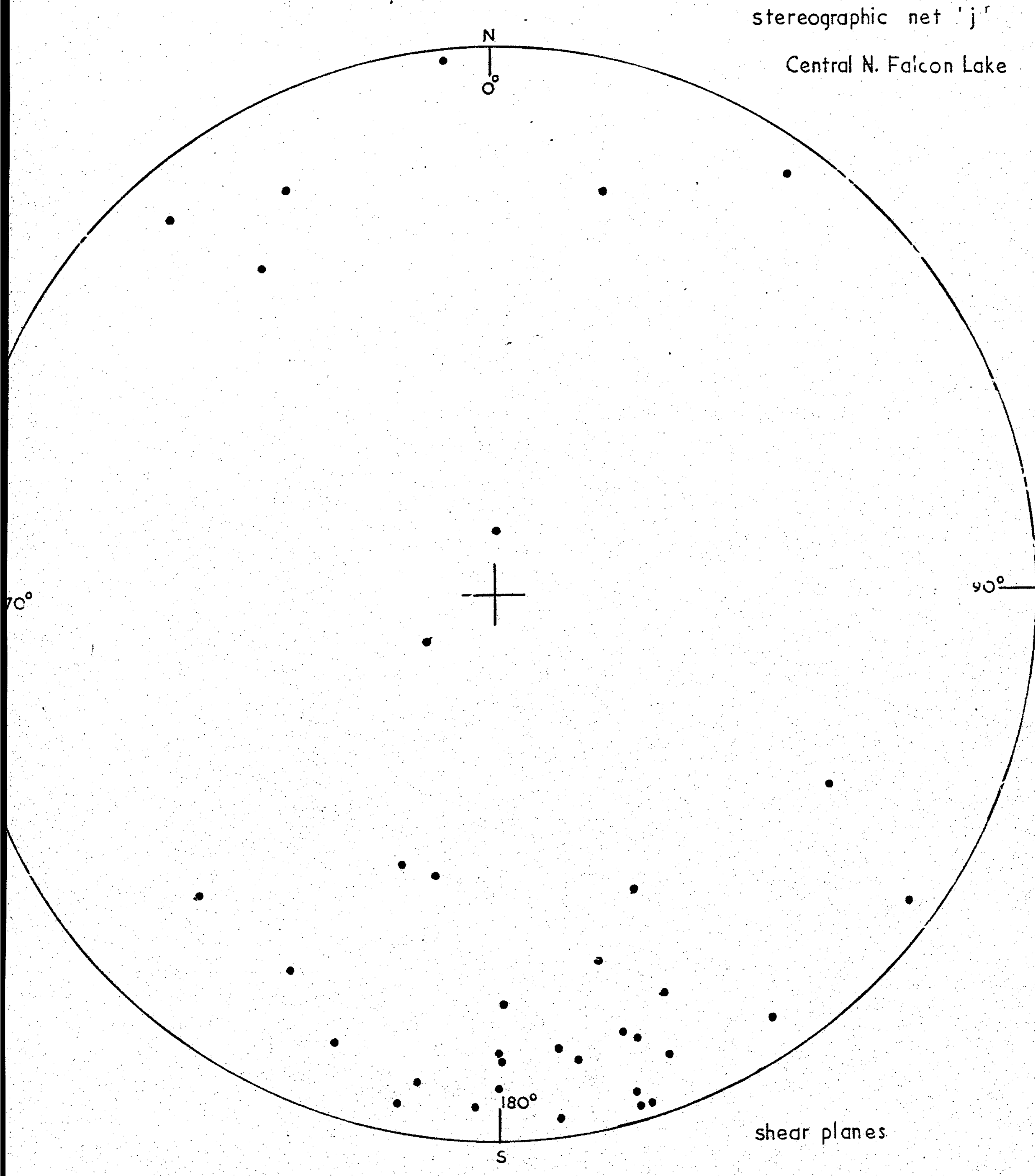
shear planes

stereographic net 'i'

S.E. West Hawk Lake

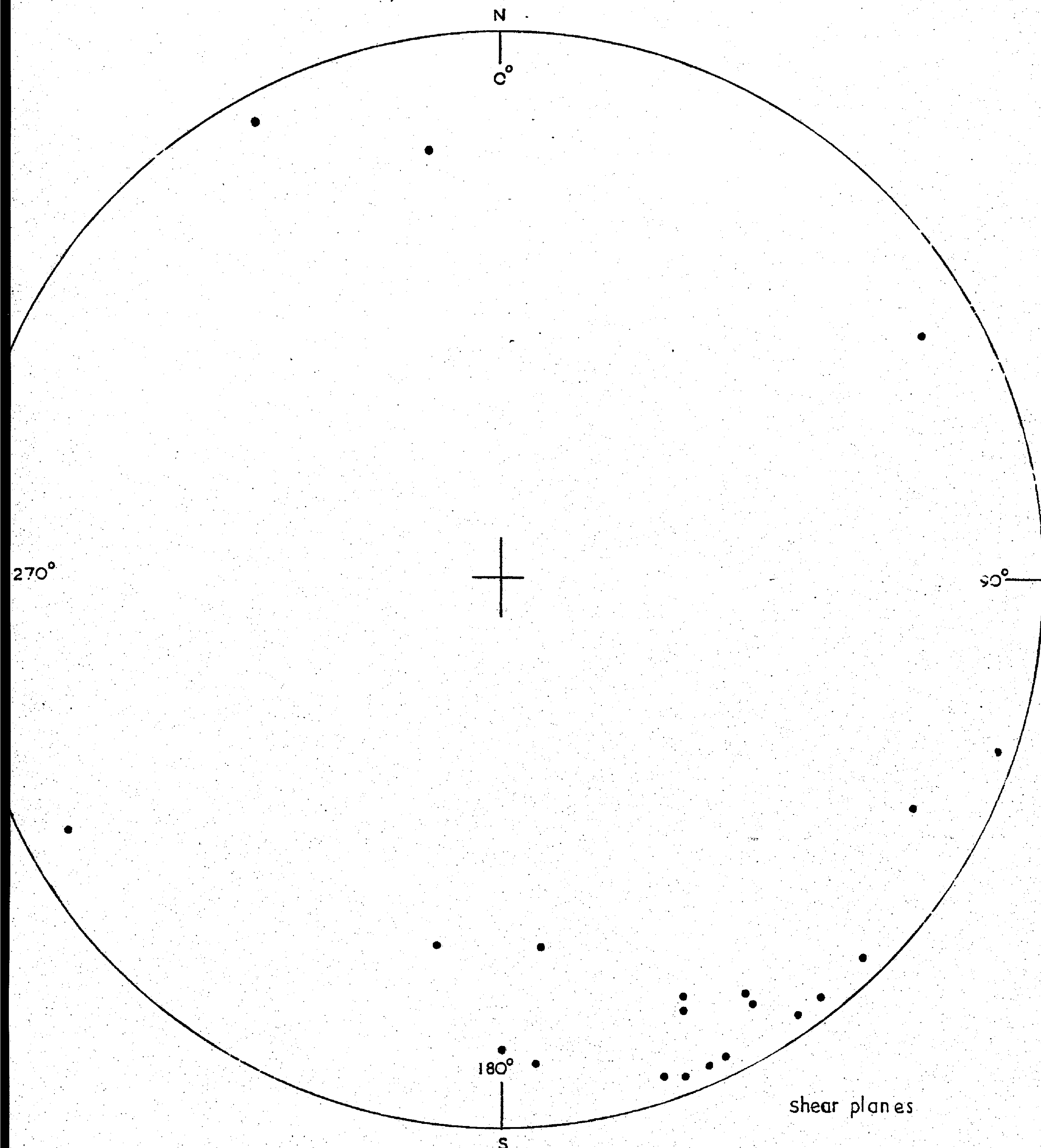


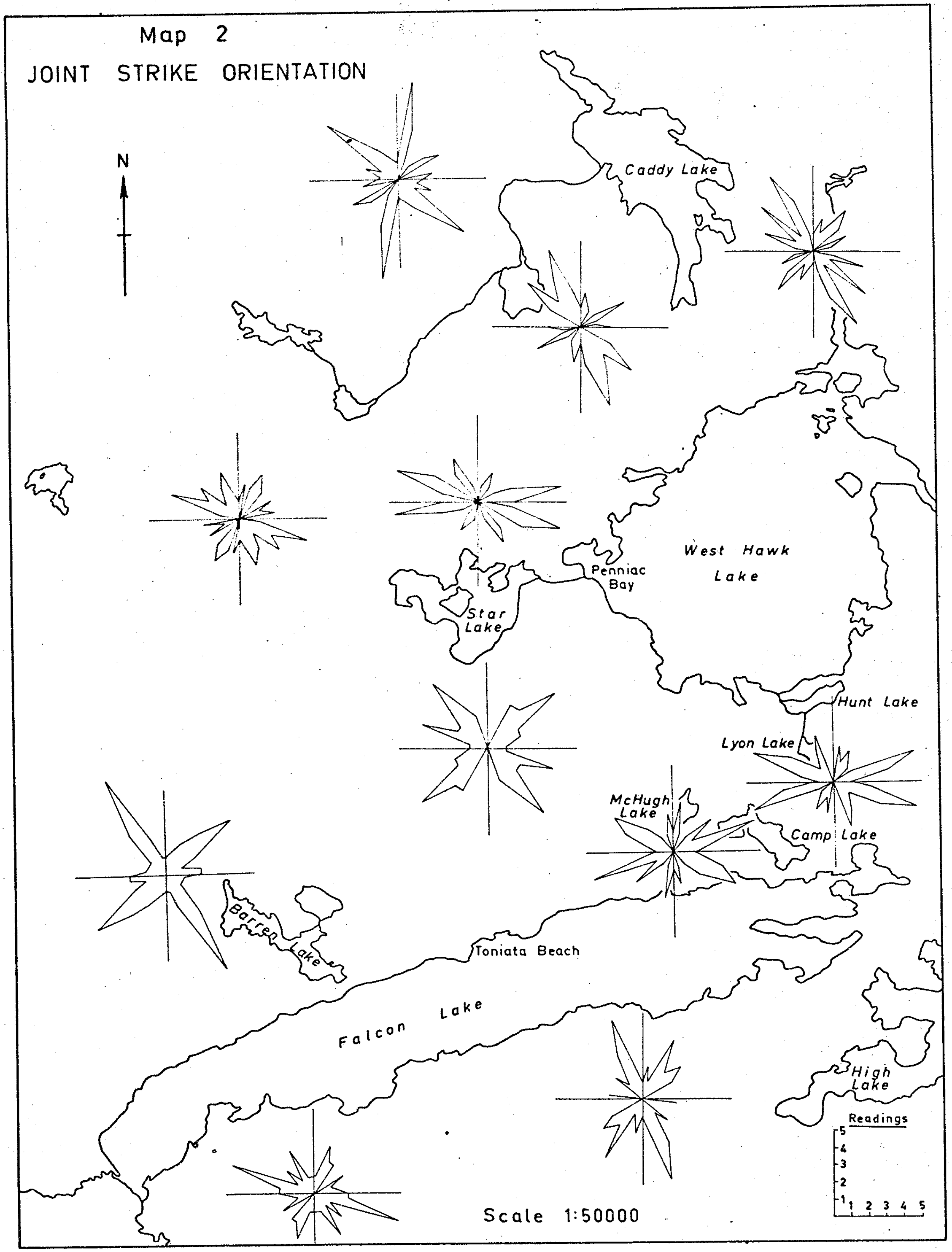
shear planes


stereographic net 'j'
Central N. Falcon Lake
N
0°
90°
70°
180°
S
shear planes

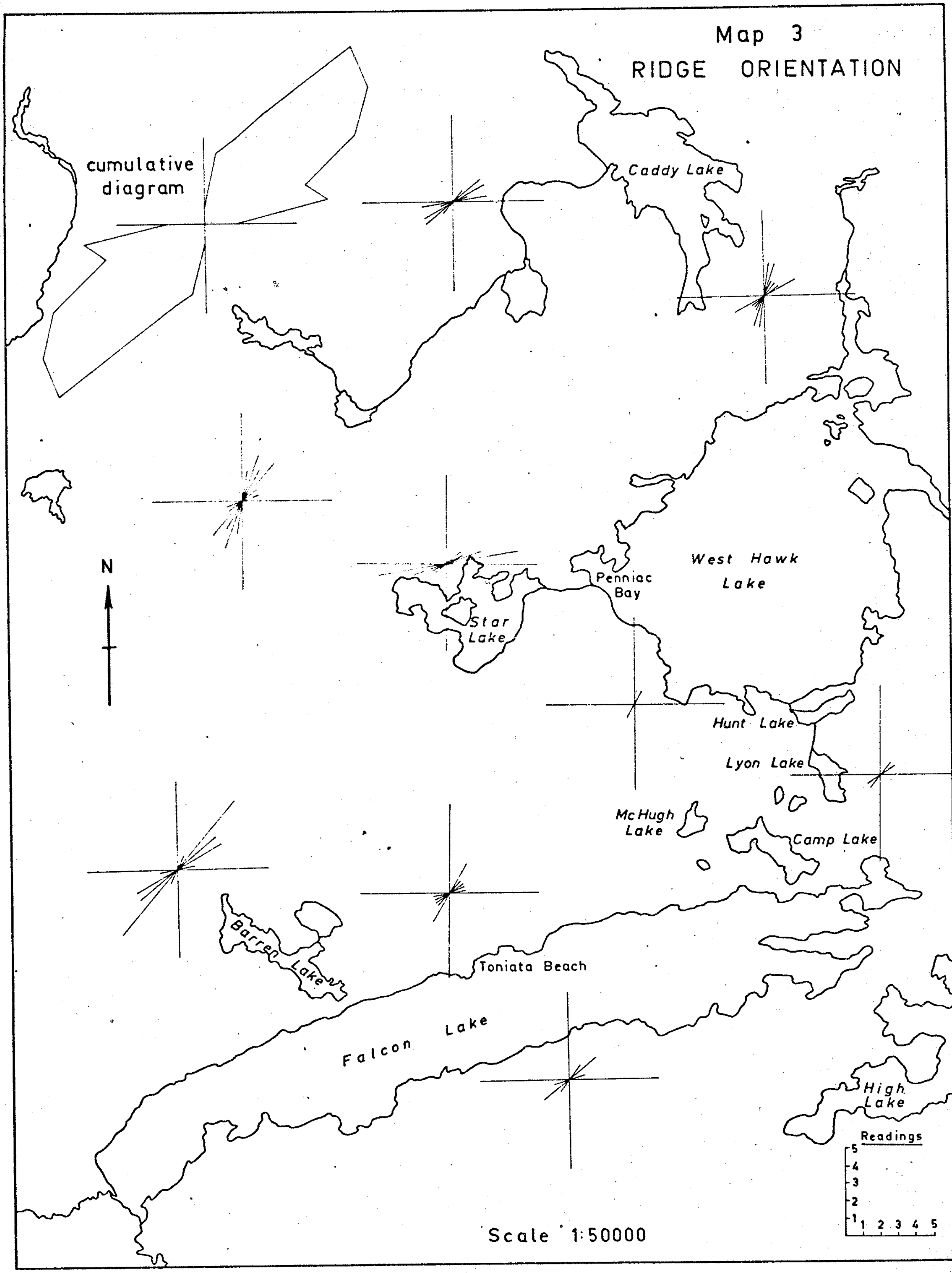
stereographic net 'k'

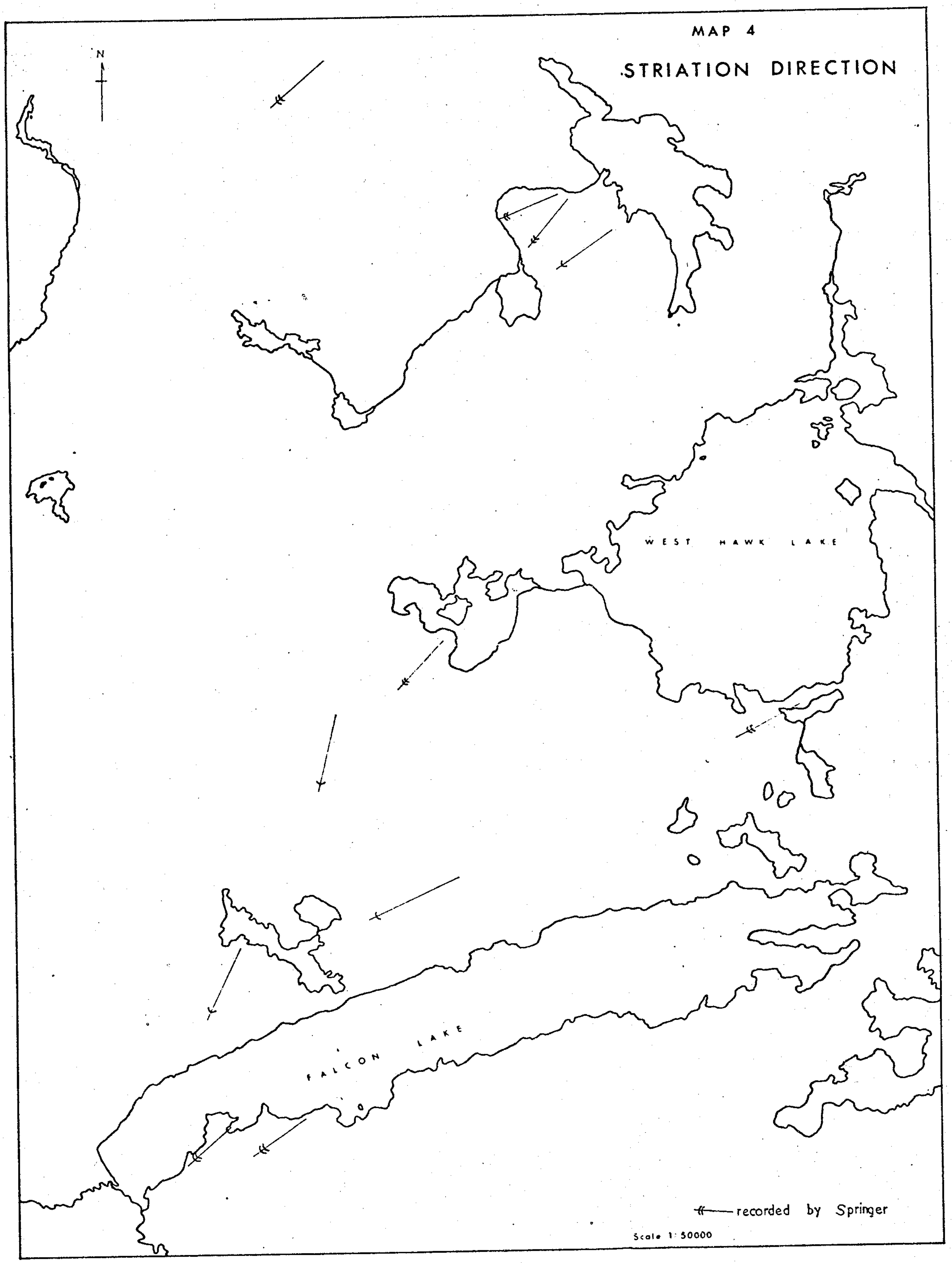
Penniac Bay

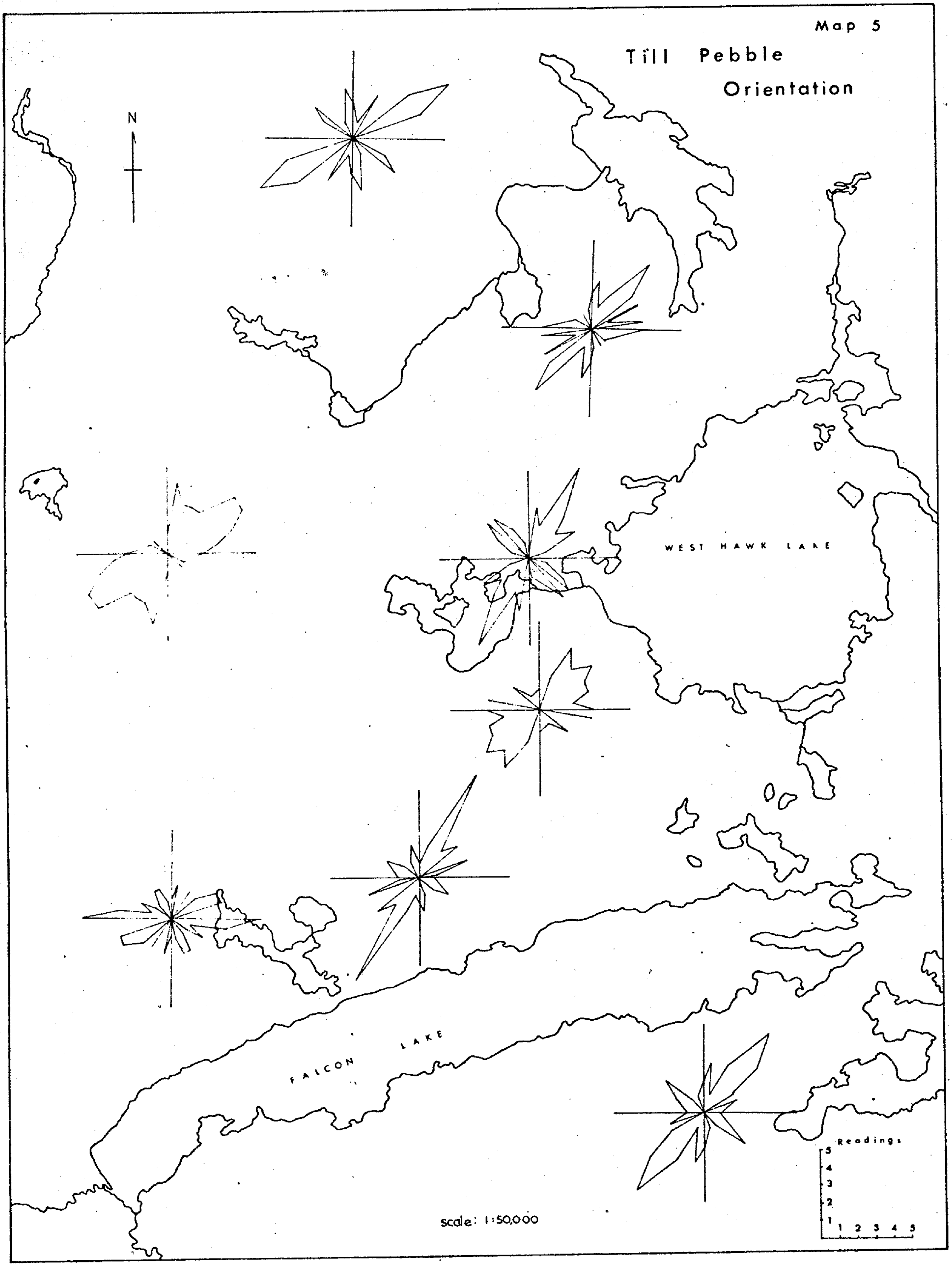


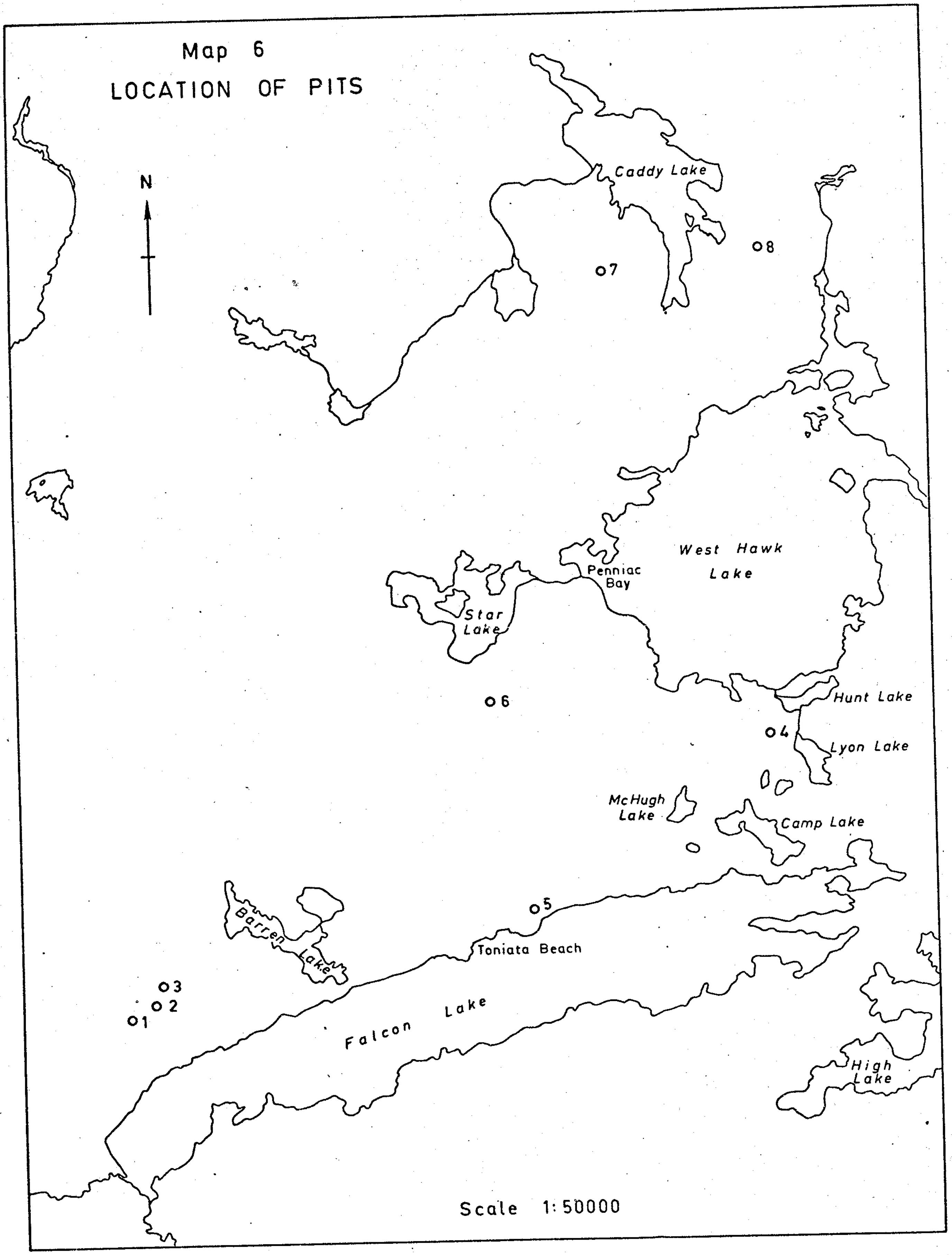


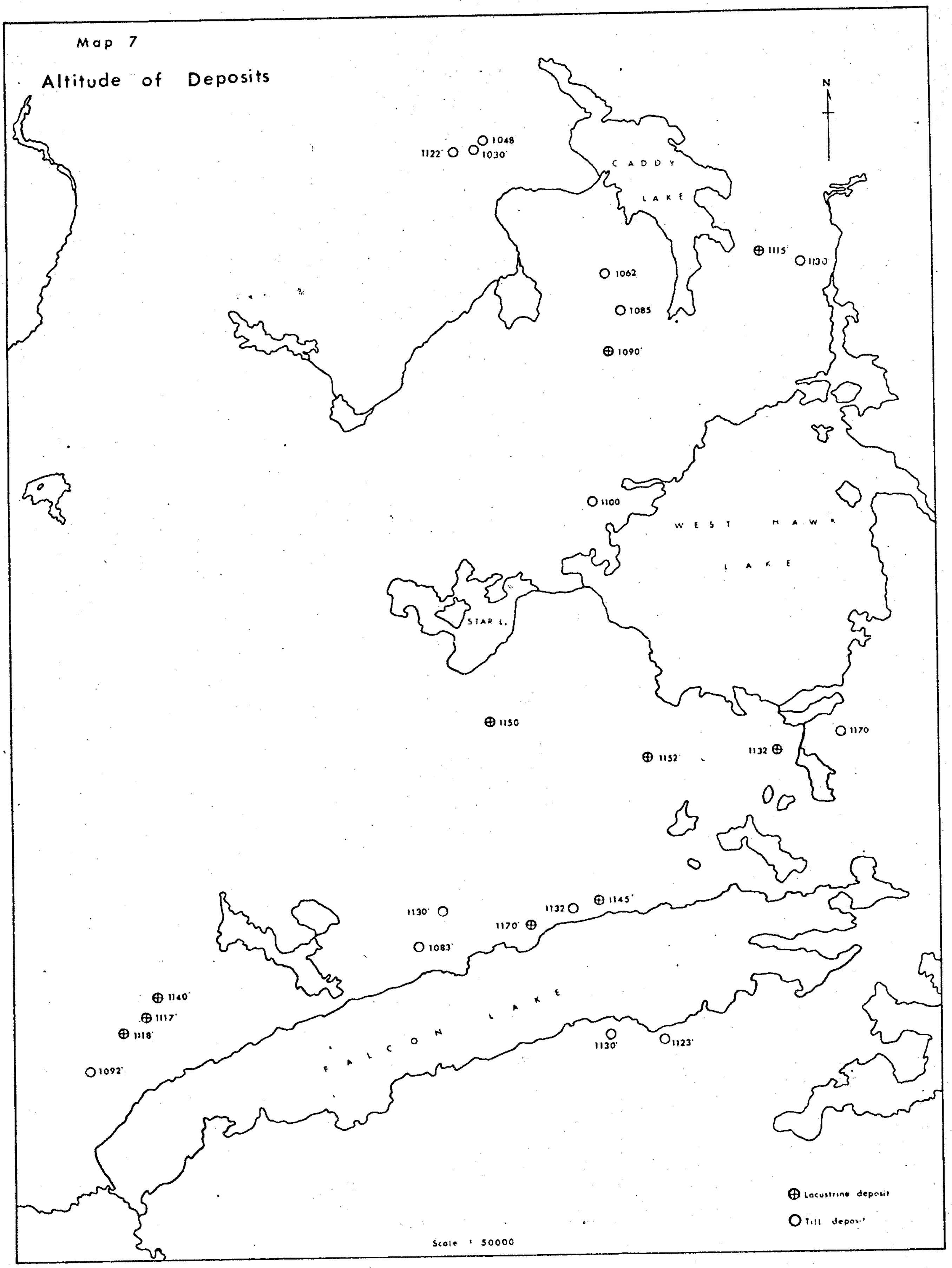
Map 2
JOINT STRIKE ORIENTATION
N
Caddy Lake
West Hawk
Lake
Penniac
Bay
Star
Lake
Hunt Lake
Lyon Lake
McHugh
Lake
Camp Lake
Barren Lake
Toniata Beach
Falcon Lake
High
Lake
Readings
5
4
3
2
1
1 2 3 4 5
Scale 1:50000


Map 3
RIDGE ORIENTATION
cumulative diagram
Caddy Lake
N
West Hawk Lake
Penniac Bay
Star Lake
Hunt Lake
Lyon Lake
Mc Hugh Lake
Camp Lake
Barren Lake
Toniata Beach
Falcon Lake
High Lake
Readings
5
4
3
2
1
1 2 3 4 5
Scale 1:50000


MAP 4
STRIATION DIRECTION
N
WEST HAWK LAKE
FALCON LAKE
recorded by Springer
Scale 1:50000


Map 5
Till Pebble Orientation
N
WEST HAWK LAKE
FALCON LAKE
Readings
5
4
3
2
1
1 2 3 4 5
scale: 1:50,000


Map 6
LOCATION OF PITS
N
Caddy Lake
O8
O7
West Hawk
Lake
Penniac
Bay
Star
Lake
O6
Hunt Lake
O4
Lyon Lake
McHugh
Lake
Camp Lake
O5
Barren
Lake
Toniata Beach
O3
O2
O1
Falcon Lake
High
Lake
Scale 1:50000



Map 7

Altitude of Deposits

CITED REFERENCE

ALDENS, W.C. (1965) The drumlins of S.W. Wisconsin. U.S. Geol. Sur. Bull. No. 273. pp.9-43.

ANTEVS, Ernst (1925) Retreat of the Last Ice Sheet in Eastern Canada. Geol. Surv. Canada, Mem. 146.

ANTEVS, Ernst (1928) The Last Glaciation. Am. Geog. Soc. Research Series No. 17

ANTEVS, Ernst (1931) Late-glacial Correlations and Ice Recession in Manitoba. Canada Geol. Sur. Mem. 168

ANTEVS, Ernst (1951) Glacial clay in Steep Rock Lake, Ontario, Canada. Bull. Geol. Soc. Am. V.62 p.1242-1262.

ARONOW, S. (1959) Drumlins and related streamline features in the Warwick - Tokio Area, North Dakota. Am. Jour. Sci. Vol. 257, p. 191-203.

BARDLEY, A.J. (1942) Aerial Photographs: Their Use and Interpretation. Harper & Brothers, New York.

BIRD, J.B. (1953) The glaciation of Central Keewatin, Northwest Territories, Canada Am. Jour. Sci. V. 251, p. 215-30.

BRIDGES, Z.M. Doornkamp, J.C. (1963) Morphological Mapping and the study of soil patterns. Geog. 48 p. 175-81.

CHAMBERLAIN, T.C. (1986) The rock-scourings of the great ice invasions. U.S. Geol. Surv. Annual Report 1885-1886 p. 14-248.

CHAMBERLAIN, T.C. (1911) Certain aspects of glacial erosion. Jour. of Geol. V. 19, pp. 193-216.

CHAPMAN, L.J. and Putnam, D.F. (1949) The Recession of the Wisconsin glacier in Southern Ontario. Royal Soc. of Canada, Trans. 3rd series vo. XFIII Sec. IV pp. 23-52.

CHAPMAN, C.A. (1958) Control of jointing by topography. Jour. of Geol. V66 pp. 552-558.

CHAPMAN, C.A. and Rioux, R.L. (1958) Statistical Study of Topography, Sheeting and Jointing in Grante, Acadia National Park, Maine. Am. Journ. Sci. V.256 No. 2 p.111-131.

COLWELL, R.N. (1954) A systematic analysis of some factors affecting photographic interpretation Photogram. Eng. V. 20 No. 3 pp. 433-454.

CROSBY, W.O. (1928) Certain Aspects of Glacial Erosion. Bull. of Geol. Soc. V. 39, pp. 1171-1181.

CURTIS, L.F., Doomkamp, J.C. and Gregory K.J. (1965) The Description of Relief in Field Studies of Soils. J. of Soil Sci. V. 16, pp. 16-30.

DAPPLES, E.C. and Rominger, J.F. Orientation Analysis of Fine-grained Clastic Sediments : A report of progress. J. Geol. V. 45 pp. 246-261.

DAVIES, J.F. (1954) Geology of the West Hawk Lake - Falcon Lake area. Dept. of Mines & Natural Resources, Mines Branch Publication 53-4.

DeLURY, J.S. (1917) Molydenite at Falcon Lake, Manitoba. Can. Min. Jour. V. 38 pp.460-462.

DeLURY, J.S. (1919) Some Economic Aspects of the Falcon Lake District, Manitoba. Trans. Can. Inst. Min. and Met. V.22, pp. 300-328.

DEMOREST, P.W. (1938) Ice Flowage as Resolved by Glacial Striae. J. Geol. V 46, pp. 700-725.

DEMOREST, Max (1942) Glacier Regimens and ice movements within glaciers. Am. J. Sci. V.240, pp. 31-66.

DEMOREST, Max (1943) Ice Sheets. Geol. Soc. Am. Bull. V. 54, pp. 363-400.

DREIMANIS A. (1953) Studies of Friction Cracks along shores of Cirrus Lake and Kasakokwog Lake, Ontario. Am. Jour. Sci. V. 251, pp. 769-783.

ELSON, J.A. (1957) Lake Agassiz and Mankato-Valder Problem Science V. 126, pp. 999-1002.

ELSON, J.A. (1961) Soils of Lake Agassiz (In Soils of Canada edited by R.F. Leggett, pp. 51-79). Royal Society of Canada, Special Publication 3, Ottawa.

ELSON, J.A. (1967) Geology of Glacial Lake Agassiz in Life Land and Water edited by W.J. Mayer-Oakes, University of Manitoba Press, p. 155-185.

FLINN, D. (1958) On Tests of Significance of Preferred Orientation in Three Dimensional Fabric Analysis. J. Geol. V. 66, pp. 526-53.

FLINT, F.F. (1929) The stagnation of Dissipation of the Last Ice Sheet. Geog. Rev. V.19, pp. 256-289.

FLINT, F.F. (1943) Growth of the North America Ice Sheet during Wisconsin Age. Bull. Geol. Soc. Am. V. 54, No. 3, p. 325-362.

FLINT, R.F. (1957) Glacial and Pleistocene Geology, New York, Wiley and Sons Inc.

GLEN, J.W. DONNER, J.J., & WEST, R.G. (1957) On the Mechanism by which stones in Till become oriented. Am. Journ. Sci. V. 255, p. 194-205.

GROVENOR, C.P. & MENELEY, W.A. (1958) Glacial Flutings in Central and Northern Alberta. Am. Jour. Sci. V.256 No. 2, pp. 715-728.

HARRIS, S.E. Jr. (1943) Friction cracks and the direction of glacial movement. Am. Journ. Sci. V.51, pp. 244-258.

HARRISON, P.W. (1957) A clay Till Fabric: Its Character and Origin. J. of Geol. V.65, pp. 275-307.

HILLS, E.S. (1963) Elements of Structural Geology, Methuen & Co. Ltd., London.

HOLMS, C.D. (1941) Till Fabric. Bull. Geol. Soc. Am. V. 52, p. 1299-1354.

HOLMS, C.D. (1960) Evolution of Till Stone Shapes. Bull. Geol. Soc. Am. pp. 1645-1660.

HOPPE, G. & SCHYTT, V. (1953) Some observations of fluted monaine surfaces. Geografiska Annaler. V. 35, pp.105-115.

JOHNS, R.J. (1943) Sheet structure in granites, its origin and use as a measure of glacial erosion in New England: Journ. Geol. V. 51, pp. 71-98.

JOHNSTON, W.A. (1916) The Genesis of Lake Agassiz, a confirmation. Jour. Geol. V. 24, No. 7, pp. 625-638.

JOHNSTON, W.A. (1921) Winnipegosis and Upper Whitemouth
River Areas, Manitoba, Pleistocene and Recent
Deposits. Geol. Sur. of Canada, Mem. 128, Ottawa.

JOHNSTON, W.A. (1935) Western Extension of Patrician
Glaciation. Pan-Am. Geol. V.63, pp. 13-18.

JOHNSTON, W.A. (1946) Glacial Lake Agassiz with special
reference to the mode of Deformation of the Beaches.
Canada Geol. Sur. Bull. No. 7.

KALLIOKOSKI, J. (1952) Weldon Bay Map Area, Manitoba.
Can. Geol. Surv. Mem. 270.

KARLSTRON, T.N.V. (1952) Improved Equipment and Techniques
for Orientation Studies of Large Particles in
Sediments. J. of Geol. V.60, pp. 489-493.

KRUMBEIN, W.C. (1939) Preferred Orientation of Pebbles in
Sedimentary Deposits, J. Geol. V. 47, pp. 673-766.

KRUMBEIN, W.C. (1941) Measurement and Geological signifi-
cance of shape and roundness of sedimentary deposits.
J. of Sed. Petrology No. 1.11 pp. 67-72.

LAIRD, Wilson M. (1964) The Problem of Lake Agassiz, Pro-
ceedings of the North Dakota Academy of Science,
V. XVIV, pp. 114-134.

LEIGHTON, M.M. (1958) Important elements in the classifi-
cation of the Wisconsin Glacial Stage. Jour. Geol.
V. 66, No. 3, pp. 288-309.

LEIGHTON, M.M. (1960) The Classification of the Wisconsin
Glacial stage of the North Central United States.
Jour. Geol. V. 68, No. 5, pp. 529-552.

LEMKE, R.W. (1958) Narrow Linear Drumlins near Velve,
North Dakota. Am. J. Sci. V. 256, pp. 270-283.

LEUDER, D.R. (1959) Aerial Photographic Interpretation,
McGraw Hill New York.

LORD, G.S. (1942) Snare River and Ingray Lake Map Areas,
North-west Territories. Can. Geol. Sur. Mem. 235.

MacGREGOR, D.R. (1957) Some observations on the Geographical Significance of Slope. Geog. 45, pp. 167-173.

MARSHALL, J.R. (1918) Star Lake Area, Manitoba. Geol. Surv. Canada, Sum. Rept. 1917, pt. D, pp. 21-22.

McGLYAN, J.C. (1959) Elbow Heming Lakes Area, Manitoba. Can. Geol. Sur. Mem. 305.

PRICE, N.J. (1959) Mechanics of Jointings in Rocks. Geol. Magazine, V. 96, pp. 149-167.

RAY, R.G. (1960) Aerial Photographs in Geologic Interpretation and Mapping. U.S. Geol. Sur. Prof. Paper No. 373.

RODGERS, J. (1952) Use of Equal Area or other projections in the statistical treatment of joints. Bull. Geol. Soc. Am. V. 63, pp. 427-429.

SAVIGEAR, R.A.G. (1965) A Technique of Morphological Mapping. Ann. Am. sso. Geog. V. 55, pp. 514-538.

SMITH, H.T.U. (1948) Giant Glacial Grooves in Northwest Canada. Am. Jour. Sci. V.246, pp. 503-514.

SPRINGER, G.D. (1952) Geology of the Rennie-West Hawk Lake Area, Manitoba. Manitoba Dept. of Mines & Natural Resources, Mines Branch, Publication 50-6.

STOCKWELL, C.H. (in Wright, J.F.) (1938) Geology and Mineral Deposits of a part of Southeastern Manitoba, Geol. Surv. Canada, Mem. 169.

SUMMEREON, C.H. (1954) A Philosophy of Photo-Interpretation Photogram. Engin. V. 20, pp. 369-397.

THWAITES, F.T. (1963) Outline of Glacial Geology. Lithographed by Edwards Brothers, Inc. An Arbor, Michigan.

TYRRELL, J.B. (1896) The Genesis of Lake Agassiz. J. of Geol. V. 4, pp. 811-815.

UPHAM, Warren (1895) The Glacial Lake Agassiz. U.S. Geol. Sur. Mono. No. 5, Washington.

VON ENGELN, O.D. (1938) Glacial Geomorphology and Glacial Erosion. Am. Jour. Sci. V. 35, pp. 426-440.

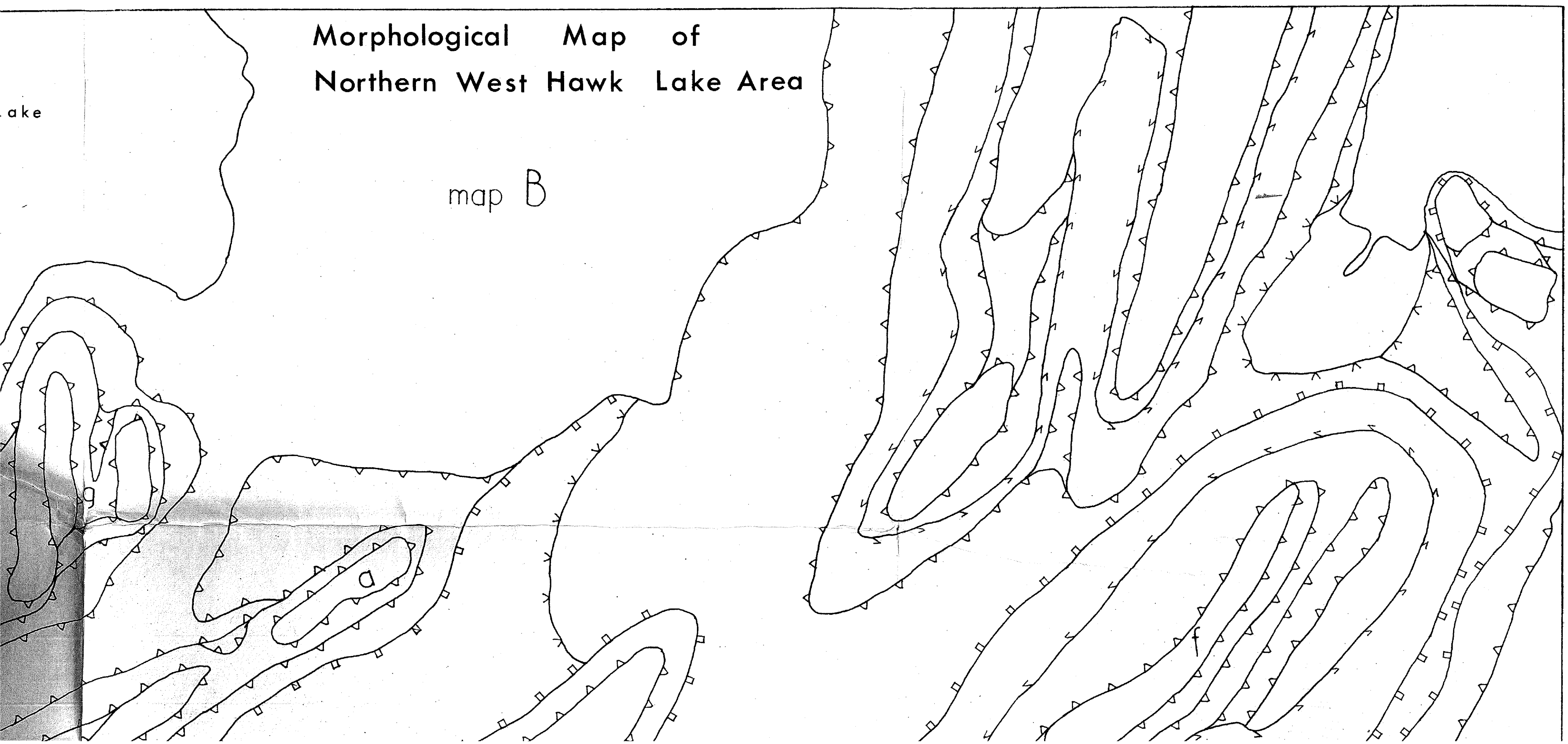
WARDLAW, R.C., STAUFFER, M.R., & HOQUE, M. (1969) Striations, giant grooves, and superimposed drag folds, Interlake area, Manitoba. Can. Jour. Earth Sci. V. 6, p.577-593.

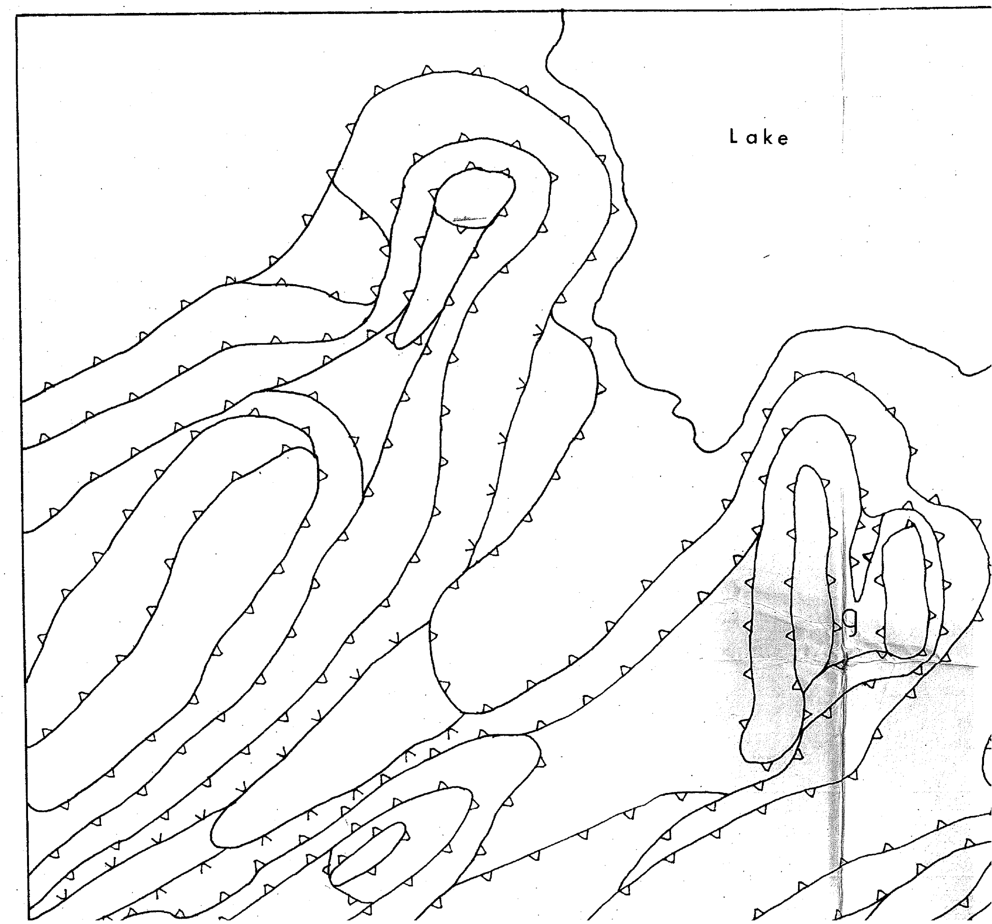
WATERS, R.S. (1958) Morphological Mapping. Geog. 43, pp.10-17.

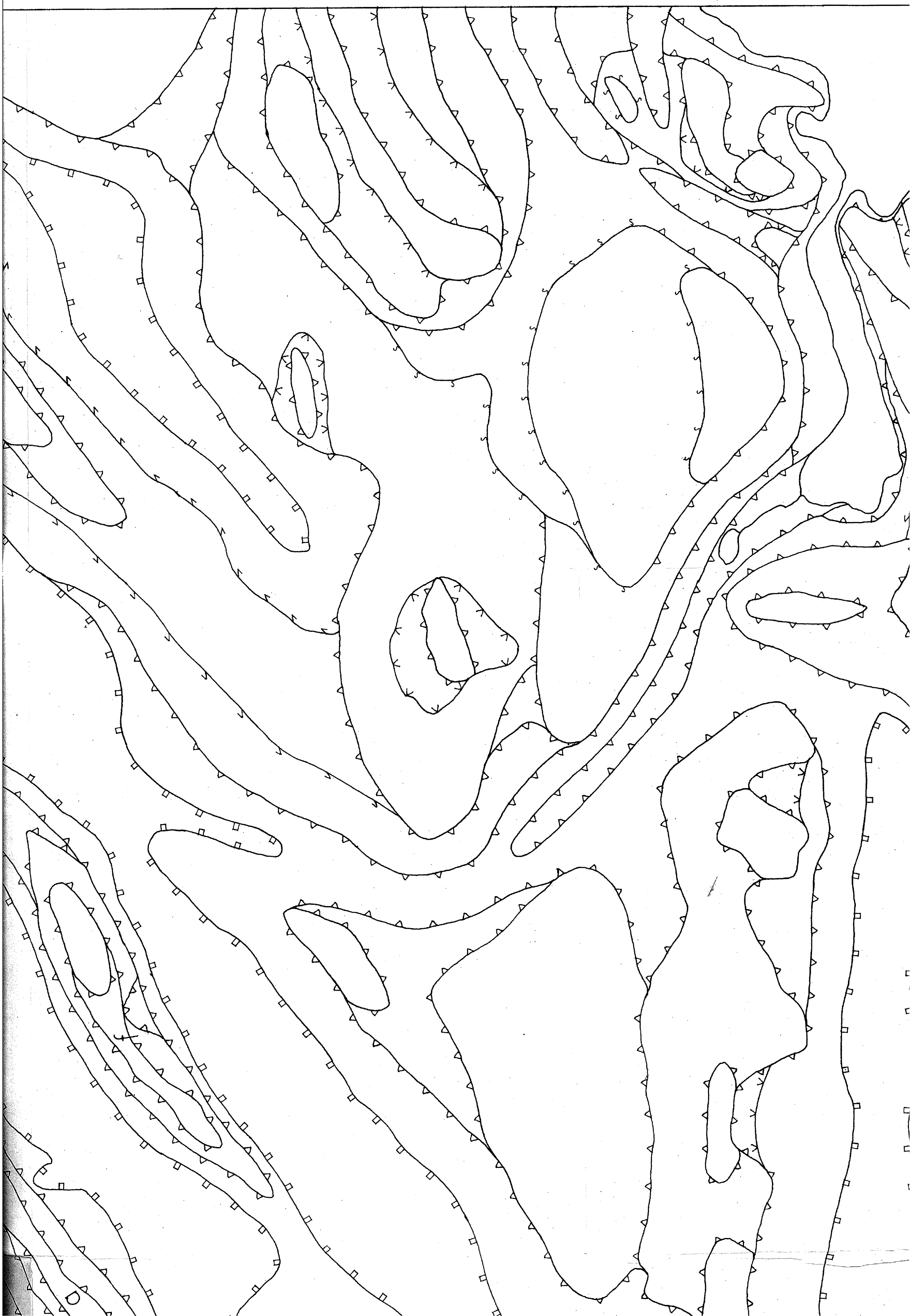
ZOLTAI, S.C. (1961) Glacial History of part of N.W. Ontario. Prec. Geol. Assoc. Can. 13, pp. 61-83.

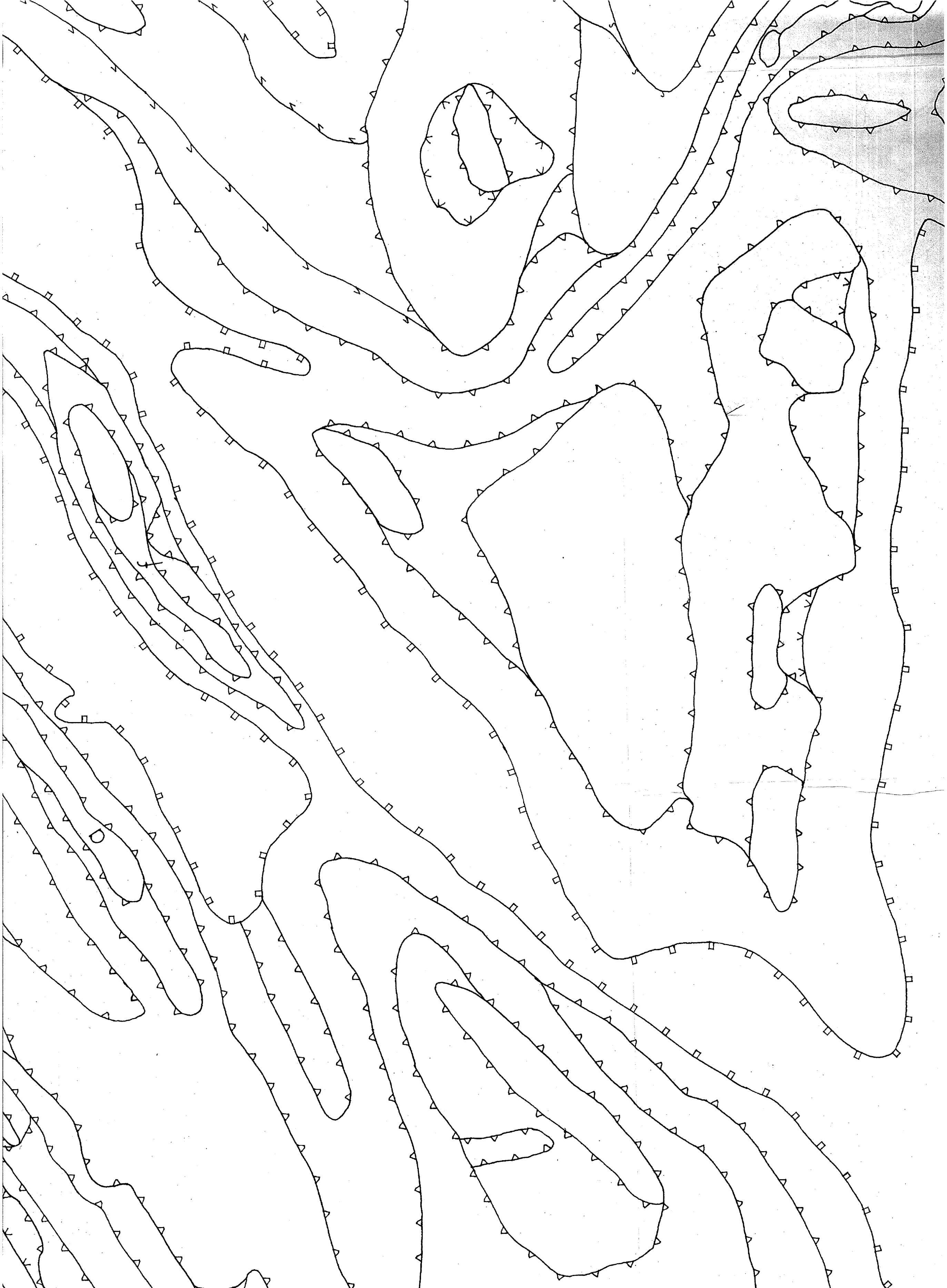
ZOLTAI, S.C. (1963) Glacial Features of the Canadian Lakehead Area. Canadian Geographer 107, No. 3, pp. 101-115.

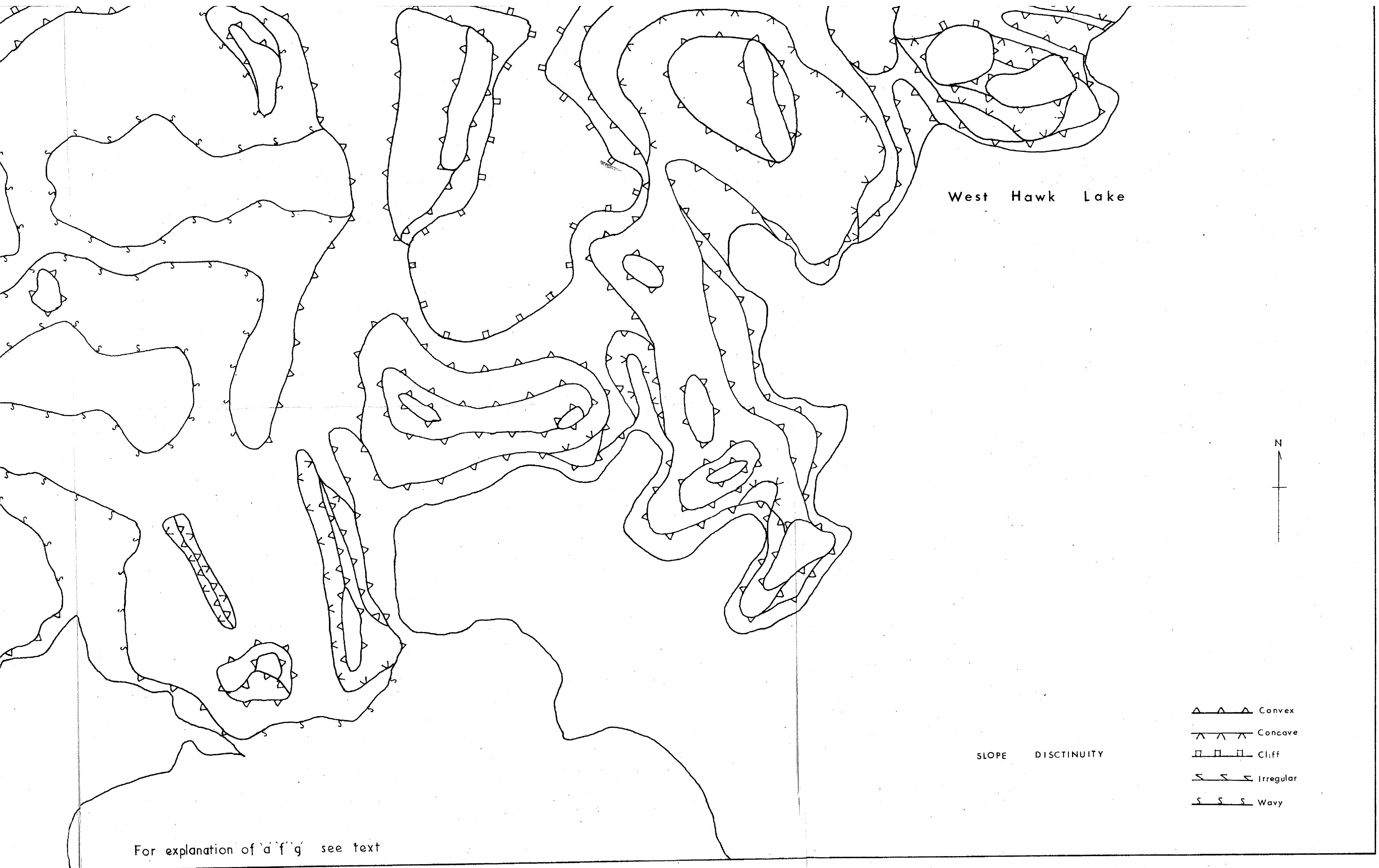
ZOLTAI, S.C. (1965) Glacial Features of the Quetico-Nipogon Area, Ontario. Can. Jour. of Earth Sciences, V. 2, pp. 24-269.


Morphological Map of
Northern West Hawk Lake Area
map B
ake
a
g
f

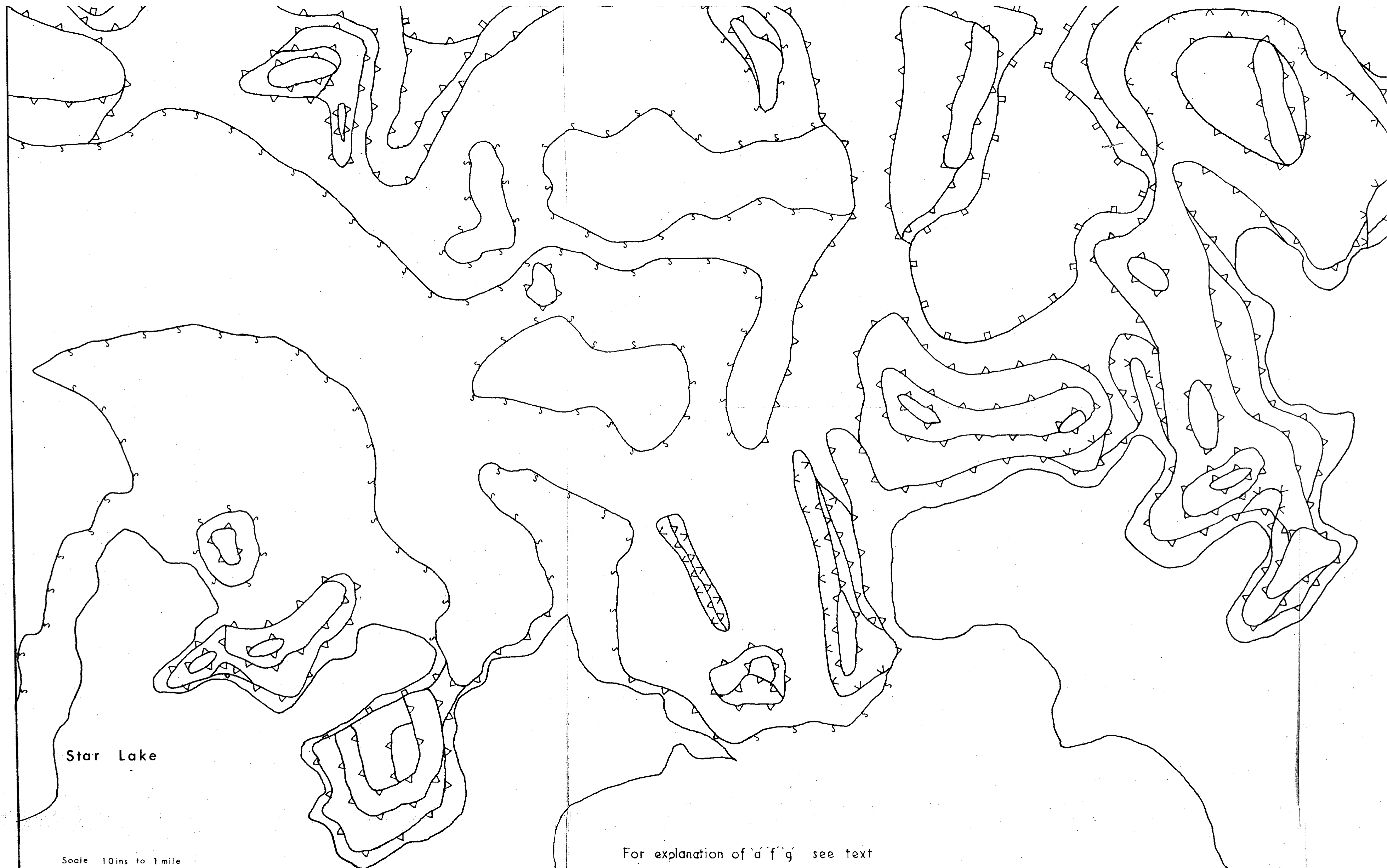

Lake

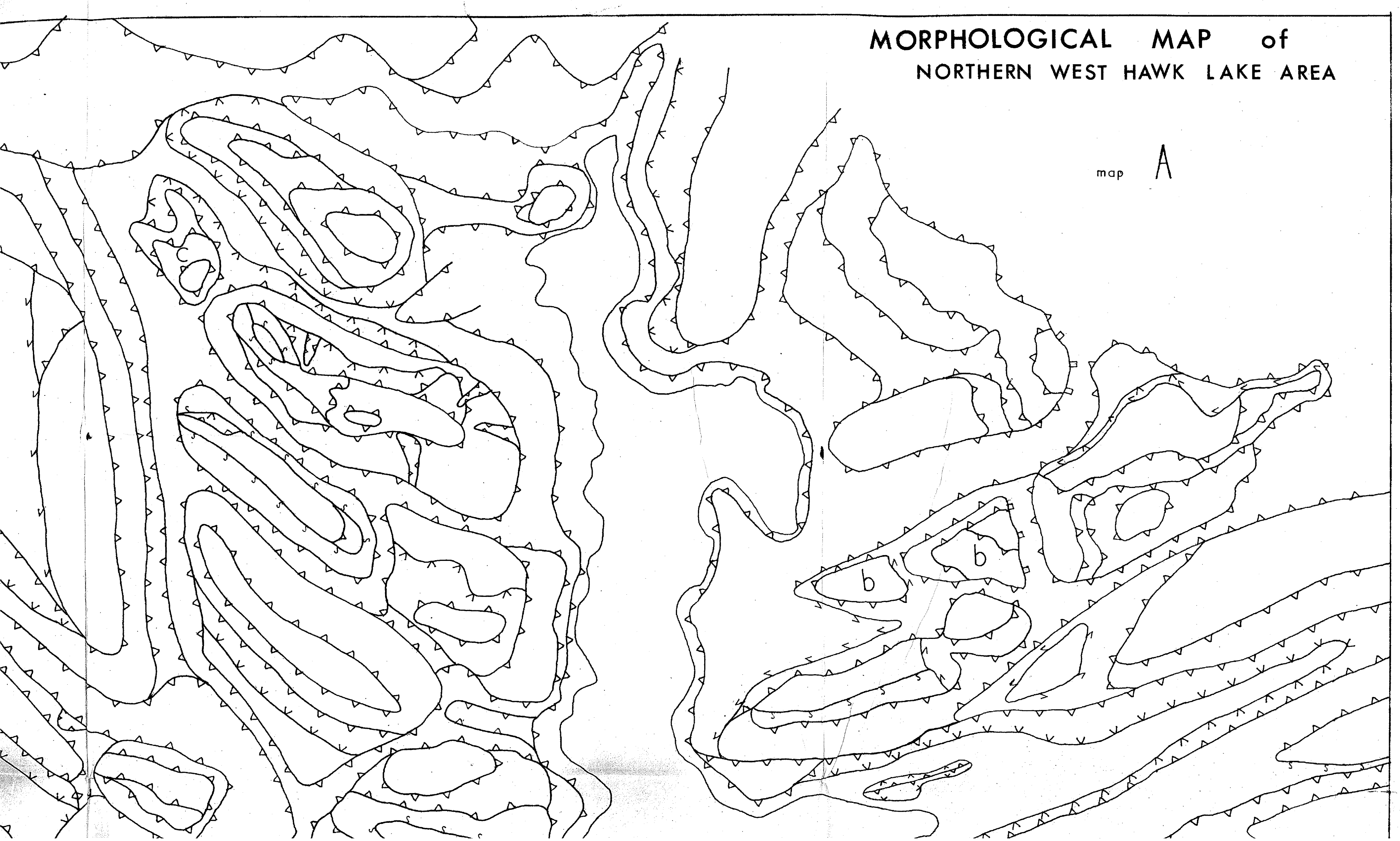


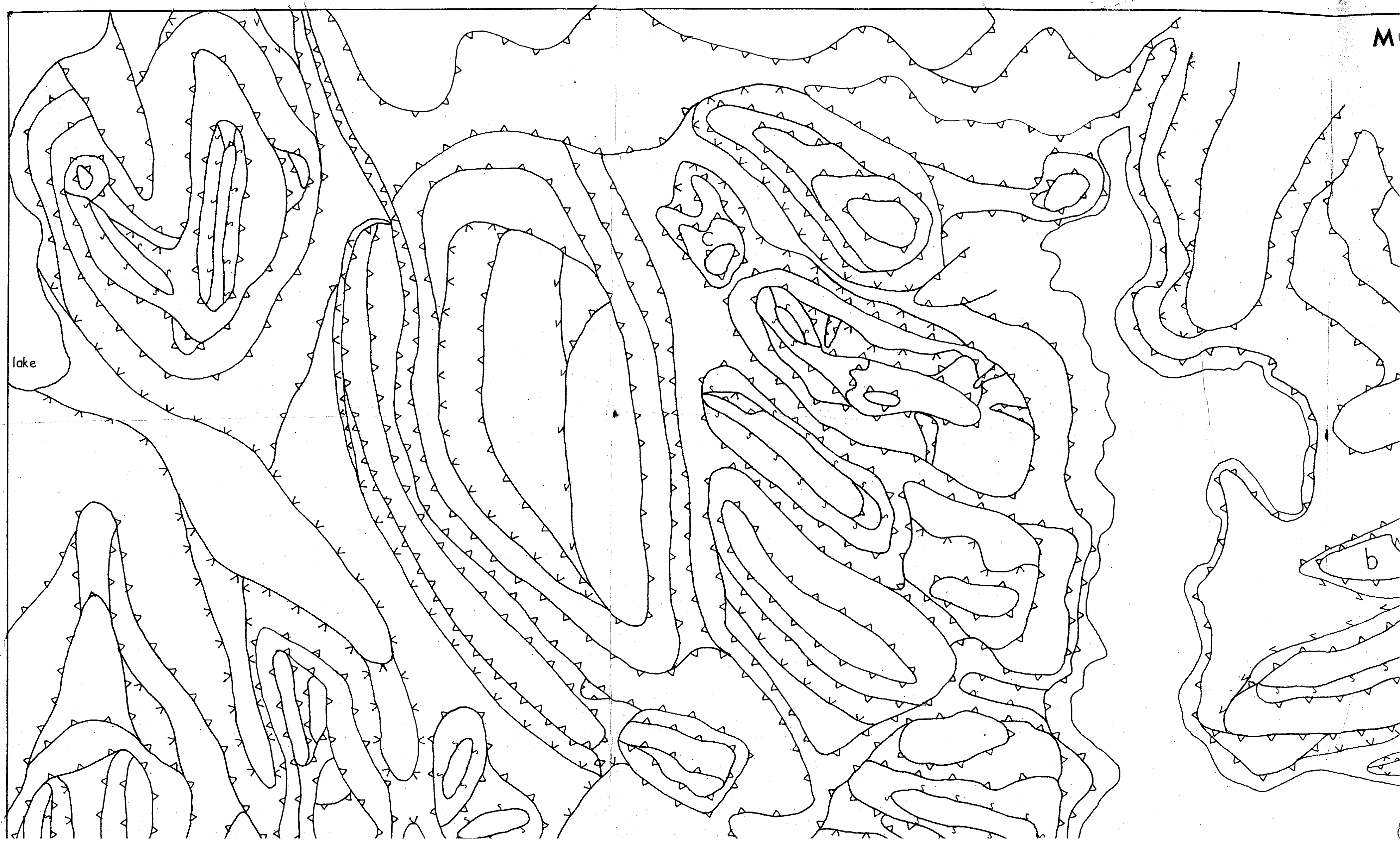




West Hawk Lake
N
SLOPE DISCTINUITY
Convex
Concave
Cliff
Irregular
Wavy
For explanation of 'a' 'f' 'g' see text

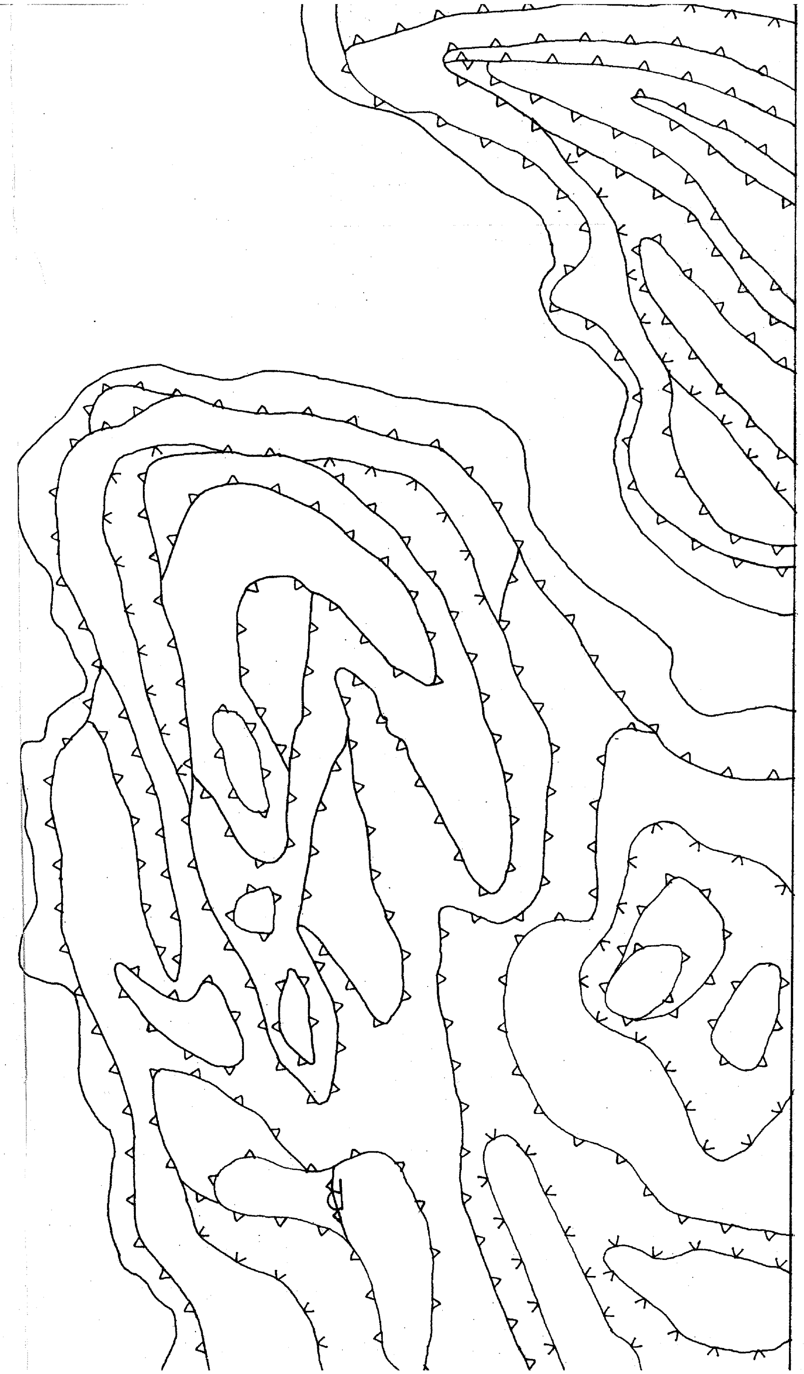

Star Lake
Scale 10ins to 1 mile
For explanation of 'a' 'f' 'g' see text

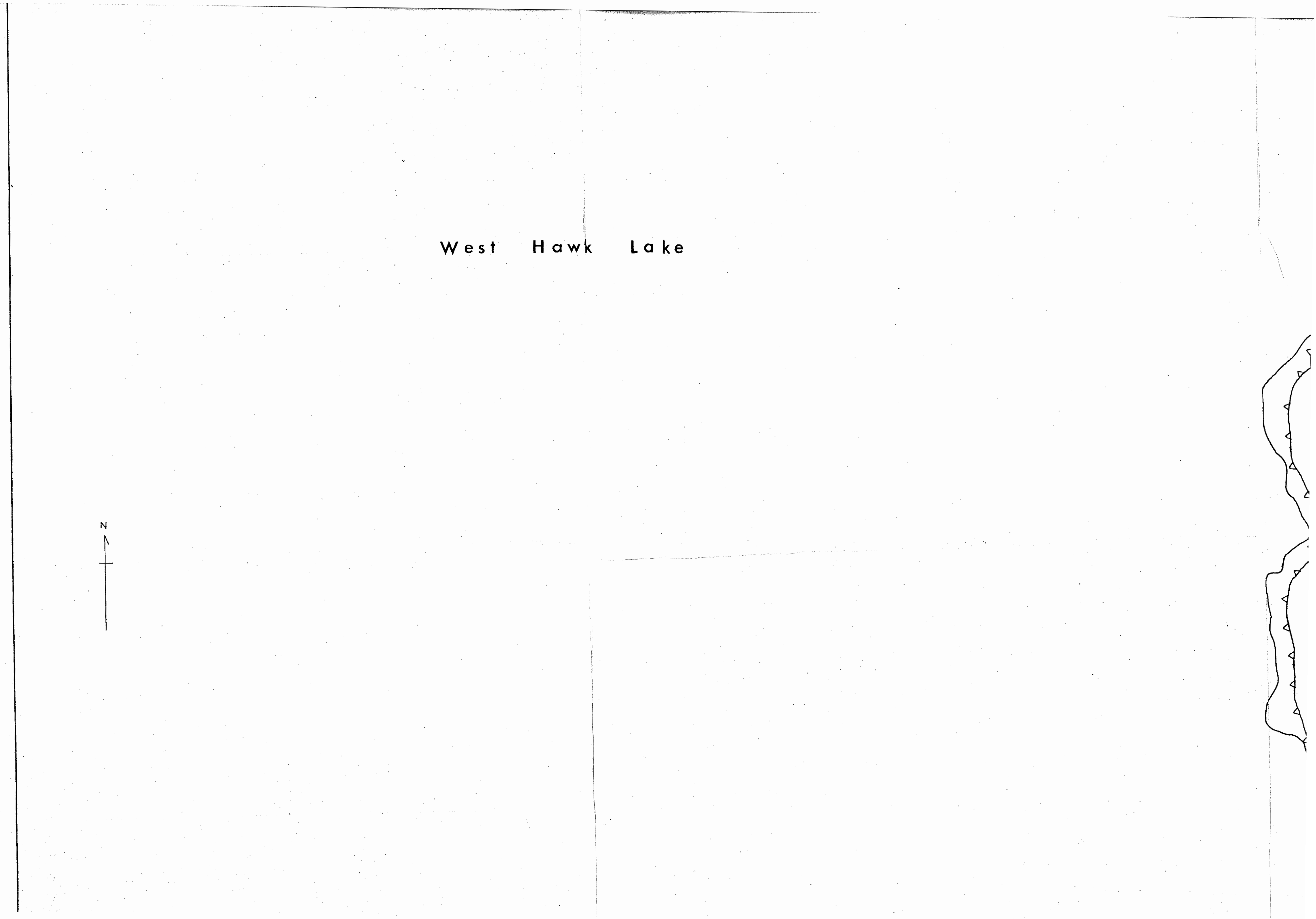

MORPHOLOGICAL MAP of
NORTHERN WEST HAWK LAKE AREA
map A
b
b
c


lake
c
b

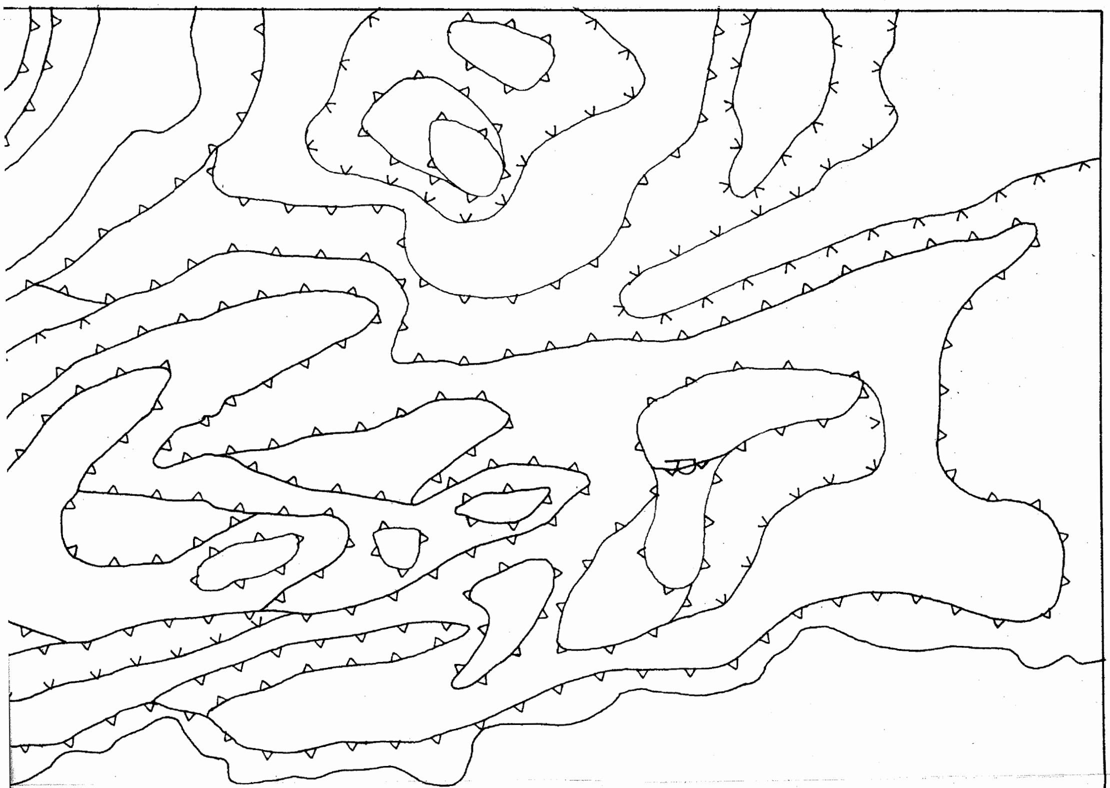

lake

Hawk Lake

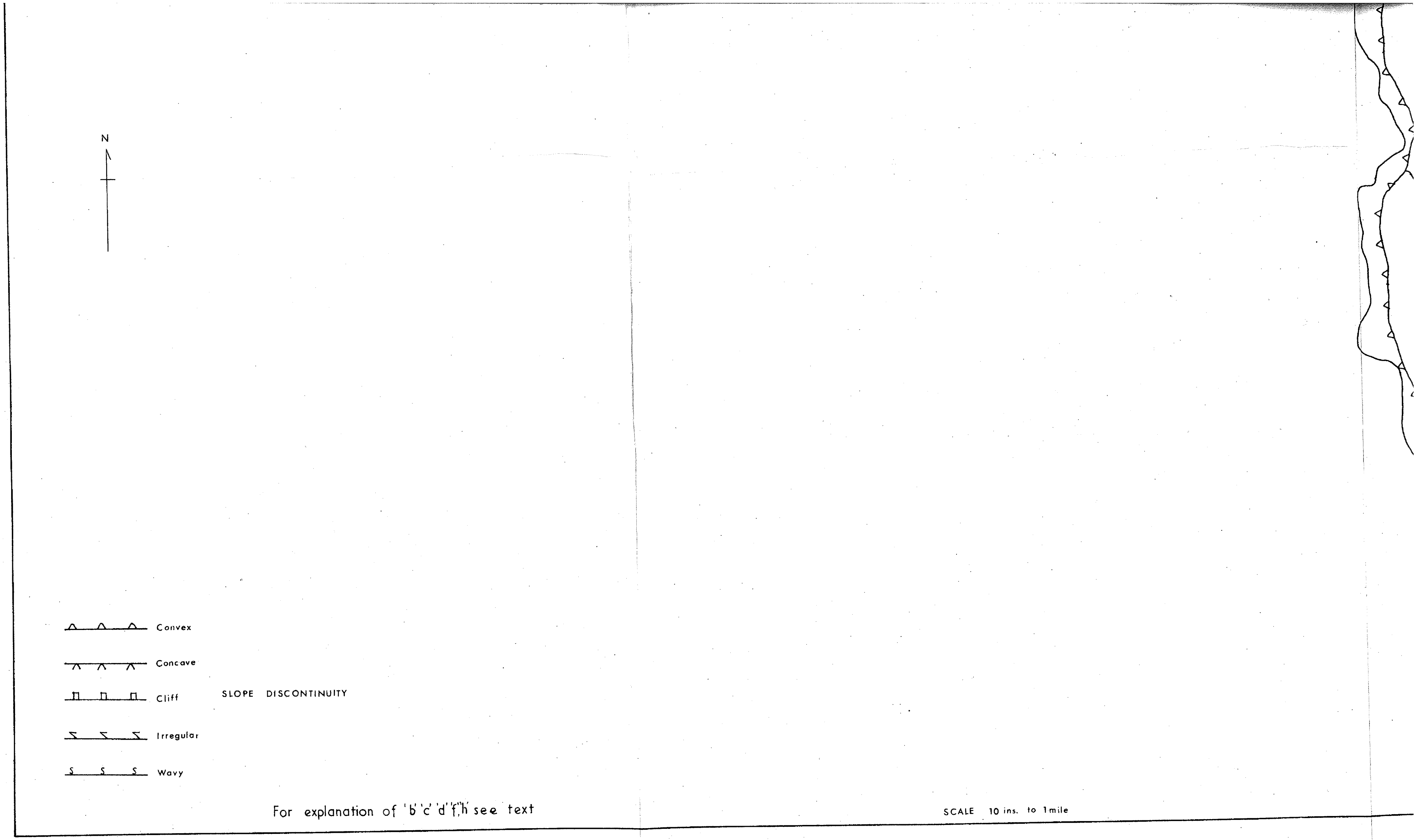




West Hawk Lake
N



SCALE 10 ins. to 1 mile


N
Convex
Concave
Cliff
Irregular
Wavy
SLOPE DISCONTINUITY
For explanation of 'b' 'c' 'd' 'f', 'h' see text
SCALE 10 ins. to 1 mile