THE GEOLOGY OF THE ARKOSE LAKE AREA, NORTH OF SEAL LAKE, LABRADOR, CANADA

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THE GEOLOGY OF THE ARKOSE LAKE AREA,
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ABSTRACT

The Proterozoic sediments of the Seal Lake Group in the Arkose Lake area are here subdivided into the Arkose Lake Formation and the Majoque Lake Formation.

The Arkose Lake Formation is subdivided into a Lower Member of coarse sandstones and grits and subsidiary conglomerates and an Upper Member of fine to coarse red sandstones with subsidiary conglomerates and red siltstones. Field, petrographic and statistical evaluation indicate deposition, by braided streams upon an alluvial fan, of immature, fluviatile sediments derived from a gneissose and granitic terrane to the north of the present area.

The Majoque Lake Formation consists predominantly of subaerial basaltic flows with some thin sediment bands. Thin, weathered basalt profiles separate the sediments from the underlying basalts. Mineralogically and chemically, the basalts are transitional between alkali and tholeiite basalts. The sediments are composed predominantly of conglomerate, grit and sandstone with local, fine,pink quartzites. Field, petrographic and statistical data suggests that they represent coarse, immature, gravel and sand deposited under semi-arid conditions on a braided outwash plain that periodically covered a volcanic 'pediment'. They were derived from a gneissic-granitic and in part acid-volcanic terrane to the north.

The area has been deformed by one major phase of compression probably associated with the Grenville orogeny. This produced northward facing, major folds and thrust faults which trend east - west. The stratigraphy within

the Arkose Lake area is significantly affected by these structures and suggests that the northern limb of the Seal Lake Basin is more complex than previous studies suggested. As a result, the stratigraphy of the Seal Lake Basin may be significantly different from that set up by Brummer and Mann (1961) and the thickness of the Seal Lake Group may be markedly less than the 42,000' suggested by the above authors.

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CHAPTER I

INTRODUCTION

The Seal Lake Basin, a basin of Precambrian sediments and volcanics overlying older crystalline basement, has seen because of its economic potential, considerable mineral exploratory activity for several decades.

The present study of the Arkose Lake area, a part of the Seal Lake Basin was undertaken as a further part of this exploratory programme.

A. Location of Area

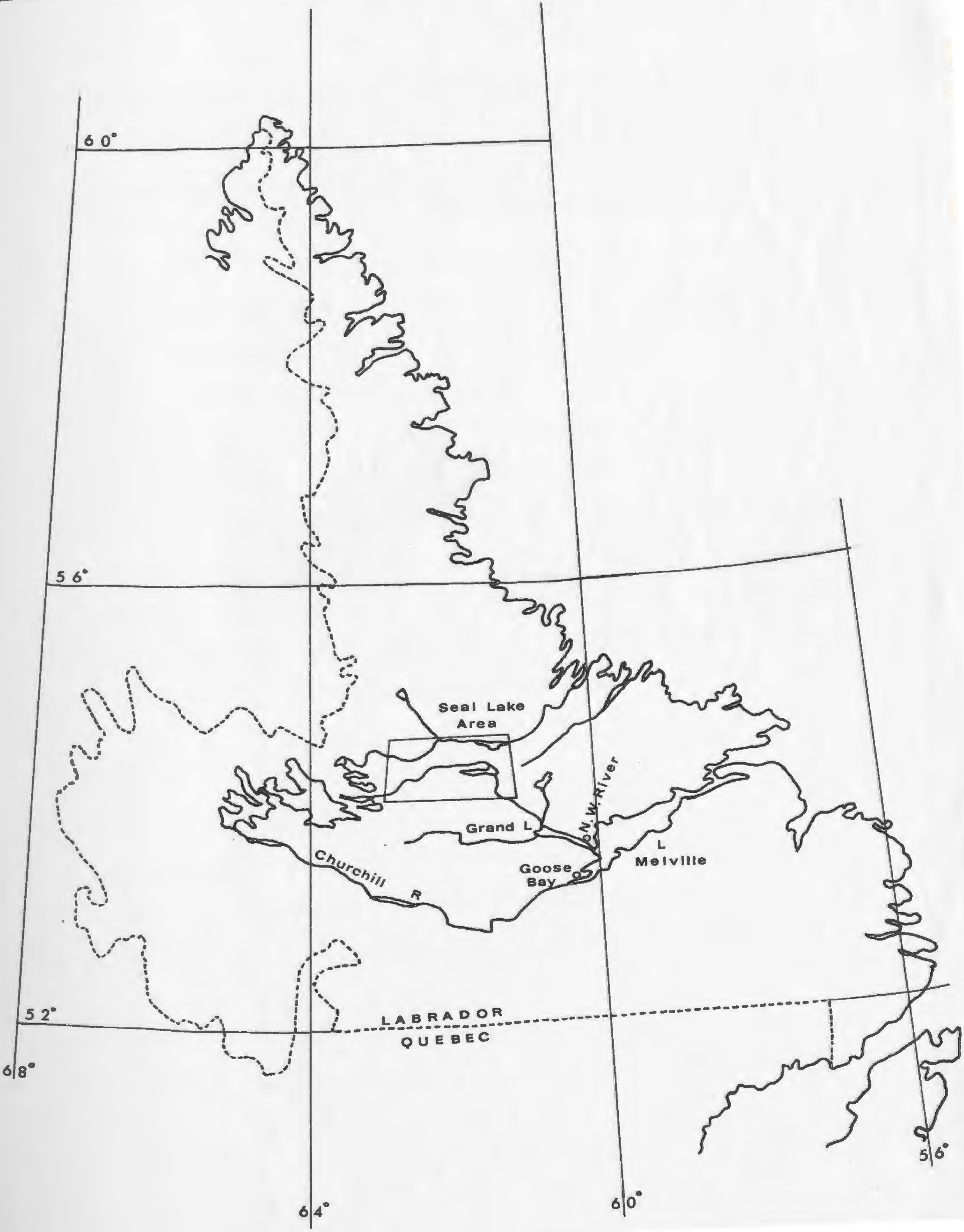
The Seal Lake area is situated about a hundred miles north-west of the populated centres of Goose Bay, at the head of Lake Melville, and North-West River at the exit of Grand Lake into Lake Melville (fig. 1). The area is reasonably accessible and in the past was reached after one weeks canoeing up the Naskaupi River which flows into Grand Lake. In comparison, the area can now be reached within an hour from North-West River by float plane.

The Seal Lake Basin was geologically defined by Mann (1959) and is some fifty miles long by twenty-two miles wide (Brummer, 1957). The Arkose Lake area is located in the northern part of the basin (fig. II). It is about twenty miles north of Seal Lake and lies just south of the Canairiktok River which forms the northern limit of the basin.

B. Area Mapped and Nature of Field Operations

An area some eleven miles long by four miles wide was mapped west from the location of the east end of Arkose Lake to longitude $62^{\circ}\ 00'$W.

Fig. I. Location of the Seal Lake Area, Labrador



It is bounded on the north by the Canairiktok River and extends south approximately to latitude 54° 30'N.

The mapping was undertaken using compiled air photo mosaics (sheet 13K/ 12SW) of approximate scale 1:24,000, as supplied by the Canada Department of Energy, Mines and Resources. One mile to the inch aerial photographs were also used to aid field work and geological interpretation. A topographic map of four miles to the inch was only useful to show relative, broad relief.

Field work covered a period of three months from mid-June to mid-September, 1970, and complete logistical support was provided by the Labrador division of the British Newfoundland Exploration Company Limited (Brinex). Field work was undertaken by foot traverse from several fly-camps scattered throughout the area although some use of a helicopter was made in areas where the bush was very dense and outcrop hard to locate as on the southern slopes of the Canairiktok River valley.

C. Physiography of the Area

The topography of the Seal Lake basin is dominated by an alternating series of ridges and lake-filled valleys which trend east-west. This trend is controlled by the strike of the underlying rocks. The area is drained by two large rivers, the Canairiktok in the north and the Naskaupi in the central part of the basin (fig. II). The highest elevations are Santa Claus Mountain and Mt. Pisa, both

Fig. II. Locality Map - Seal Lake Area.

2000' above sea level. Seal Lake is the longest stretch of standing water and is nearly twenty-four miles long and in places up to one or two miles wide.

The area of Arkose Lake itself has the characteristic east-west ridge-valley topography seen elsewhere in the Seal Lake basin. Ridges capped by brown weathering, relatively hard, volcanic rock overlook swampy and densely vegetated valleys. The valleys are eroded into softer sediments or along thrust faults both of which strike east-west. The valleys usually contain lakes which are invariably very long in comparison to their width. The longest lake within the actual map area (named by the author Club Lake because of its shape) is two and three-quarter miles long and at its widest point, half a mile wide. Arkose Lake is two miles long and half a mile wide. Part of the southern limit of the area mapped lies along the irregular and indented, northern shore of a lake which is some four miles in length.

Relative relief between valley bottom and ridge summit is of the order of 500' when developed to its maximum as in the case of the basalt ridge south of and overlooking Arkose Lake. This ridge forms the highest point in the area reaching a height of 390 meters (1300' O.D.). The tops of the ridges average between 330 to 390 meters O.D. suggesting that they represent the erosional remnants of an earlier peneplain (Brummer & Mann, 1961).

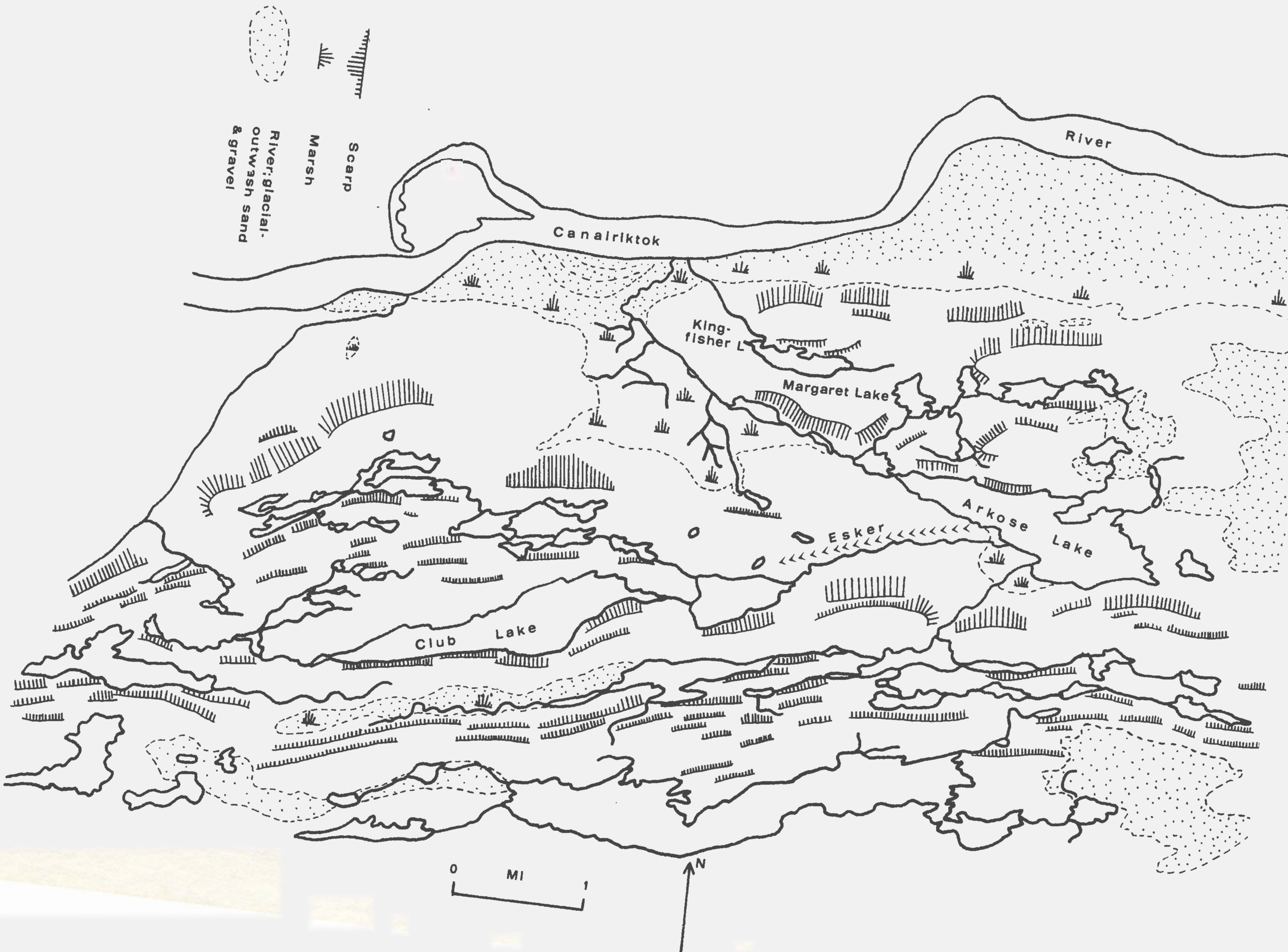
The ridges have northward facing cliff scarps which are generally bare rock (plate I), sometimes over-hanging and thus inaccessible. In other instances, the cliffs are made up of a series of vegetated, step-like ledges. Scree composed of angular blocks of basalt and sediment, blankets the base of the cliffs and infills the edges of lakes. Depending upon their age, the screes may or may not be wooded.

The summits of the ridges pass gradually into gently dipping southern slopes. The angle of the slope may be less than or correspond approximately with the inclination of the underlying rocks.

The system of lakes of the southern and central part of map area is drained by rivers and streams which flow east to east-north-east into the valley of Arkose Lake (fig. III). The lakes to the north of Arkose Lake drain south-west into the Arkose Lake valley. Arkose Lake drains north-westwards into the broad valley of the Canairiktok River which flows eastward to the Atlantic Ocean. The western boundary of the area follows a river which flows north-east into the Canairiktok.

This drainage system is immature and illustrates a trellis drainage pattern. The pattern is superimposed upon a ridge-valley system left after the eastward passage of a Pleistocene continental ice sheet through the area (Brummer and Mann, 1961). Smooth, polished and striated outcrops both in valleys and especially on ridge tops, glacial outwash sands and a gravel-sand esker running from Arkose Lake, west-south-west towards Club Lake (fig. III) provide evidence of the glaciation. Mann (1959) and Brummer and Mann (1961) suggest that the

... Physiographic Features in the Arkose Lake Area



Pleistocene glaciation modified an earlier, late Tertiary drainage system which had eroded into the softer metasediments of an older peneplain.

Recent water erosion has not noticeably modified the effects of the glaciation. With post-glacial uplift, out-wash sands have been dissected but the bed rock is essentially untouched except for the development of screes at the base of cliffs. Only in the broad Canairiktok Valley has the valley profile been greatly altered by:

a) scree formation on the valley sides,

b) deposition of extensive river sands by the meandering river on the floor of the valley.

The valley of the Canairiktok is densely forested as are the gentle slopes of the ridges. The bare or sometimes shrub covered tops of the ridges grade into spruce forest with dense shrub undergrowth. Tree density increases downslope although undergrowth may disappear. The valley floors, however, especially in the vicinity of lakes and water courses are again heavily shrub covered and forested. Such dense vegetation makes traversing extremely difficult and also obscures outcrop which is very scattered and often absent on the southern slopes of ridges and in some of the valleys. Outcrop overall is less than ten percent of the total area and major exposures are restricted to cliff faces and ridge tops.

The main trees present in the forest are: spruce, fir, birch, poplar and rowan, whilst the undergrowth is an entangled, near impenetrable network of alder and willow. Where the forest is absent or has been reduced by fire, mosses, lichen and ground shrubs such as blueberry, blackberry and partridgeberry are abundant. Bakeapple, squashberry, crowberry and a variety of ferns, grasses, flowers and other fruits supplement the flora. The fauna is sparse with beaver and red squirrel, common but only occasional black bear, caribou, porcupine, moose, otter and hare, was seen. About twenty varieties of birds were recognised. The more common varieties include canvas-black ducks, sprucegrouse, solitary sandpipers, black and brown-capped chickadees, veery thrush, myrtle warblers, pine grosbeaks, slate-coloured juncos, Canada jays and American rough-legged hawks. Insects were abundant with several species of butterfly and dragonfly. In the damper areas, blood sucking flies abound - they include mosquitoes, black flies and timber flies.

The climate of the area during the months worked was favourable. Days were generally sunny and warm with temperatures ranging from 50^0 F. to 80^0 F. in mid-July. However, in late August and at night, temperatures often fell to near freezing. Rain was common as either prolonged storms or as unexpected mid-day showers, both of which served to interrupt field work, in the former case, often for some days. In August and September, field work was also hampered by thick fog which would usually ascend into the area along the main river valleys and become trapped in the valley bottoms. At other times, the fog was several hundred feet thick and it hindered field work by grounding the helicopter and preventing location of outcrops.

CHAPTER II

GEOLOGICAL SETTING OF THE SEAL LAKE BASIN

A. History of Previous Research

Although the Seal Lake Basin has been investigated geologically for the last twenty years, most of the work has been concentrated in the vicinity of Seal Lake itself by virtue of the possible presence of economic copper deposits. This is in contrast to the minor investigations in the northern part of the basin which contains Arkose Lake.

The copper deposits of the Seal Lake area were investigated in the early fifties by Frobisher Exploration Ltd. (Evans, 1952) and Kennco Exploration Ltd. (Brummer, 1957) and more recently by BRINEX (Kidd, 1968). As a result of the work of the Frobisher and Kennco Companies, Mann (1959) produced a regional compilation of the geology of the Seal Lake region (see also Brummer and Mann, 1961).

Mann's map (1959) and those produced by the Geological Survey of Canada (Fahrig, 1952 and Roscoe, unpublished) are the only maps which present a regional picture of the geology of the Seal Lake Basin and the surrounding rocks but they give only a broad outline of the geology of the Seal Lake Basin. Recently, however, Baragar (1969) investigated the volcanics and sediments of part of the area near Snegamook Lake in the north-east and Stout Lake in the north-west (fig. II). The discovery of high radiation counts in the sediments of the former area attracted industrial interest in this area (Spriggs, 1969). As a result of this interest the present study was undertaken with the support of BRINEX.

B. General Geology

The rocks of the Seal Lake Basin form a succession of Proterozoic sediments and volcanics and their low grade metamorphic equivalents. The rocks which are all part of the Seal Lake Group (Brummer and Mann, 1961) overlie both unconformably and structurally older crystalline basement or older Proterozoic metasediments and volcanics (fig. IV).

The Seal Lake Group is composed predominantly of clastic sediments and basic volcanics intruded by a large number of diabase and gabbro sills. Minor occurrences of carbonates are also known. The work of the Frobisher and Kennco Exploration companies led to the stratigraphic subdivision of the group as in figure V. Brummer and Mann (1961) gave a thickness of 42,000' (12,600 m.) for the group whilst more recently Baragar (1969) has estimated a total thickness of 21,000' (6,300 m.). The reduction in thickness was based upon recognition by Baragar of major thrust faulting in the area.

The basin is folded into a broad, canoe-shaped syncline with the southern limb of the syncline overturned to the north. Mann (1959) shows that it is possible to trace the formations around the syncline. As a result, he correlated the basal Bessie Lake Formation of the southern limb of the syncline with the Majogue Lake Formation which forms the basal

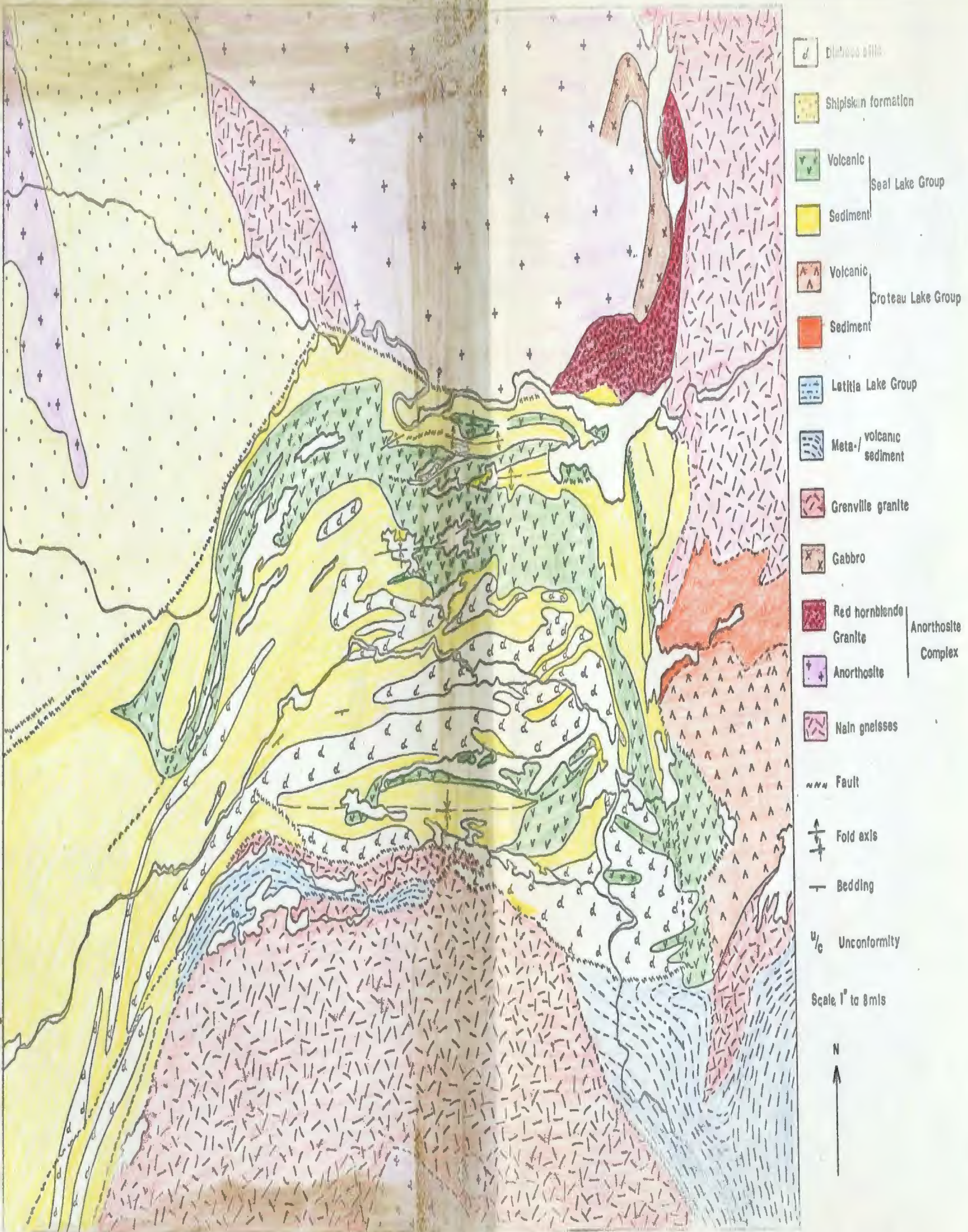


Fig.IV. Geological map of the Seal Lake area (modified from [illegible] 1959, & Brummer & Mann 1961)

FIGURE V - Stratigraphic Subdivisions of the Seal Lake Group

Lithologies (After Brummer & Mann, 1961)	Brummer & Mann (1961)	Baragar (1969)	Hale (1968 & Kidd (1968) Compiled by author		This Work
Mainly red quartzite; argillaceous at base and some conglomerate	Upper Red Quartzite Formation, 2600' (780m)	Upper Red Quartzite Formation, 1,500' (450m)	Upper Red Quartzite Formation		
Greenish-grey, black, red to purple slates and shale; Pink and white quartzites and argillaceous quartzite.	Adeline Island Formation, 1400' (420m)	Adeline Island and Salmon Lake Formations 4500' (1350m)	Salmon Lake Formation 1900' (570m)	Adeline Island Formation 600' (130m) to 800' (240m)	
Interbedded red and maroon, purple shales and gray-green and green shale; amygdaloidal basalt and diabase sills	Salmon Lake Formation, 3000' (900m)				
Red shale; grey-green slates and phyllites; red silty argillites and minor red quartzites	Whisky Lake Formation, 3000' (900m)	Wuchusk Lake Formation 7000' (2100m) (Closely spaced sills with minor fine sediments)	Wuchusk Lake Formation	Whisky Lake Formation	
Interbedded chert, variegated shales, phyllites, hornfels, argillites, fine quartzites thin limestones; intruded by thick diabase, metadiabase and gabbro sills	Wuchusk Lake Formation, 20,000' (6000m)	Wuchusk Lake Formation 2500' (750m) (Closely spaced sills with red quartzites, arkoses and some black shales			
Blue, white and pink, clean, quartzites; feldspathic, gritty and conglomeratic at base; amygdaloidal basalts in south. Feldspathic sandstones and grits overlain by thick columnar basalts with thin interbeds of arkosic conglomerates and sandstones and only occasional pink quartzite in north.	Bessie Lake Formation, 4200' (1260m) (south limb of syncline) Majoque Lake Formation 12500' (3750m) (north limb of syncline)	Majoque Lake Formation 5000' (1500m) Red Arkose 800' (240m)			Majoque Lake Formation, 3000'+ (900m) Arkose Lake Formation 900' (270m) - 2000' (600m)
Total thickness	42,000' (12,600m)	21,000' (6300m)	Approximate maximum thickness of group is		19,400 (5820m)

stratigraphy in the north of the basin. The two formations contrast with one another in thickness and content of volcanic rocks (Brummer and Mann, 1961). The Bessie Lake Formation in the south contains local basal conglomerates, quartzites, sandstones, grey and black silts and shales, crystalline tuffs and only minor basalts with a maximum thickness of 4,200' (1,260m) (Brummer et al., 1961). In contrast, except for a basal unit of arkosic sediment, the Majoque Lake Formation is dominated by basaltic flows with only thin intercalated bands of coarse clastic sediments. Brummer and Mann (1961) estimated a thickness of 12,500' (3,750 m.) for the Majoque Lake Formation which is substantially thicker than its southern equivalent, but Baragar (1969) indicates that the formation is little more than 5,000' thick. Baragar omitted the basal arkosic unit from the formation and describes the formation as dominated by plateau basalt flows with minor pillow lavas, pyroclastics and sediments. The present study was located in the volcanic and sedimentary rocks of the Majoque Lake Formation and in the basal arkosic unit of Baragar.

The base of the overlying Wuchusk Lake Formation is delineated by first appearance of diabase sills (Brummer and Mann, 1961; Baragar, 1969) intruding into clastic and some carbonate sediments. Brummer and Mann (1961) describe the formation as "interbedded chert, variegated shales, phyllites, hornfels, argillites, fine-grained quartzites and thin calcareous beds intruded by thick sills of normal diabase, metadiabase and very coarse-grained diabase." They give us a figure of 30,000' (9,000 m.)

for the thickness of the formation but Baragar (1969) reduces the thickness of the formation to 9,500' (2,850 m.). The latter is probably more accurate considering the presence of thrust faulting in the area (Hale, 1968; Baragar, 1969). Furthermore, Baragar showed that a lower subdivision of coarse, clastic quartzites and arkoses form the basal part of the Wuchusk Lake Formation (fig. V) whilst the sediments of the top 7,000' of the formation are dominated by fine-grained silts and shales. Also included in the upper Wuchusk Lake are thin bands of oolitic and stromatolitic limestones.

The stratigraphy of Brummer and Mann (1961) shows that the Wuchusk Lake Formation is overlain by a series of formations which are relatively thin in comparison. Names and lithological description are given in figure V. The published map and sections by Brummer and Mann (1961) shows that these formations can in fact be traced from north to south. However, the recent work of Baragar (1969), Hale (1968) and Kidd (1968) has drawn attention to possible correlations between the fine-grained slates and shales of the Wuchusk Lake and Salmon Lake Formations with the fine sediments of the Whisky Lake and Adeline Island Formations of Brummer and Mann. Baragar omits the Whisky Lake Formation from his stratigraphy though he gives no reason why, whereas Kidd (1968) who carried out detailed mapping of the area of Adeline Lake and the more general work of Hale (1968) suggests that the Whisky Lake Formation is equivalent to the upper part of the Wuchusk Lake Formation and the lower part of Salmon Lake Formation whilst the Adeline Island Formation is equivalent to the upper part of the Salmon Lake Formation. Figure V shows the author's compilation of these recent ideas which if correct, result in a substantial reduction in the thickness of the Seal Lake Group.

Overlying the fine sediments of the Salmon Lake and Adeline Island Formations, the top of the Seal Lake Group is marked by the upper Red Quartzite Formation.

Sedimentation throughout the depositional history of the Seal Lake Group is continental to shallow marine (Kidd, 1968; Baragar, 1969) and the accompanying volcanism is of continental plateau basalt type.

C. The Structure of the Seal Lake Basin

The Seal Lake Basin has been folded into a large east-west trending synclinorium which Mann (1959) describes as 'canoe-shaped.' The synclinorium is a broad asymmetrical structure containing many subsidiary folds whose axes parallel the east-west trend. The deformation is markedly stronger in the south of the syncline where the southern limb of the syncline is overturned and cut by several large thrust faults. The northern limb of the syncline, however, was previously regarded as a homoclinally, southward dipping, succession of conformable rocks which were only occasionally folded as at Edwards Lake (Mann, 1959). Associated with the folding was an east-west,south dipping, axial planar cleavage which increased in intensity to the south. Low grade metamorphism is particularly evident in some of the volcanics which are altered to chlorite-epidote assemblages of the Greenschist Facies (Brummer et al., 1961). The metamorphism appears to increase toward the southern margin of the basin where deformation is strongest.

Brummer and Mann (1961) attribute the deformation of the Seal Lake Basin to compression between granite gneisses to the south and an anorthosite massif to the north. The overturning of the southern limb of the synclinorium and the associated thrusting is attributed to northward movement of the granite gneisses whilst the anorthosite acted as a rigid buttress. The movements are of Grenvillian Age and Wynne-Edwards (1971) suggests the Seal Lake Basin represents the northern deformation limit of the Grenville Province in this area.

D. The Geology of the Areas Surrounding the Seal Lake Basin

Except for sediment of the Shipiskan Plateau to the northwest which is probably of similar age (Brummer and Mann, 1961), the Seal Lake Basin is surrounded by older rocks. The surrounding basement rocks can be subdivided into five distinct complexes.

1. Grenville Granites

The Seal Lake Group lies directly north of the Grenville Front. The Grenville rocks to the south of the basin include medium-grained hornblende granites, porphyritic granites and biotite-hornblende granites. Pegmatites, aplites and quartz veins cut across this granite terrain. Enclosed in the granitic rocks, there occur small bands of quartz-sericite schists, chlorite-epidote schists, white quartzites and epidote-amphibolite schists. These bands are suggested by Brummer and Mann (1961) to be remnants of an old metasedimentary complex.

South-west of Otter Lake (fig. IV) to the east of the Seal Lake Basin, Fahrig (1959) describes a belt of igneous rocks which consist of coarse-grained porphyritic, granitic and dioritic rocks with minor anorthosite bodies which are probably also of Grenvillian Age.

The Grenville granites have an east-west foliation which increases in intensity as one approaches the contact with the Seal Lake Group (see contact relationships with Seal Lake Group). The granites away from the contact show gradation from unaltered granites to sheared and schistose granite (Brummer and Mann, 1961). Stockwell (1965) shows the granites to be originally Archean and to have been reworked in the Kenoran, Elsonian and Grenvillian Orogenies.

2. Anorthosite Complex - North of the Canairiktok River

Anorthosite and associated rock types such as adamellite, mangerite and gabbro intrude Archean granitic gneisses to the north of the Canairiktok River. The mass is extremely large and is probably related to the Anorthosite masses of Nain and Michikamau which have been described by Wheeler (1960), Emslie (1969), Morse (1969) and Wheeler (1969).

The complex north of the Seal Lake Basin has not been mapped in detail. However, the centre of the complex has been recognised as anorthosite (Fahrig, 1959) and some possible differentiates and late stage intrusions have been located. A red hornblende granite and rusty-weathering gabbro occur at the periphery of the anorthosite to the north of Snegamook Lake (Fahrig, 1959) and mangerite is shown to occur in the north-west near the head waters of the Canairiktok River (Emslie, 1969) (fig. IV). The importance of the mangerite and the red hornblende granite is as a possible source of detrital fragments of perthitic feldspar which are common throughout the sandstones of the northern part of the Seal Lake Basin.

The age of the intrusions is Paleohelikian as distinct from the Neohelikian age of the Seal Lake Group. The anorthosites have been dated at 1,400 m. yrs. by the Sr 87/86 radiometric method (Heath, et al, 1969) and also by the K/Ar method (Emslie, 1969). They intruded Archean Gneiss during the Elsonian orogeny (Stockwell, 1965).

3. The Nain Province Gneisses

In the north, the basin overlies gneisses which are intruded by the anorthosite complex. Fahrig (1959) describes these gneisses as being a migmatite complex ranging from white muscovite granite to amphibolite gneiss in which banding is straight, regular and steeply dipping. Emslie (1969) and Wheeler (1969) refer to the gneisses as paragneiss which they describe as quartzo-feldspathic rocks of no definable metamorphic facies. Emslie indicates however, the presence of granulites containing pyroxenes and perthitic alkali feldspars to the north-west of Seal Lake.

The gneisses belong to the Nain Province of Stockwell (1965) and can be split into two complexes based upon their orogenic history. To the north and north-west of the Seal Lake Basin, the gneiss has been deformed in the Kenoran and Elsonian orogenies (Stockwell, 1965). However, a belt of gneisses which trends north-east from Snegamook Lake to Hopedale on the Labrador Coast was deformed only in the Kenoran Orogeny (Stockwell, 1955). This belt contains the Hopedale Gneisses of Gandhi, Grasty and Grieve (1969).

4. Letitia Lake Group

To the southwest and west of the basin, the Seal Lake Group overlies rocks of the Letitia Lake Group. The Letitia Lake Group consists of a thickness of 2500 m. of Proterozoic metavolcanics, metasediments and intrusives overlying Grenville Granites. The volcanics are acid types with:

1) A lower division of intrusive quartz-feldspar porphyries, quartz porphyries and feldspar porphyries.

2) An upper complex of rhyolites, rhyolite porphyries, tuffaceous rhyolites, banded tuffs together with some argillites, quartz-sericite schists and agglomerates (Brummer and Mann, 1961).

Soda -rich syenites intrude these rocks and are associated with banded amphibolites and feldspathic schists which occur in shear zones within the syenites. Quartz veining in common throughout. The rocks are foliated and complexly deformed but little is known of the structure.

5. Croteau Lake Group

The Seal Lake Basin is terminated in the east by the north-south trending Pocketknife Fault. To the east of the fault, a belt of sedimentary and volcanic rocks which belong to the Croteau Lake Group occur.

The Croteau Lake Group consists of two subdivisions. The lower subdivision is predominantly sediments and falls into two sequences. Near the base of the Croteau Lake Group, near Snegamook Lake, the sediments include pyritic black shales with minor quartzites and dolomites and some metabasalts (Fahrig, 1959). This lower sequence is overlain by red sandstones, boulder conglomerates containing jasper and red quartzite pebbles and boulders, red shales and crystal tuffs (own observations). This lower sedimentary subdivision unconformably overlies the Archean Gneisses to the east of Snegamook Lake (Fahrig, 1959).

Above the lower subdivision a predominantly volcanic sequence occurs. The rocks range from basaltic lavas and tuffs to dacites and rhyolites. Minor quartzites and shales also occur (Baragar, 1969). Baragar gives a thickness for the upper division as 6,322 m.

Brummer and Mann (1961) suggest that the Croteau Lake Group is equivalent in age to the Letitia Lake Group to the west of the Seal Lake Basin. This is based upon the common presence of acid volcanics, porphyries and radioactive mineralisation.

E. Contact Relationships Between the Seal Lake Group and the Surrounding Complexes

The contact relationships between the Seal Lake Group and the rocks which underlie and surround it are complex. Both sedimentary and structural contacts exist but in many cases, the contacts are not exposed.

1. Contact Relations with the Grenville Granites

Both unconformable and structural contacts have been described by Mann (1959). In the vicinity of Wilbert Lake and Lolah Lakes (fig. IV), basal conglomerates have been described which overlie locally sheared granites. In many other places, a thrust faulted contact exists between the basal Bessie Lake Formation and the granites, and granite slices have been thrust over the sediments as at Esmee Lake (fig. IV). The fault zones are usually mylonitised.

2. Contact Relations with the Letitia Lake Group and Croteau Lake Group

Following the southern contact westwards from Bessie Lake, the Bessie Lake Formation unconformably overlies the Letitia Lake Group in the vicinity of Ten Mile Lake. The unconformity is marked by a poorly developed, highly sheared basal conglomerate containing pebbles and fragments of Letitia Lake Group. The contact between the Letitia Lake Group and the Grenville Granites is obscured by drift.

The contact between the Seal Lake and Croteau Lake Groups occurs along the Pocketknife Fault Zone. This complex fault zone trends north-south from Snegamook Lake to south of Namycush Lake (fig. IV) and it shows both strike slip and dip slip components of movement (Degrace, 1969).

Brummer and Mann (1961) suggest that the Croteau Lake Group is equivalent in age to the Letitia Lake Group but older than the Seal Lake Group, and this latter proposal is supported by Degrace (1969).

3. The Contact Relations With the Anorthosite and Gneiss Complex

In the north, the contact between the Seal Lake Group and the anorthosites and gneisses of the Nain Province is obscured by the river sands of the Canairiktok valley. Fahrig (1959) and Brummer and Mann (1961) believe the contact to be an unconformity but the present study indicates this original unconformity maybe strongly modified by faulting.

F. The Age of the Seal Lake Group

Absolute age data for the Seal Lake Group is limited and contradictory. Post deformational galena veins have been dated at 1,685 m.y. (Cummings et al, 1955) while K/Ar whole rock isochrons for basalts of the Salmon Lake Formation and a diabase sill in the Wuchusk Lake Formation gave dates of 960 $\pm$ 90 m.y. (Wanless et al, 1966) and 865 $\pm$ 100 m.y. (Wanless et al, 1965), respectively. The significance of these dates is uncertain but it seems probable that the K/Ar dates are indicative of a Grenville Age of deformation and metamorphism. Brummer's (1971) correlation of the Seal Lake Group with the metasediments of the Labrador Trough on the basis of the galena age is no longer tenable in the light of the other figures.

CHAPTER III

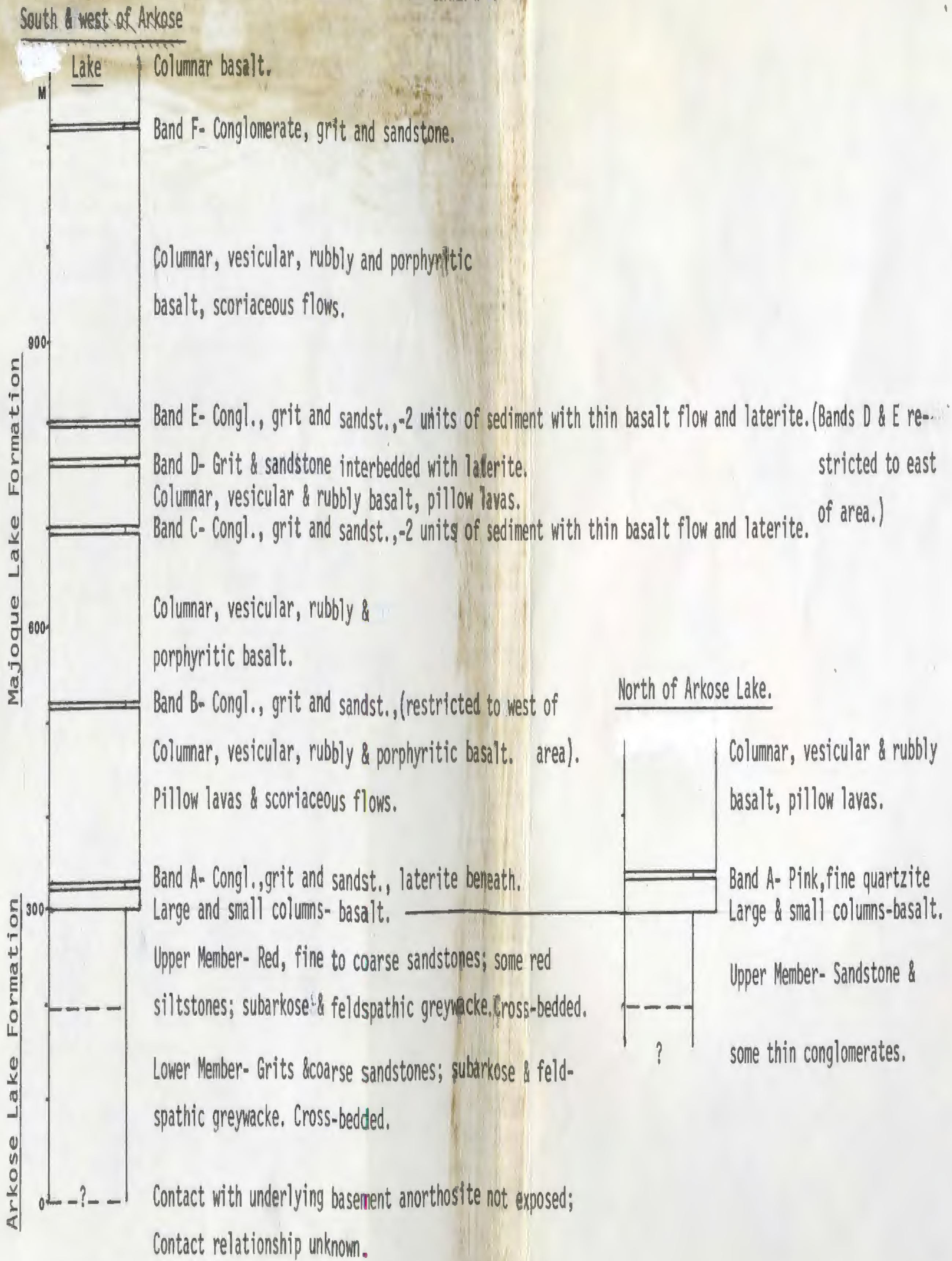
STRATIGRAPHY OF THE ARKOSE LAKE AREA

The detailed stratigraphy of the Arkose Lake area is given in figure VI. Brummer and Mann (1961) included the succession within the Majoque Lake Formation but since it is comprised of two distinct mappable units, Baragar (1969a) separated a lower arkosic unit from the overlying volcanics. He called the former the Basal Arkose and for the latter, he retained the name, Majoque Lake Formation. It is the opinion of the author that the Basal Arkose should be assigned to the status of a formation. Not only is there a marked difference in lithologies but the contact between the two lithologies is sharp and well defined throughout the Arkose Lake area and continues as such eastward to Snegamook Lake and in the area south of Snegamook towards Pocketknife Lake. However, the lower contact of the Basal Arkose is nowhere exposed although it is assumed that it is an unconformable and/or faulted contact with the underlying basement rocks in the vicinity of the Canairiktok River. Also because of the limited exposures, no complete section through the formation is available although it is felt that the important details of the succession have been determined (see later text). It is thus proposed that the Basal Arkose of Baragar (1969) be in future referred to as the Arkose Lake Formation with a type area rather than section located in the vicinity of Arkose Lake. The contact between the Arkose Lake Formation and the overlying Majoque Lake Formation is defined by the first influx of volcanic rock which terminates the deposition of subarkoses and feldspathic greywacke clastics of the Arkose Lake Formation.

A. The Arkose Lake Formation

The Arkose Lake Formation is a succession of clastic sediments. The

Fig. VI. Stratigraphy of the Arkose Lake Area.



thickness of the formation is difficult to calculate due to :

1. Poor and scattered exposures,
2. The presence of structural complexities of folding and related thrust faulting,
3. The lack of an exposed basal contact between the formation and the underlying basement rocks.

The formation could range from a minimum of 150 metres up to 600 m. thick, as calculated by altimeter traverses and from geological profiles perpendicular to strike (see sections A, B & C). The figure of 600 m. was calculated from Section C assuming that the unexposed basal contact between the sediments and the underlying basement occurs in the vicinity of the Canairiktok River and that the succession at this point is not folded or faulted but is dipping constantly southwards at approximately 20^{o}.

1. General Lithologies

The Arkose Lake Formation is predominantly a succession of feldspathic and quartzose sandstones and grits* with occasional horizons of red and green siltstone and pebble clast and intraformational conglomerates. The grain size of the sandstones ranges from very fine to very coarse (Wentworth, 1922). Coarse and very coarse sandstones with minor medium and fine sandstones form the lower

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* Grits are used here to refer to clastic sediments composed predominantly of particles of 2-4 mm in size. This term is thus equivalent to granular gravel of Wentworth (1922) and Udden (1914) (see Pettijohn, 1957, p. 19). Since it is a common rock type in the area and was previously used by Mann (1959), it is proposed to retain its usage.

parts of the formation whilst medium and fine sandstones are dominant in the higher horizons. The sandstones and conglomerates are cross-bedded.

The formation consists of two members. The lower member consists of purple-red, pink, creamy and pale green, coarse and very coarse sandstones and grits which are associated with finer-grained, red sandstones and some thin silts. Occasional thin conglomerate horizons also occur. The upper member is formed of red, fine to coarse sandstones and also has a higher content of red siltstones. Intraformational breccias and conglomerates are very common within this member.

II. The Lower Member

This member because of its areal extent within the Arkose Lake region appears to form the bulk of the formation. However, for the reasons outlined previously it is difficult to determine the true thickness of this member and the thickness could range from 60 metres up to 510 metres.

The sediments throughout the member are dominantly medium to very coarse sandstones together with an appreciable amount of grit. Occasionally, thin pebble bands and conglomerates also occur and these become more frequent in the west of the area. Fine sandstones and siltstone horizons are thin and infrequent throughout the member and occur as lenses within the coarser sediments.

The coarser sandstones and grits are usually creamy white, pink or pale green in colour depending upon their composition. Quartz rich sediments are usually white whilst abundant pink feldspar and some iron staining may impart a pink colour to the sediments, a high clay content gives a pale green colouration. The coarser sandstones may also be red in colour but red and purple-red colouration is predominantly found in fine and medium sandstones. Colour banding may occur when the fine and coarse factions are interlayered.

The sediments are throughout feldspathic. Fresh feldspars are pink but some are altered and bleached to a white or green colour. Several varieties of quartz occur. White quartz which is often a bluish-white, opalescent variety is the most common but purple and pink quartz also occur. Red chert and jasper are occasionally found in the grits and conglomerates which may also contain an occasional basalt pebble and red silt clast.

The feldspar content of the sediments varies considerably. Based on field observations, the grits can contain up to 30 - 40% feldspar though generally only 10 - 15% is present. In the conglomerates, quartz pebbles usually dominate but in one very pebbly, very coarse sandstone horizon seen in the west of the area (Grid. Ref. 030 040) at least 30% feldspar content was recorded.

Heavy minerals can bee seen scattered through some of the pebble beds but they may be concentrated into thin 1 mm. laminae within sandstones, where they define cross-bedding.

The sediments are generally relatively poorly sorted although the finer sandstones and an occasional thin, one pebble layer conglomerate show moderate sorting. In the field, it is possible to see sand - silt - clay mixes in sandstones and this is supported by thin-section study (see later). Granules and pebbles show poor to good rounding. Quartz clasts are usually moderately well rounded but feldspars can be tabular and poorly rouded to well rounded. The pebbles are commonly 1 - 1½ cm. in diameter but pebbles up to 3 cm. diameter were recorded in the west of the area (Grid. Ref. 030 040).

a. Sedimentary Structures

1. Cross-bedding

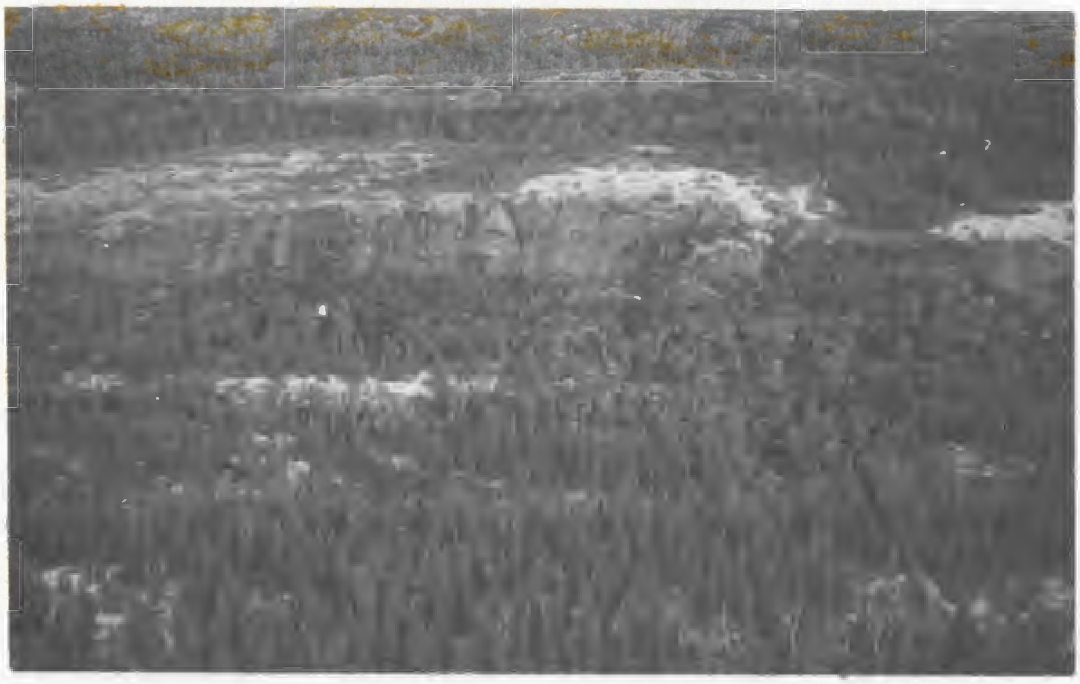
Cross-bedding is the most important sedimentary structure and occurs throughout the member. Various types of cross-stratification are recognised based on criteria of Allen (1963).

i. Large Scale Trough Cross-bedding

Large scale trough cross-bedding forms sets up to 75 cm. in thickness and two metres in width and two to three metres in length. Successive troughs (Pl. II) cross cut and truncate one another. The base of each set is marked by an irregular undulose or smooth planar to curved, erosive scour. The foreset beds are 3 - 5 cm. thick and dips up to 40° were recorded.

In some instances, the foreset beds of the margin of the trough are slightly crenulated. These crenulations are small scale and die out into the centre of the trough and are also restricted to one set. Such crenulations are common sedimentary features of cross-bedded sandstones in both recent and fossil sands (Harms, McKenzie and McCubbin, 1963; Frazier and Osanik, 1961; Friend, 1965). Suggested origins include mass flow down foreset slope (Harms et al, 1963; Kuenen, 1948), current drag (Stewart, 1961; McKee et al, 1962) and post depositional gravity deformation (Dott and Howard, 1962). The latter possibility seems most likely in this instance. The crenulations are usually found beneath a concave erosion surface and are overlain by the thickest part of an overlying trough. The load of the overburden may induce the deformation in the water laden sediment of the edge of the trough. The deformation possibly is linked to the setting up of a shear couple beneath the thickest part of the overlying trough where maximum compression (due to gravity load) is greatest.

The large scale trough cross-bedding usually occurs in sediments of grit to medium sandstone grain size. The sediments are usually poorly sorted even though grading occurs within the overall cross-bedded unit, i.e. between the base and the top of the trough. Grading does however, occur in the foreset beds and



Pl. I. View of typical, topography and scenery of the Arkose Lake area.

Pl. II. Festooned, large scale, trough cross-bedding in coarse sandstone and grits of Lower Member of the Arkose Lake Formation.

such grading of foreset beds is known in many sandstone deposits. The grading has been attributed to the dumping of bed load at the top of an avalanche face (foreset) of a migrating dune or sand bar where the velocity of a stream is checked due to deepening of the water and subsequent slip of the deposit down-slope such that the coarser material occurs at the base of the slope (Bagnold, 1954; Allen 1965b). Although this appears to be the main process, Jopling (1963, 1965) also notes the minor role played by grain size segregation during sediment movement (see also Brush, 1965) and the effects of settling paths and backflow upon sediment which is in suspension as it passes over the lee side of a ripple or bar.

The large trough cross-beds are usually overlain by several sets of large trough cross-bedding of smaller dimensions. They usually produce festoon cross-bedding of approximately 15 cm. thick. The sandstones involved are equally coarse as in the larger forms of cross-bedding.

Large scale trough cross-bedding is usually associated with migrating linguoid, lunate ripples (Allen, 1963) or catenary ripples (Williams, 1971) or with spoon-shaped scours which occur upon bars such as were described by Harms and Fahnstock (1965) and Williams and Rust (1969). They are known to form in the upper part of the lower flow regime (Harms and Gahnstock, 1965).

ii. Small scale cross-bedding

Small scale festoon, trough cross-bedding is restricted to the fine to medium sandstones. It is 4 cm. in depth by twelve cms. in length. Such cross-stratification is usually associated with migrating current ripples (Allen, 1963).

2. Other Bedforms

i. Plane Beds

The coarsest sediments display plane bedding. Pebble bands and grits have horizontal bedding attitudes and overlie horizontal planar or irregular scour which truncate underlying cross-bedded sandstones. The beds are usually poorly sorted but grading from grits up into gritty, coarse sandstones, does occur. Such relatively unsorted deposits probably represent deposition of bed load within a channel, as they possess no internal sedimentary structures. Williams & Rust (1969) suggest that the lack of internal structures is related to the ratio of pebbles to matrix in gravel deposits of the Donjek River. Doeglas (1962) has however, reported such deposits occurring in channels of a braided river in France resulting from a supply of sediment in excess of that being removed when the river is in flood.

Well sorted grits and pebble bands containing very little sand, are also present (Map Ref. 162 042). These deposits are usually thin, often only the thickness of one layer of pebbles and they overlie an erosive surface which is planar and horizontal and truncates underlying sediments and structures. The deposits appear to be restricted and end within a few metres either against an erosive surface or by simple passage laterally into sandstones. The good sorting and restricted areal extent suggests that these pebble and grit bands represent lag deposits formed in channels by winnowing of grit or pebble - sand deposits to leave only the coarsest faction (Happ et al, 1940; Allen, 1965c). Harms and Fahnstock (1965) indicate such lag deposits occur in the cross-stratified sands of the Rio Grande and suggest that the deposits may be produced by transport of pebbles in high regime flow and later concentration into a layer by undercutting of the pebbles in lower flow conditions so that the pebbles appear to roll upstream and concentrate in a scour, a process suggested by

Fahnstock and Haushild,(1962).

ii. Fine horizontal laminations

Thin lenses of very fine sanstones and coarse silt occur locally within the coarser sediments. The lenses are up to a metre or so in length and usually about 4 cm. thick. They lie upon the top surfaces of earlier deposits of sandstone but they are usually cut out laterally by an erosive surface which is overlain by coarse, cross-bedded sediments. The silts and very fine sand lenses display fine, horizontal lamination, which is picked out by grain size and colour variations. No mudcracks or ripple marks were found associated with the lenses which are very rare throughout the area. However, mudcracks were found in similar lithologies in outcrops along the west shore of Snegamook Lake suggesting that such structures probably exist in the Arkose Lake area but were not seen because of the poor outcrop.

Such fine lithologies suggest deposition of suspended fine material in quiet water conditions such as may occur at low water discharge (eg. dry season). Fines can thus be deposited in a number of situations including shallow water areas over a bar, eg. inner part of a meander or channel bar, in quiet deeps within a channel and in channel cut offs, Doeglas (1962), Williams and Rust (1969).

b. Relationship of Bedforms and Grain Size Within the Sediments

Although not often observed in the field, a relationship appears to exist between grain size and sedimentary structures. This relationship indicates an ideal sequence of events as follows.

1. A planar or irregular scour truncating earlier sediments and structures occurs at the base of the sequence. The scour surface probably represents the

floor of a channel.

2. Deposition of a poorly sorted, massive bedded grit or conglomerate. This deposition may be winnowed to produce a basal lag deposit of well sorted sediment.

3. Deposition of trough cross-bedded grits and sandstones on a large scale. Much of the deposition is in the form of graded avalanche deposition over the lee side of a sediment bar. The size of the troughs appear to decrease upward although they all belong to the large scale class of Allen (1963). One to three all represent upper flow regime conditions.

4. Formation of small scale trough cross-bedding which represent migrating small scale ripples in lower flow regime conditions (Harms and Fahnstock, 1965; Allen, 1965).

5. Deposition of silts displaying fine horizontal laminations overlying the sand deposits and probably representing the cessation of strong current activity

Features representing this sequence may occur on a scale of a few metres but are not often completely developed. Throughout the area, the large scale trough cross-bedding is almost ubiquitous but frequently the basal grit or pebble bands and the higher finer grained sands and silts may be absent. In the western part of the area, however, well sorted pebble and grit beds are overlain by sands displaying small scale cross-bedding and this grit, cross-bedded sand relation may occur several times within 30 - 50 cm. In every case, however, when the sequence or part of the sequence is observed, it is one of fining upwards, of better sorting upwards and of decreases in size of the sedimentary structures upwards.

c. Paleocurrent Data

Figures VII (a - e) shows the paleocurrent data collected for the lower member. All directions collected throughout the area were taken on bedding plane exposures which are not very common. The directions record the axis of a trough. For those localities where there were enough directions collected to be significant, there is a strong southeast to south direction of current flow. All the directions for each locality are relatively tightly grouped with unimodal distribution. When the mean azimuth for each locality is plotted on a map (Fig. VIII) it can be seen that the current direction appears to be gradually shifting from east-south-east to west of due south.

III. The Upper Member

The upper member of the Arkose Lake Formation is characterised by

1) A higher percentage of finer-grained sands.

2) The occurrence of lenses of coarse and medium silts.

3) The presence of abundant red silt clasts in the sandstones.

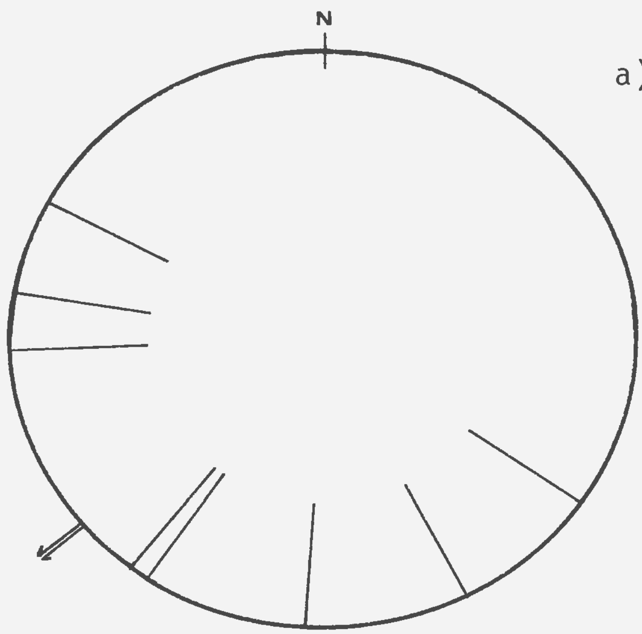
4) The predominance of red coloured rocks.

The thickness of the member is about 100 metres as measured by altimeter from a scarp south of Arkose Lake (Grid. Ref. 149 039).

Many of the sandstone units are of medium to coarse grain size. However, fine sandstones are also relatively abundant which is in marked contrast to the lower member. The sandstones are red in colour although the coarser sediments can be pink or creamy. The sandstones contain abundant pink feldspars and occasionally white mica is found on the bedding planes of the fine sands and coarse silts. Red silt clasts are scattered throughout the sandstones (Fig. IX)

Fig. VII. (a - e). Palaeocurrent Distribution for the Lower Member of the Arkose Lake Formation.

East end of Arkose Lake.



a)

—— Unidirectional reading-trough cross-bedding.

⟹ Vector Mean.

Directions corrected for dip of bedding and plunge of folds in the field.

b)

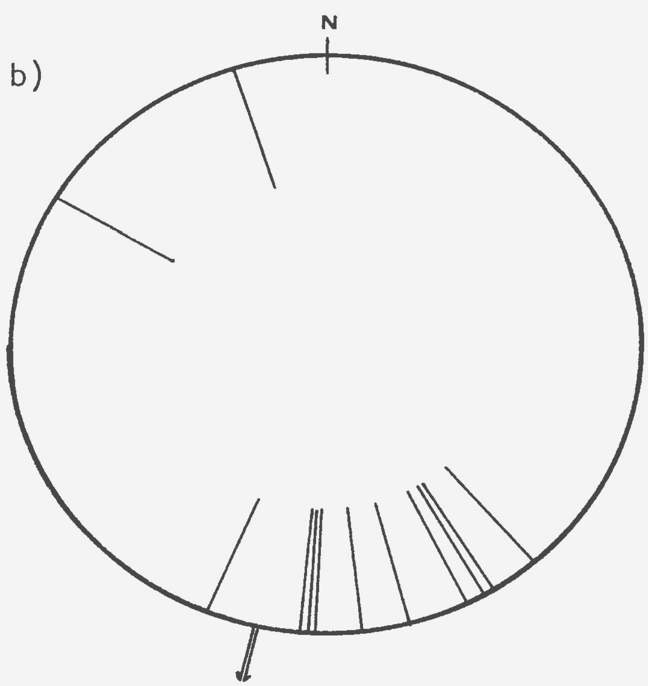
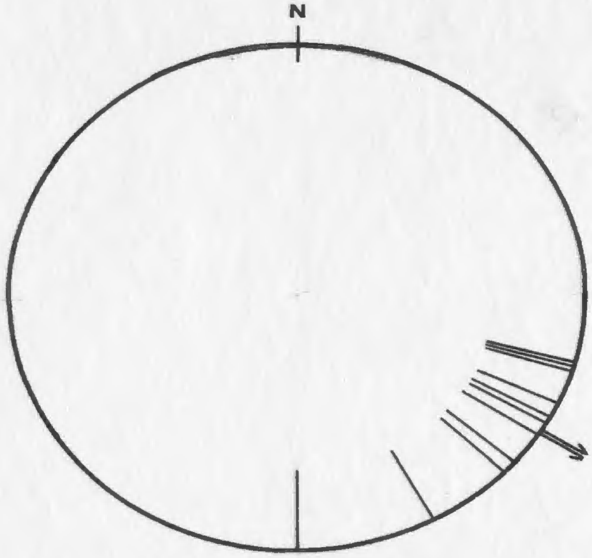
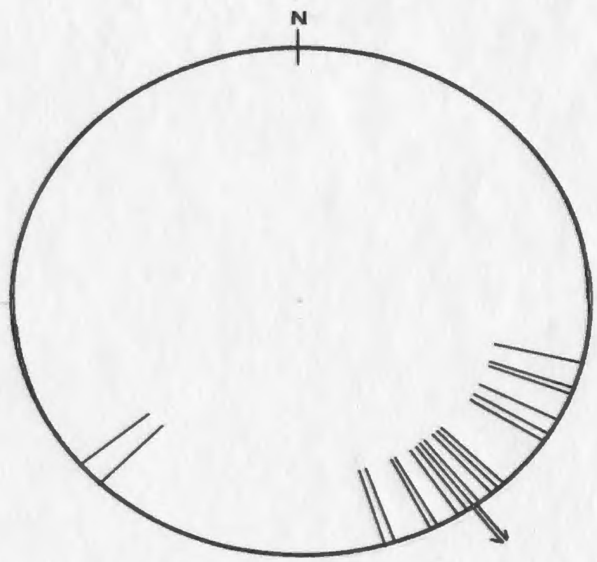


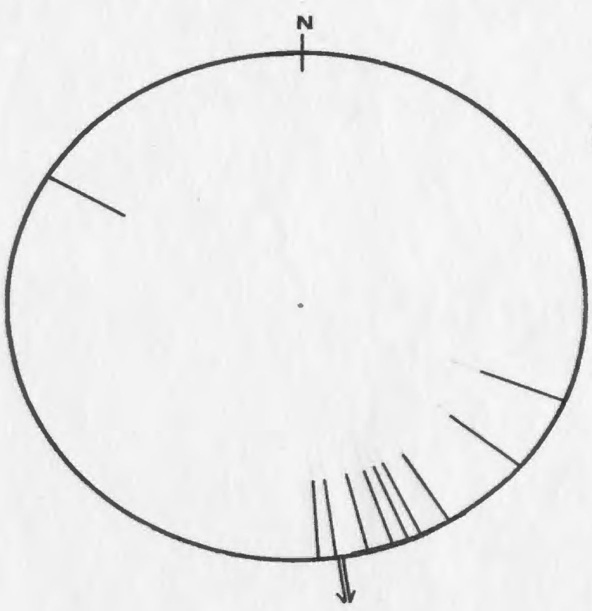
Fig. VII. West of Arkose Lake.



c)

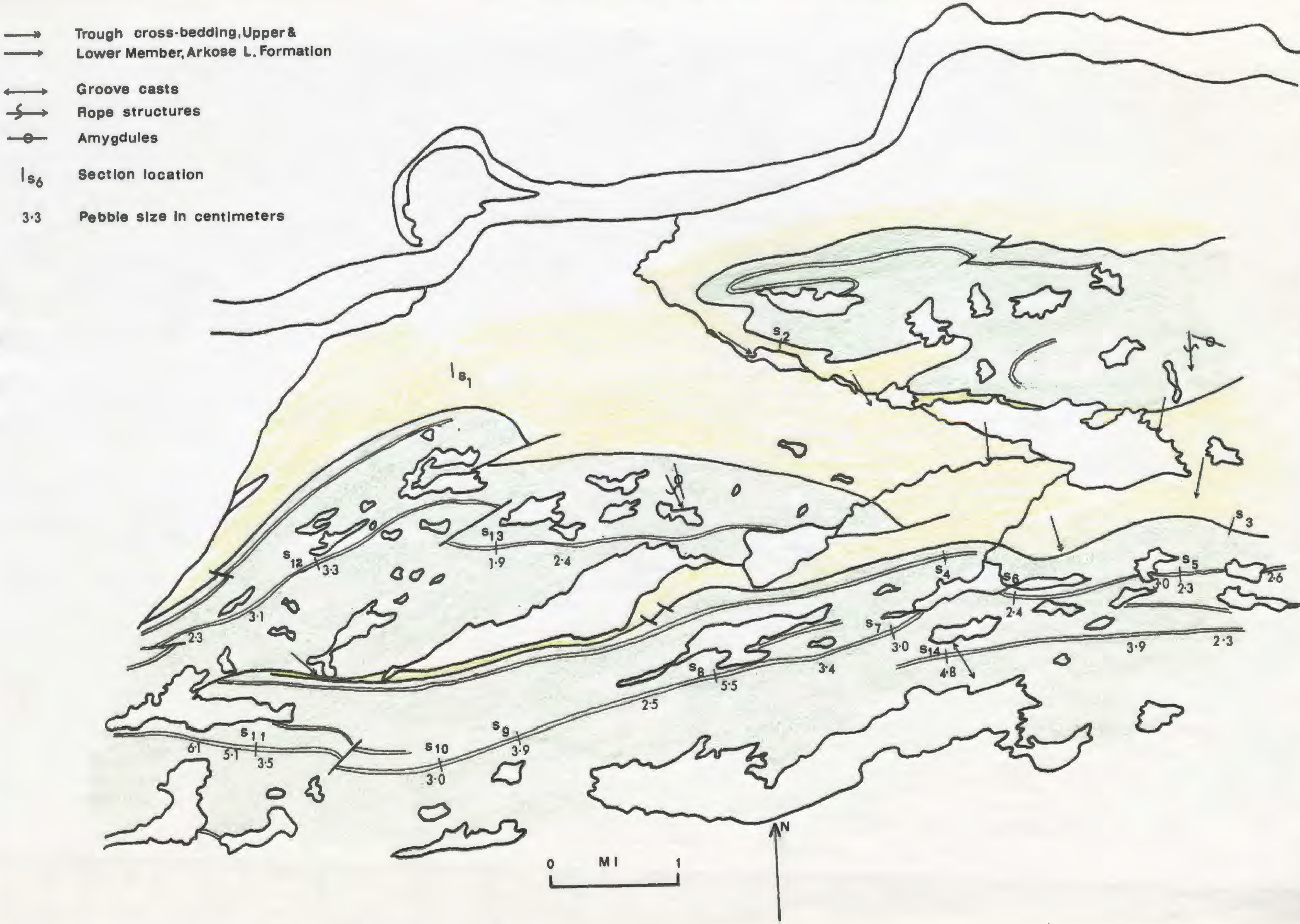
d)





e)

Fig. VIII. Palaeocurrent synthesis, section location, and pebble size variations for Arkose Lake and Majoque Lake Formations.



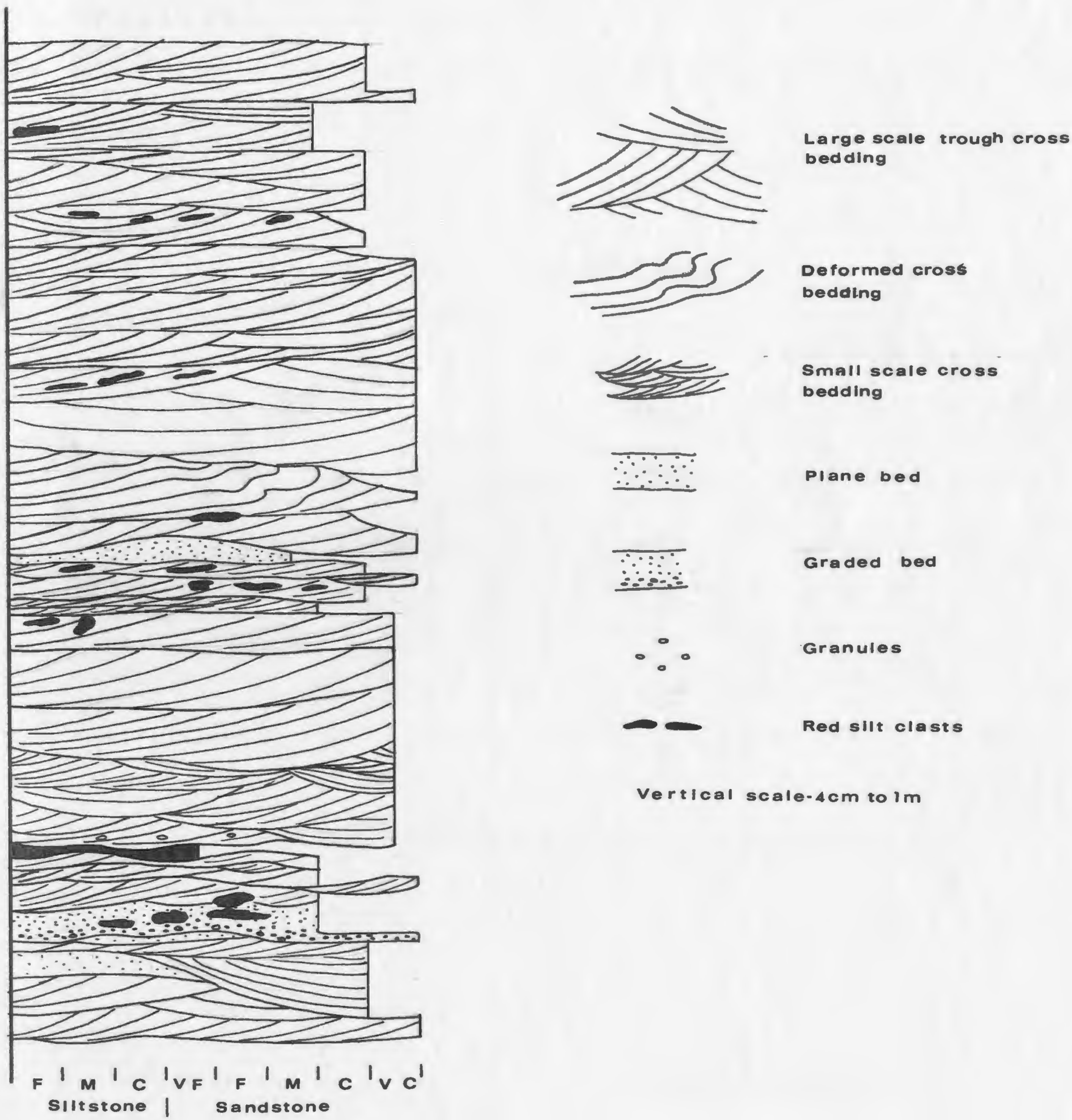


Fig. IX. Section 1 in Upper Member Sandstones of the Arkose Lake Formation.

and may form intraformational conglomerates. The clasts although occasionally rounded are generally thin and irregular in shape with distinctive fingers and spidery projections and range in size up to 6 cm. by 3 cm. (Plate III). This suggests that they were plucked forceably from a silt layer. Clasts of this type show that silt deposits existed and were rapidly reworked within the environment since only one siltstone horizon of any thickness was recorded (see later). The generally irregular shape of the clasts, however, indicates that they were not transported far.

The member appears to coarsen northwards. Very coarse and coarse sandstones and a number of conglomerate bands occur (Fig. X). White quartz is the dominant pebble type and pink feldspars only make up 30% of the clast type. The conglomerates are poorly sorted with pebbles ranging from 0.5 cm. to a maximum of 2.1 cm. diameter and they are set in a matrix of very coarse sandstone and grit. The pebbles are moderately to poorly rounded. One of the pebble bands passes laterally into grit and then very coarse sandstone whilst within another conglomerate horizon there are several gradations from conglomerate up into coarse sandstone which is in turn gradational overlain by the next conglomerate.

a. Sedimentary Structures

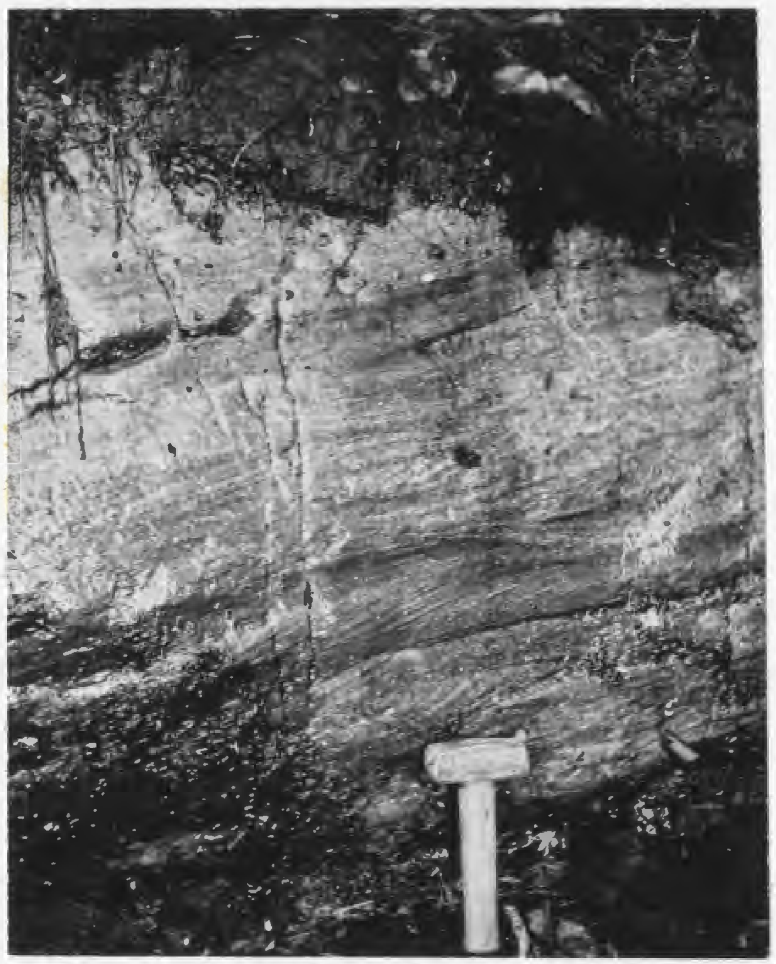
As in the lower member, the main sedimentary structure in the upper member is cross-stratification.

1. Cross-bedding

i. Large Scale Trough Cross-Bedding

Large scale,trough cross-bedded units (Fig. X) can be up to 40 cm. but are usually about 15 cm. thick and a metre or two wide. The length of the units was not determined because of lack of suitable exposures. Several units of cross-

Pl. III. Red silt clasts set in red sandstone, Upper Member of the Arkose Lake Formation.



Pl. IV. Small scale, trough cross-bedding, Upper Member of the Arkose Lake Formation.

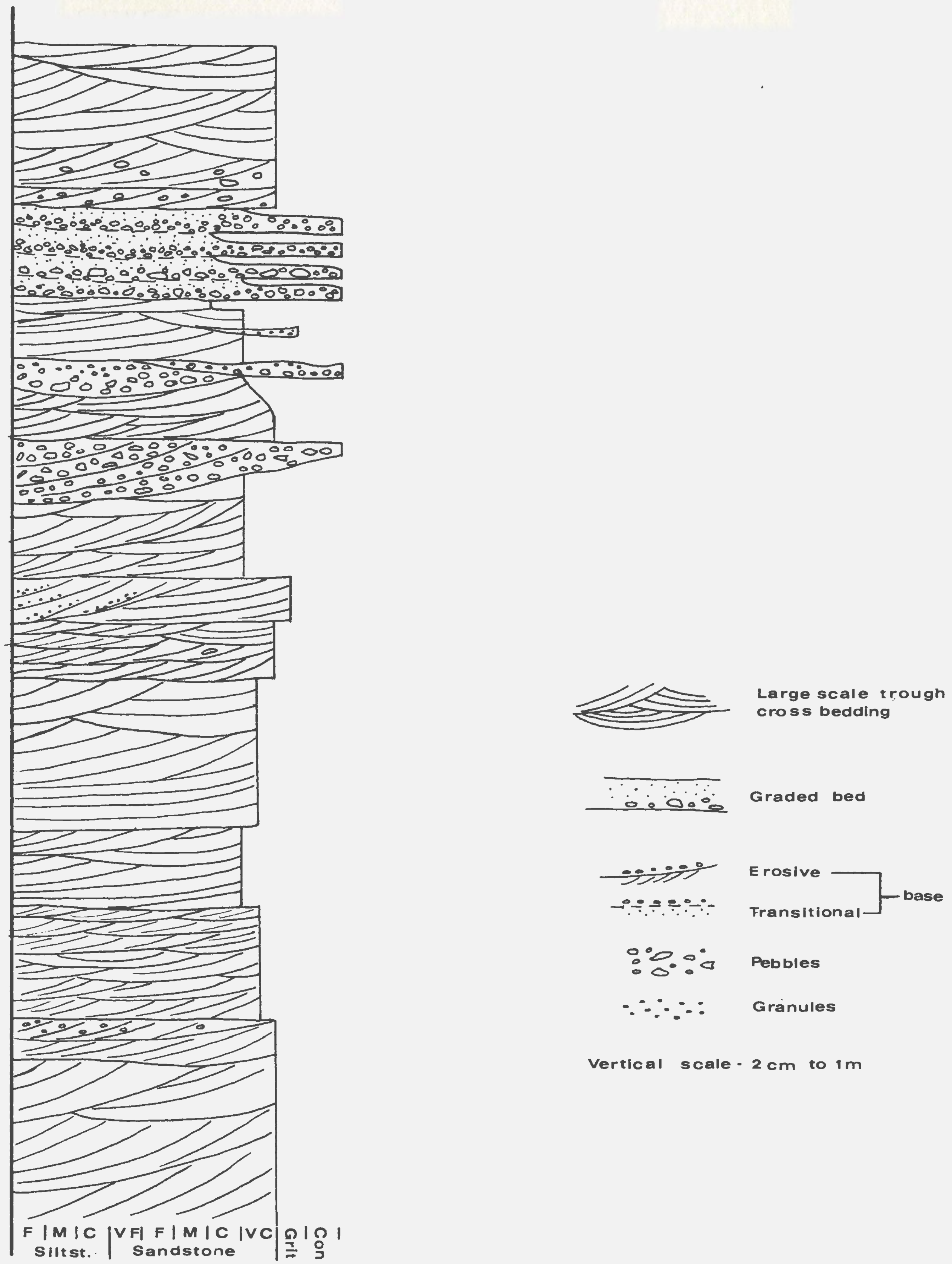


Fig. X. Section 2 in Upper Member of the Arkose Lake Formation.

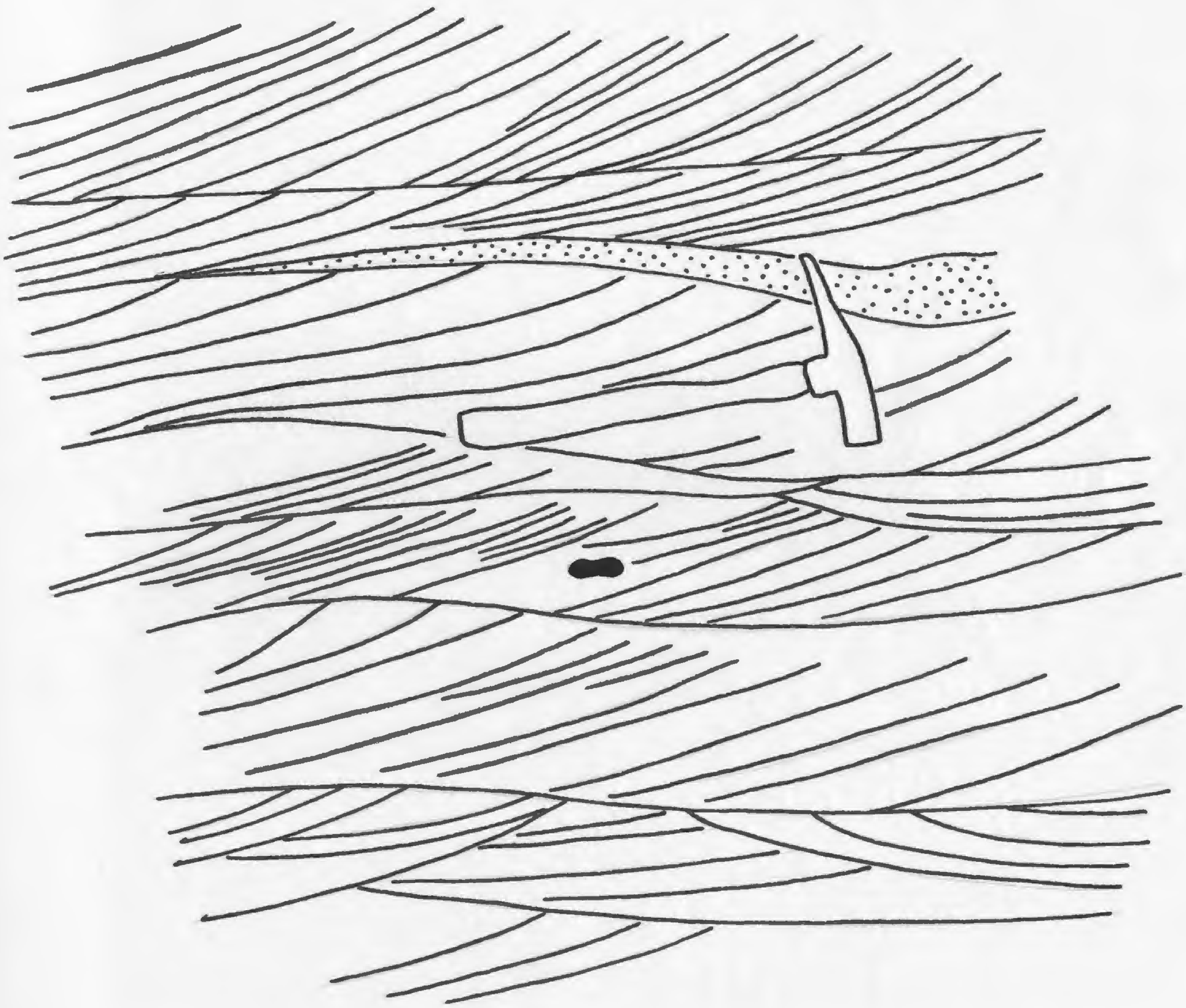


Fig. XI. Large-scale, trough cross-bedding in coarse sandstones of the Upper Member of the Arkose Lake Formation. Red silt clast and thin plane bed also shown.

bedding occur within a bed which is generally a metre thick and several metres wide. The overall form of such composite sets is usually lensoid. Each unit of cross-bedding has a basal, concave scour which truncates the underlying sediments.

The structures occur in medium to very coarse sandstones. The foreset beds are usually about 1 cm. thick and grade from very coarse sandstones at the base of the foreset up to medium sandstone at the top. This also gives an overall upward, fining within each unit so that most of the coarser sand is at the base of the unit. This can be attributed to slip down foreset slopes so that the larger heavier sand grains segregate to the base of the foreset slope (Bagnold, 1954).

Concentrations of red silt clasts often occur overlying the basal erosion surface (Pl. III). These concentrations are viewed as lag deposits occurring within a scour depression and later overlain by cross-stratified sands (Harms and Fahnstock, 1965). Isolated red silt clasts also occur parallel to the foreset bed slopes of the cross-bedding (Fig. IX).

As in the lower member, the large scale,trough cross-bedding is associated with either migrating large scale ripples or scour fill structures in bars formed under conditions of the upper part of the lower flow regime (Allen, 1966, Harms and Fahnstock, 1965).

ii. Small Scale Cross-Stratification

Small scale, festoon trough cross-bedding usually less than 5 cm. thick and less than 30 cm. in length occursin well sorted,medium and fine sands. Many of the forms in longitudinal section resemble Nu type cross-stratification of Allen (1963) with a concave scour base (Pl. IV). Many units of small scale cross-stratification occur within beds up to a metre in thickness (Pl. V).

These bed forms are probably associated with migrating small scale linguoid ripples (Harms and Fahnstock, 1965; Allen, 1963) and thus are formed in lower flow regime conditions (Harms and Fahnstock, 1965).

2. Other Bed Forms

i. Massive Bedding

Massive bedding was observed on a few occasions. The beds are lensoid deposits of fine-medium sandstone. Internally uniform, they are usually 3 - 8 cm. thick. They lie upon planar or curved scours and are themselves truncated and eroded by a scour surface of an overlying unit of cross-bedding (see Fig. IX).

These beds may represent remnants of plane beds such as may form in the transitional and the lower part of the upper flow regime or in the lower part of the lower flow regime (Allen, 1965c).

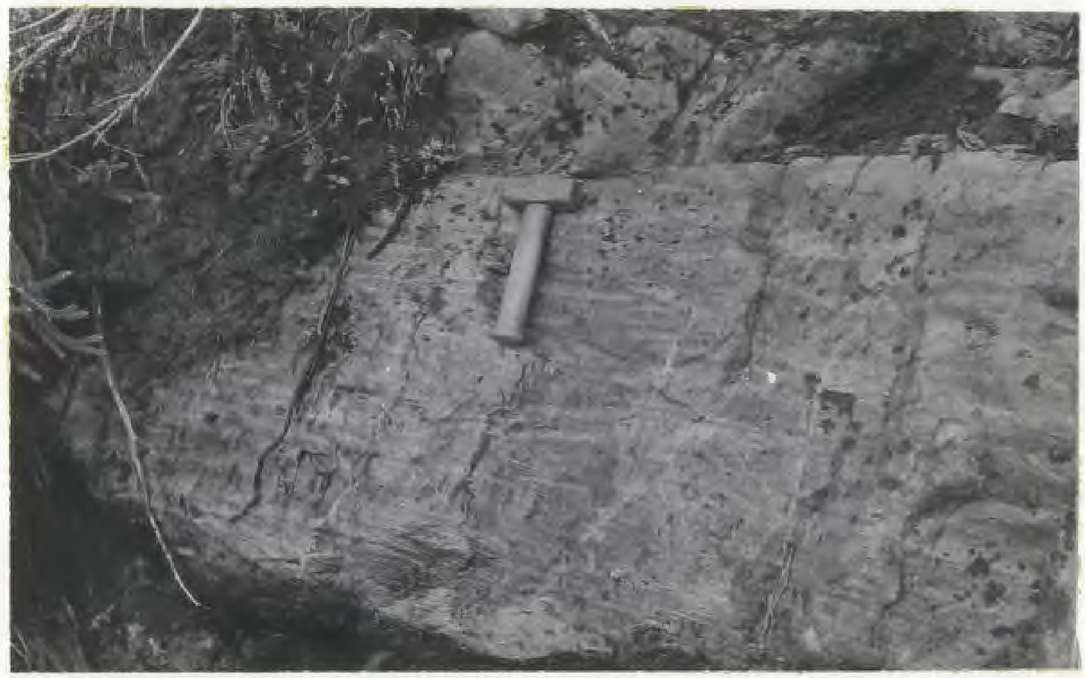
ii. Flat Bedding

This occurs in sediments of varying grain size.

a. Conglomerates

Figure X shows flat bedded or planar bodies of conglomerate which dip at only a few degrees. The planar bodies grade up into thin 3 - 5 cm. coarse sandstones which are transitionally overlain by more conglomerate. The conglomerates are poorly sorted.

This form of bedding can be related to deposition of coarse sediment in high flow regime conditions (Allen, 1965c). Most probably, the deposit formed as a longitudinal bar such as can be found in braided streams (Smith, 1970; Doeglas, 1962) where the coarse material was deposited as a sheet into relatively deeper water than that in which it was being transported. Since the contacts



Pl. V. Small scale, trough cross-bedding in pink, medium sandstone, overlying thin horizontal beds. Upper Member of the Arkose Lake Formation.

Pl. VI. Cross-section of pipe structures displaying internal concentric structure. Upper Member, Arkose Lake Formation. The pipe structures continue through and are exposed on the underside of the sample.

between each conglomerate - sandstone and sandstone - conglomerate layer is gradational, the bar must have been vertically aggraded.

b. Fine sandstones and coarse siltstone

Thin 1/2 to 1 cm. thick flat bedding occurs in micaceous, fine sandstones and coarse siltstones. These sediments also contain some scattered, pink feldspars of medium sandstone size. The beds are thinly laminated (McKee and Weir, 1953) but no parting lineations were observed on the bedding planes.

The flat bedded, fine sediments overlie festoon, trough cross-bedded, coarse sandstones and are also associated with coarse siltstones which display ripple drift laminations; the ripple drift being picked out by coarse sandstone lenses in the troughs of the ripples.

The lack of a parting lineation and the presence of thin laminations and associated small scale ripples indicates that these fine sediments were laid down in quiet conditions of shallow stream or a cut off channel (Doeglas, 1962).

iii. Horizontal Laminations

Thin lenses of coarse silts usually display fine, horizontal laminations. The laminations are shown by 1 mm. medium silt partings which separate the coarse silt. The lenses are up to 10 cm. thick and overlie the ripple tops of beds of small scale, cross-stratified sandstones. The silts are usually truncated by an irregular, erosive surface of an overlying, large scale, cross-stratified sandstone.

Such deposits probably represent the deposition of suspended, fine material during quiet shallow water conditions or in deep pools during times of low stream flow.

iv. Deformed Bedding

Two examples of sedimentary deformation structures were observed in the upper unit of the Arkose Lake Formation.

1. Convolute bedding involving fine and medium sandstone occurs on the southeast shore of Club Lake (Grid. Ref. 085 034). Figure XII shows that the deformation of a possible small scale cross-stratified unit occurred very early after deposition of the sediment. The structures were then truncated by a scour which forms the base of an overlying cross-stratified, very coarse sandstone. Such structures may be classed as symmetrical (Friend, 1965) and are probably gravity load structures (Dott and Howard, 1962).

2. A second example of deformation occurs in medium and coarse silts which are found just below the contact with the Majoque Lake volcanics to the southeast of Arkose Lake (Grid. Ref. 166 035) (Fig. XIII). Short, cylindrical, pipe like structures occur in a bed of coarse and medium siltstone 1 metre thick. In cross section the pipeappears to have a concentric structure of rings as picked out by weathering (Pl. VI). This ring structure continues along the length of the pipe which were observed up to 2 cm. in length but are probably much longer. The pipes form in the lower 50 cm. of the bed and the upper 50 cm. appears to be a mixed rock composed of a fine sandstone containing very abundant 1 - 2 mm. long red silt fragments. This deformed bed is overlain by alternations of medium and coarse siltstone which display thin laminations alternating with 1 to 2 cm. of massive siltstone which is mudcracked. Also present are 1/2 cm. beds of micro-cross-lamination which is related to micro-ripple-drift. The silts are overlain by small scale, cross-stratified sandstones which contain red mud clasts.

Pipe structures have been recorded within successions of similar rocks by a number of authors (Allen, 1961; Dinely, 1960; Friend, 1965). In each case, the pipes occur in fluvial sediments usually siltstones or fine sandstone. The structures described here however, appear to be smaller in diameter, only

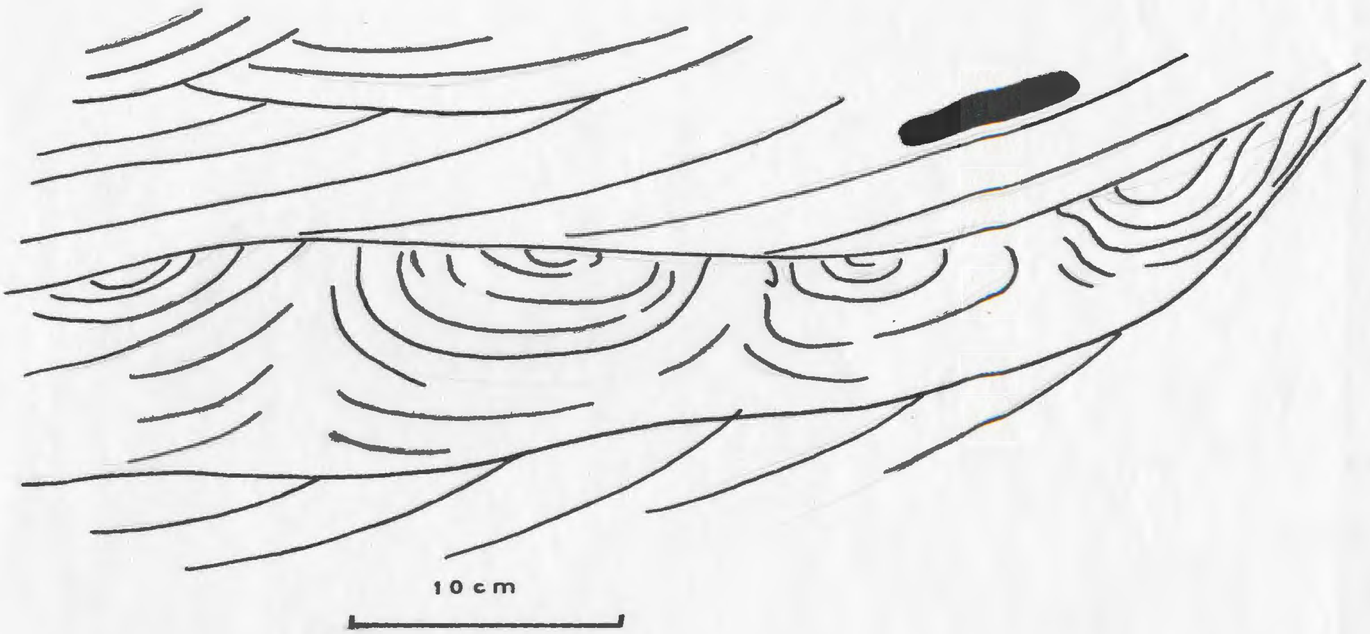


Fig. XII. Small scale, convolute deformation in thin, fine sandstone bed overlying cross-bedded, coarse sandstone. Deformation structures are truncated by undulose scour which is overlain by cross-bedded sandstones containing red silt clast.

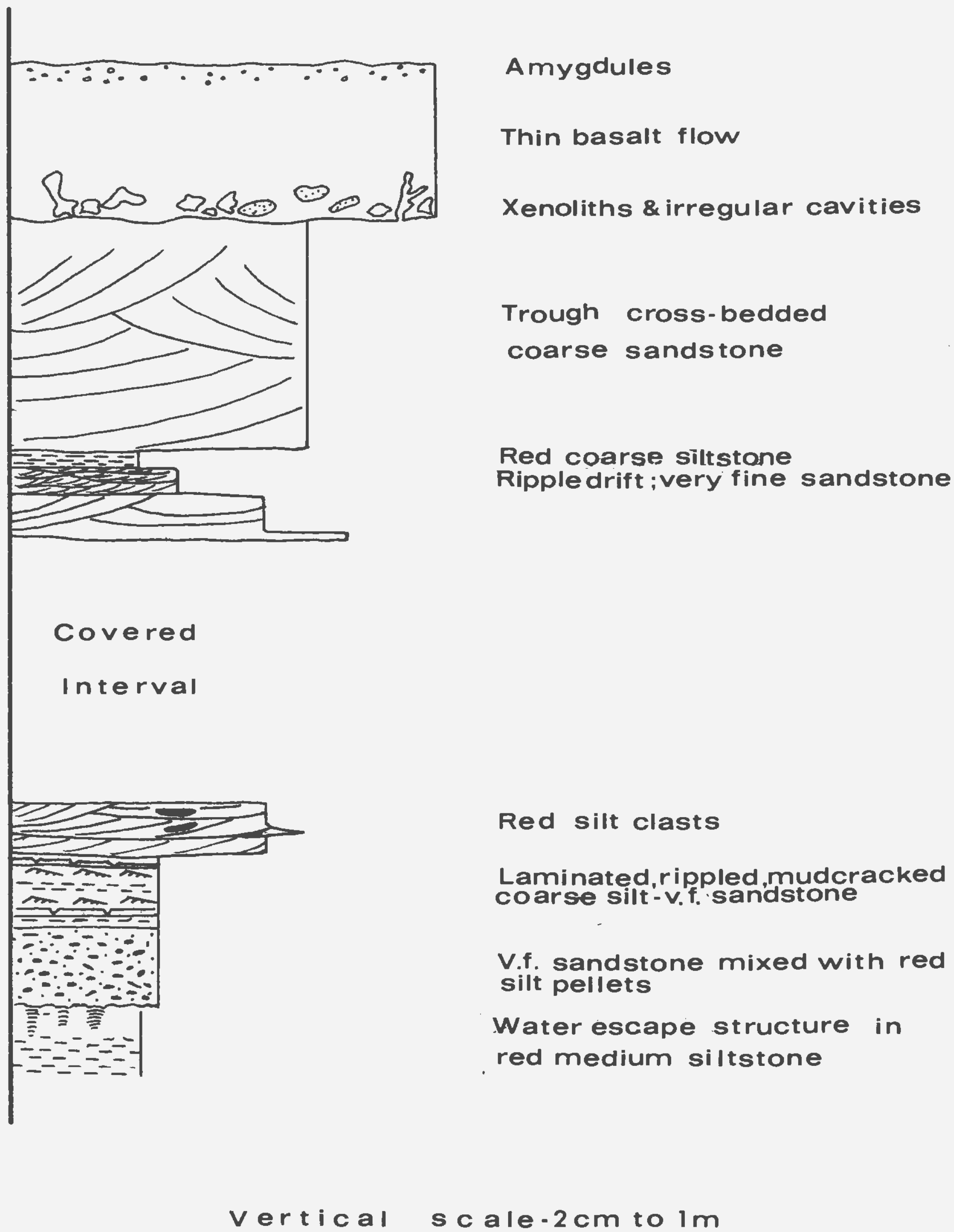


Fig. XIII. Section 3 measured just beneath the Arkose Lake/Majoque Lake Formational contact. Section includes deformation structures of vertical pipes cutting red siltstone.

1 - 2 cm. as compared to 4" (Dinely, 1968), 5 - 20 cm. (Friend, 1965) and 3 - 25 cm. (Allen, 1961). The structures of Dinely were described as spring pits but those of Allen and Friend were thought to be related to ducts which allowed the upward passage of water. Williams and Rust (1969) also describe active subaqueous silt volcanoes in first and second order channels of the braided Donjek River. The cone structures range in size from 1 cm. to 15 cm. and they occur in silt-sand layers which overlie a gravel bar. The volcanoes are formed when water percolates downwards through the gravel from the overlying silts which are water saturated, until they emerge at a lower point but through the same silt layer. At this point, silt volcanoes are formed.

In the case of the present example, the underlying sediments are not exposed but nevertheless, the mechanism for formation of these pipes is thought to post date the deposition of several layers of sediment. The pipes probably represent water escape structures whereby upward moving water carried fragments of red silt from below and mixed the fragments together with an already deposited fine sandstone layer to produce the mixed lithology of the upper 50 cm. of the bed. The process was probably contemporaneous with sedimentation.

b. Relationship of Bed Form and Grain Size Within the Upper Member

The relationships between different sediment sizes and sedimentary structures is similar to that presented for the Lower Member. The sequence of events following the formation of an erosive surface is the deposition of sediments which fine upwards together with increase in sorting and decrease in size of sedimentary structures. The presence of abundant silt clasts indicates that there was substantially more fine sediment of overbank or channel fill origin which was rapidly reworked in the succeeding cycle thus suggesting rapid change in channel directions. Occasionally some overbank or channel fill silts are preserved.

c. Palaeocurrent Data

Very little palaeocurrent information was obtained for the Upper Member of the Arkose Lake Formation. All the directions were gathered from trough cross-bedding and are plotted in figure XIV. Those directions obtained to the south of Arkose Lake (Grid. Ref. 138 037) show a bimodal distribution with a mean direction of 161^{o}. To the west of Club Lake only four directions were obtained which give a mean azimuth of 133^{o}. Once again, however, there is a general, southward direction of currents at the time of the deposition of the member.

IV. Contact Between the Upper Member of the Arkose Lake Formation and the Overlying Majoque Lake Volcanics

Where the contact between the two formations is seen, the sediments of the upper member are baked indicating that the contact is depositional and not tectonic. The contact surface is planar (Pl. VII) with the volcanics baking the underlying sediments to a depth of 10 cm. The baked rock is usually bleached and may contain sedimentary structures. Plate VIII shows linguoid ripples which are preserved by the influx of volcanics (Grid. Ref. 139 037) and to the west of Club Lake, large scale, trough cross-bedding is preserved (Grid. Ref. 040 021). The linguoid ripples were the only example of ripple marks exposed on a bedding surface in the area. This suggests that they did occur but were usually re-worked or truncated by later sedimentation processes.

The linguoid ripples are small scale suggesting shallow water stream deposition so that the volcanics may have flowed in over water laden sediment.

Located south of Arkose Lake.

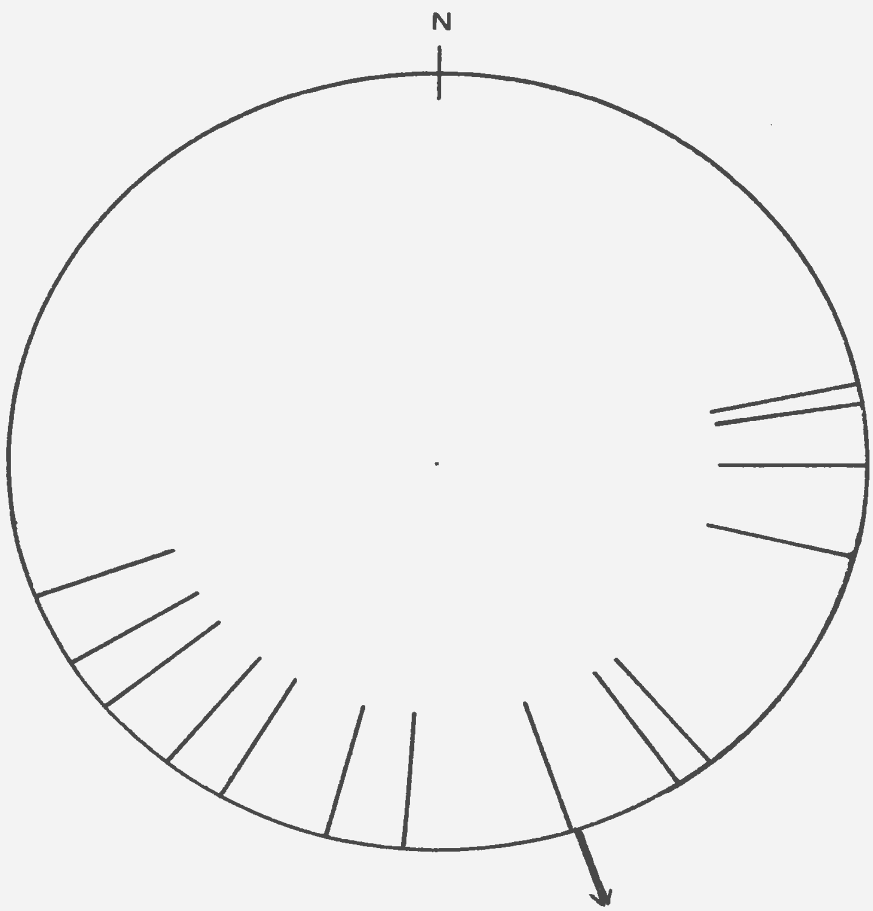
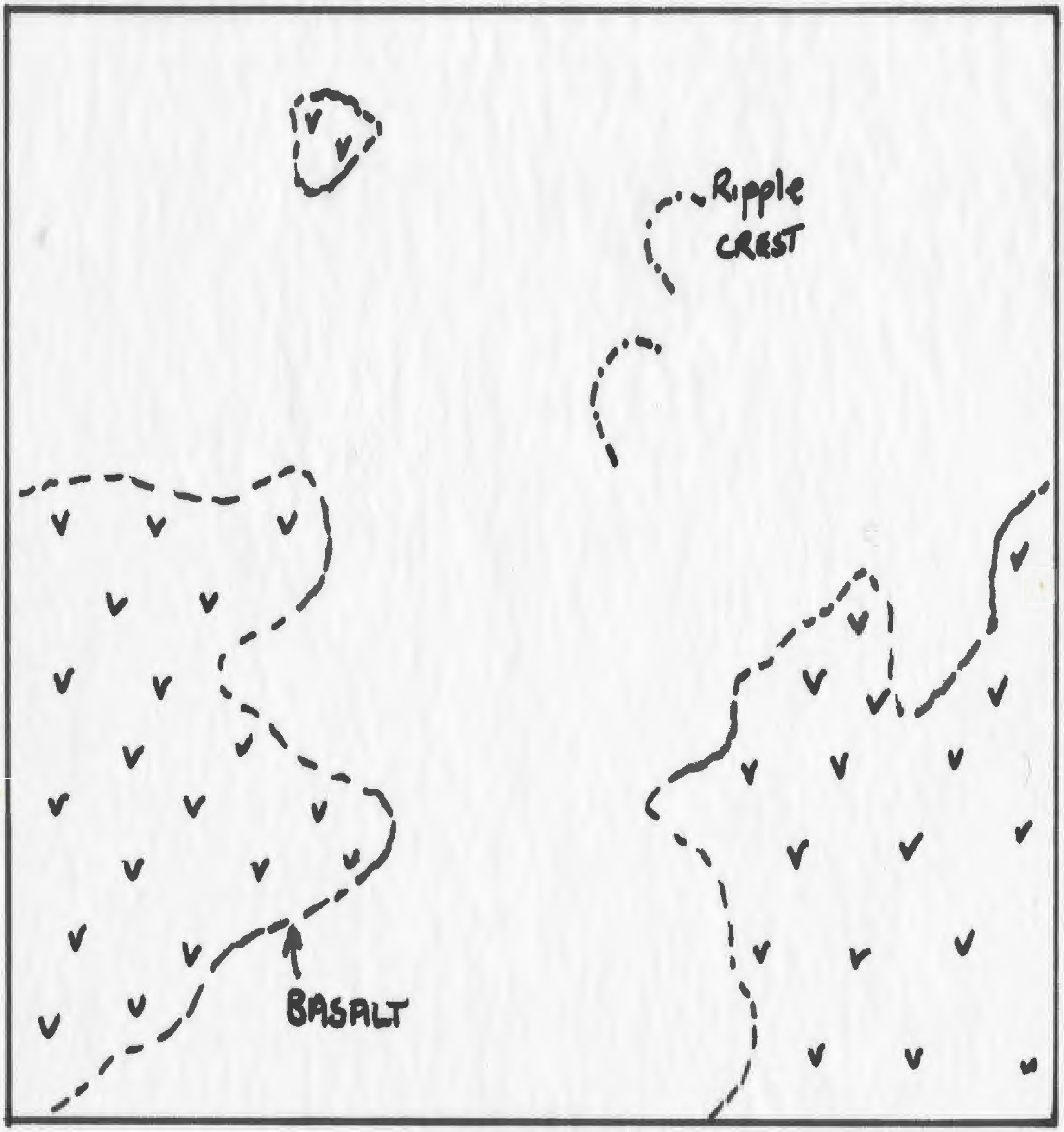


Fig. XIV. Palaeocurrent distribution - Upper Member, Arkose Lake Formation. Directions corrected for dip of bedding and plunge of folds in the field.


Ripple
CREST
BASALT

Pl. VII. Contact between sediments of the Arkose Lake Formation (to left) and the basalts of the Majoque Lake Formation.

Pl. VIII. Linguoid ripples preserved in sandstones at the Arkose Lake/ Majoque Lake Formations contact by basalt (dark areas lower left and right).

This is supported by the existence of irregular cavities in the basal part of a thin flow which overlies the sediments to the southeast of Arkose Lake (Fig. XIII) (Grid. Ref. 166 035). These cavities probably result from the trapping of water vapour produced by heating of water laden sediment (Waters, 1960). At the same locality, irregular xenoliths of green, sugary quartzite are enclosed within the volcanics.

V. Intrusive Rocks

Within the lower member of the formation, a single, poorly exposed, basic volcanic body occurs. It can be traced from Grid. Ref. 171 048, to 156 047 and is a sill like body which apparently dies out to the west. The basic rock is fine-grained but is heavily chloritised and cut by epidote filled tension gashes. At one locality (Grid. Ref. 156 048) it is cut by a low angle thrust fault. At the same locality, the basal contact is exposed and it appears to have been a surface of tectonic movement since it is slickensided and the basalt and sediment at the contact are heavily sheared and recrystallised. This is shown by the obliteration of the granular texture of the underlying feldspathic grit which has become a homogeneous, fine-grained, pink rock. Nowhere is the upper contact exposed, but the body is at most only 2 m. thick.

The body is thought to be an intrusive sill since it occurs well below the first volcanic influx within the area and it is internally structureless.

B. The Majoque Lake Formation

I. General Statement

The Majoque Lake Formation comprises a thick succession of basaltic lava flows with several thin sedimentary interbeds. Baragar (1969) estimated a maximum thickness of 5000' for the formation. As a result of this study of the Arkose Lake area, however, it is estimated that the Majoque Lake Formation is probably thicker than Baragar's figure since approximately 3000' was encountered in this study and this represents less than half of the total thickness that would be traversed for the complete formation.

The base of the Majoque Lake Formation is marked by the first volcanic flows that terminate the sedimentation of the Arkose Lake Formation. The contact is conformable as the volcanics definitely interrupt active sedimentary processes (see page 52).

As the volcanic rocks compose more than 95% of the Majoque Lake Formation, they will be described first.

II. The Volcanic Rocks of the Majoque Lake Formation

The volcanic rocks of the Majoque Lake Formation are composed entirely of basalt (Baragar, 1969, see later). The basalts are aphanitic to porphyritic, dark grey rocks. The porphyritic basalts usually display abundant 1 mm. long plagioclase laths but some infrequent and isolated flows exhibit large plagioclase phenocrysts of up to 1.5 cm. long. No primary mafic minerals can be recognised in the field although specks of dark green chlorite are scattered through many of the basalts and may represent altered mafic minerals. At one locality (Grid. Ref. 119 063) north of Margaret Lake, settling of magnetite to the base of a thick basaltic flow was found.

Several different flow types have been recognised. The most common are thick, columnar-jointed flows. These are capped by massive, amygdaloidal and rubbly basalt. They also appear to pass laterally into rubbly Aa type flow structures as well as into flows displaying typical Pahoehoe structures. Discrete Aa and Pahoehoe flows which are relatively thin also occur as well as scoriaceous flows, pillow lavas and pillow breccias. These latter flow types have a hyaloclastic matrix between the pillows and pillow fragments.

a. Flow Types

1. Columnar Jointed Flows

Columnar jointed flows from 15 to 30 metres thick are common throughout the area. Such flows are made up of several tiers of columns with each tier being separated by a slightly irregular, horizontal joint surface (Pl. IX). Sometimes a 30cm. layer of horizontally jointed massive basalt occurs between each tier. Usually the columns which comprise each stack are small in size, being 1 to 3 metres in length and about 20 to 30 cm. in diameter and they are uniform in size throughout the flow. Occasionally however, large columns occur at the base of a flow. These are 5 to 7 metres in length and at least a metre in diameter (Pl. X) and are developed throughout the area; as for example, in a flow directly overlying the lowest sediment band in the formation.

The columnar centres and bases of the flows pass upward into massive basalt with poorly developed columnar jointing. Horizontal joints and streamers of amygdales infilled by epidote and chlorite characterise the massive basalt. Towards the top of the flow, the basalt becomes progressively more vesicular and it is common for the top of the flow to be broken and fragmentary.

The columnar basalt flows of the Majoque Lake Formation compare favourably with those described by Waters (1960) in the Columbia River Basalts, Oregon. Waters describes similar thicknesses and also arrangement of large, basal and small upper column layers and horizontal joints and massive basalt layers. It is probable that the horizontal joints and massive basalt layers described here may be equivalent to isothermal cooling surfaces. No evidence of tilted column stacks indicative of flow directions was found in the Arkose Lake area. Occasionally the small, isolated, tilted and bent columns which do occur are probably

Pl. IX. Well developed columnar-jointing in basalts of the Majoque Lake Formation.

Pl. X. Large scale, columnar-jointing developed in the basalt flow overlying Sediment Band A (area III), Majoque Lake Formation.

of tectonic origin.

Columnar jointing is difficult to distinguish unless seen in cliff sections. Isolated outcrops of basalt rarely show the well developed jointing indicative of columnar basalt. However, many outcrops display poorly developed jointing which is often associated with a network of reddish-brown rings of iron oxide. The iron oxide is distributed in three zones which make up each ring. Two marginal zones occur on either side of a median zone which is marked by intense red colouration or by a vein of iron oxide (Pl. XI). The area between the outer and the median zones is not so heavily stained. The rings are polygonal, spherical or irregular in shape and surround an area of stain free basalt. In many cases, the median vein corresponds to a vertical fracture within the basalt and this may represent incipient columnar jointing (Mann. 1959). In other cases, the rings disregard such fractures. The rings usually occur near the top of individual basalt flows often immediately below a red oxidised, rubbly or vesicular top. Rings have also been seen within the massive flow centres of Aa and Pahoehoe flows where the tops of such flows have been heavily oxidised. No rings have been seen in association with perfectly formed columnar jointing.

Two origins for this phenomena seem likely: 1. The precipitation of iron oxides from iron-rich fluids migrating along fractures and joints and affecting the immediately adjacent basalt. 2. The weathering and oxidation of the basalt controlled by pre-existing fractures particularly the position of these fractures in relation to the top of a flow.

The concentration of oxides in the three zones of the rings and the presence of the iron oxide vein in the centre of the ring zone suggest the former origin may be correct. Iron-rich fluids would pass through the central

Pl. XI. Iron rings developed in massive basalt, Majoque Lake Formation.

Pl. XIII. Small scale rope structures in the basalts (area II) of the Majoque Lake Formation.

fracture and percolate into the basalt on each side causing a front to develop on each side of the fracture. This mechanism is probably similar to that of paper chromatography.

The main objection to this mechanism however, is that such rings are not found throughout the complete thickness of a flow and are certainly not associated with perfectly developed columnar joints.

The second outlined mechanism of ring formation appears more probable however. It is favoured by the restricted location of the rings adjacent to tops of flows and by rings occurring in the massive centres of Aa flow types which have a rubbly oxidised top as can be seen northeast of Arkose Lake (Grid. Ref. 150 057). Oxidation of flow tops may be the result of several mechanisms.

1. Circulation of groundwater (Macdonald, 1967)
2. Air trapped in the basalt (Macdonald, 1967)
3. Magmatic gases (Einarson, 1949).

Probably all three mechanisms could have caused the oxidation but the circulation of groundwater is essential to the movement of the iron from the oxidised flow tops down along the fractures deeper in the flow. In thick columnar jointed flows such circulation would be restricted downwards and the rings will only occur in the upper parts of a flow.

The process is one which occurs either contemporaneously with the final solidification of a flow or post-dates solidification and takes place in advance of the influx of the next flow.

2. Pahoehoe and Aa Flows

It is difficult in the field to divide flows into discrete pahoehoe and Aa types as the two grade into one another within the same flow.

The pahoehoe flows are characterised by densely vesicular tops, massive flow centres and coarse vesicular bases (Pl.XII). The top of the flow is usually smooth and undulatory with a vesicle free crust up to 2 cm. thick occurring at the surface. Below the crust, densely packed,small, spherical vesicles occur but the density decreases into the flow whereas vesicle size increases. At the base of the flow, the vesicles are larger and generally irregular in shape. Vesicles may be stretched by flow in the upper parts of the flow. The vesicles are commonly infilled by quartz, calcite, epidote, chlorite, haematite, and zeolites.

Surface rope structures occur throughout the area (Pl.XIII). They are never greater than 70 cm. in width and a metre or so in length but it is common to see a number of rope structures at one locality (eg. Grid. Refs. 087 039 and 150 056). The ropes are similar in form to those described by Macdonald (1967), being curved with the convex side pointing in the direction of flow.

Small dykes of basalt invade the breaks in slab-like pahoehoe and vesicular basalt (Pl.XIV) and large, irregular cavities are not uncommon. On the sides of the cavities, congealed drips of basalt occur on smooth mammilated and folded surfaces. These features all indicate that there was draining of pockets of liquid lava within consolidated basalt during movement of the flow and at the same time, the flow crust was fracturing to give slab-like pahoehoe and being injected with fluid lava from the centre of the flow. Flat elongate and irregular shaped cavities which lie parallel to the tops of the flows also occur. They may be up to a metre in length and several may occur at one level to form an almost continuous cavity. They may remain open or be infilled with grey quartz and epidote surrounded by calcite. They probably represent parting of consolidated lava along a horizontal joint parallel to the surface of the flow

Pl. XII. A thin basaltic flow (area II) displaying vesicular base, massive centre and vesicular top typical of flows of Pahoehoe type.

Pl. XIV. Small, basalt dyke intruding vesicular, fractured top of basalt flow (area I), Majoque Lake Formation.

Pl. XV. Basalt rubble from top of flow of Aa type, (area I).

whilst liquid lava continued to flow beneath the consolidated crust.

To the northeast of Arkose Lake, (Grid. Ref. 152 053) the top of a pahoehoe flow was arched to form a tumuli or pressure ridge (Fig. XV)(Daly, 1913). The arching is shown by jointing and the centre of the arch is a large cavity which is filled with basalt rubble. The arch is overlain by horizontally jointed,vesicular basalt of a later flow. Such features are produced by movement of liquid lava beneath a solid crust causing pressure upon the crust. Macdonald (1966) describes such ridges in Hawaii where they occur near the margins of flows and where flow has become dammed. In Iceland, such ridges are common throughout the terrestrial lava fields (personal observation).

Structures typical of Aa flow types are easily recognisable throughout the area. They are characterised by blocky, fragmentary tops overlying a central portion of massive basalt which in turn overlies more rubbly basalt. The rubbly top of one flow (Grid. Ref. 150 057) was measured as 85 cm. thick. as compared to 15 cm. of central,massive basalt and 20 cm. of basal,rubbly basalt. It is however, not always possible to see this three-layer arrangement in outcrop and most often just the rubbly tops can be seen (Pl. XV).

The basalt fragments which form the tops of the flows may be up to 30 cm. in diameter but are usually 10 cm. or less. They are jumbled haphazardly with many sizes intermixed (Pl.XV). The fragments are generally angular but their edges may be rounded because of wear during flow movement. The basalt rubble is vesicular although the vesicles tend to be irregular in shape and two or more vesicles are often linked. The rubble is loosely bound by fusion at the contacts of adjoining fragments but later mineral cement infilling the cavities is also common (Pl.XVI).

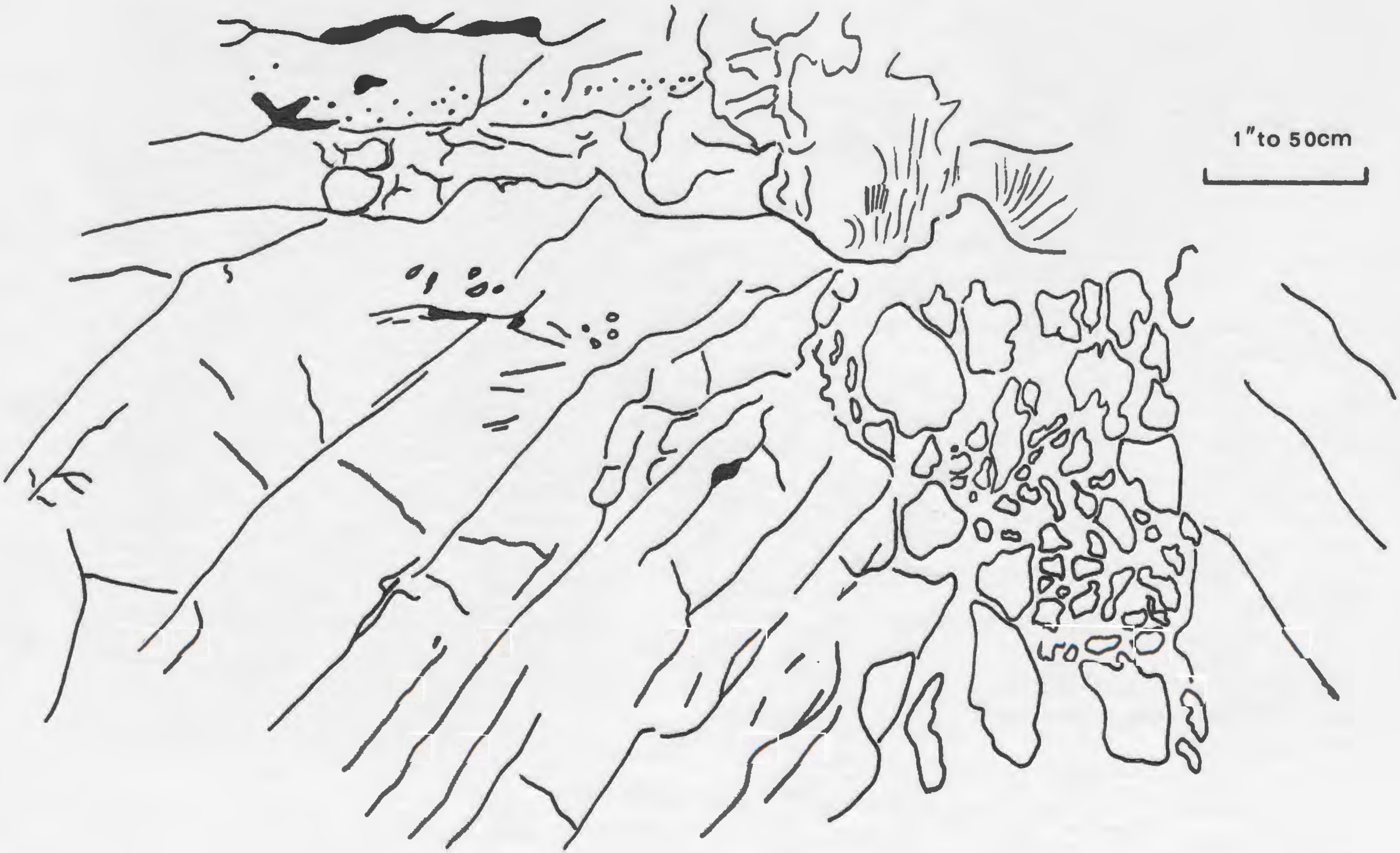


Fig. XV. Tumuli in basalt, area I, northeast of Arkose Lake.

Pl. XVI. Smooth, glaciated surface in rubble top of Aa flow; white areas between fragments consist of quartz or calcite mineralisation.

Pl. XVII. Smooth, glaciated surface cross-cutting pillow structures (light areas) which are set in dark, hyaloclastite matrix in pillow lava, (area I) Majoque Lake Formation.

The upper rubble zone of the Aa flows is usually heavily oxidised and this gives the flow top a deep brown-red colour.

The thickness of flows of pahoehoe and Aa types could be only measured occasionally indicating thicknesses between 1 and 3 metres.

3. Scoriaceous Basalt

Occasionally, flows of scoriaceous basalt occur in the succession. These flows are distinct from Aa flows as they do not possess a central massive portion. The flows are made up of small scoria fragments which enclose larger, rounded knobs of vesicular basalt. Fine fragments and dust infill between the scoria and a chloritic - epidotic - haematite aggregate cements the rocks. The matrix possess a distinct undulatory foliation in places which bends around the larger fragments and is parallel to flow tops. This foliation may be due to compaction with collapse of the honeycomb structure of the fragments and compression of the matrix in the vicinity of the larger fragments. The flow is highly oxidised and very deep reddish-brown in colour. Botryoidal haematite occurs within the vesicles.

One flow is up to 2 metres thick and can be traced intermittently for two kilometers along strike (from Grid. Ref. 114 022 west to 083 015).

4. Pillow Lavas and Pillow Breccias

Pillow lavas occur at scattered localities throughout the area. They do not appear to be very extensive deposits although the outcrop does not permit tracing along strike.

The pillow lavas are made up of loosely to quite densely packed pillows set in a fine-grained matrix of basalt fragments and tuffaceous material. The pillows which may be up to a metre in diameter are spherical, elongate or irregular in shape (Pl.XVII). Vesicles are not common in the pillows although some small vesicles occur in the centres. Radial fractures typical of the internal structure of a pillow (Macdonald, 1966) can be seen in some of the pillows (Pl. XVIII).

If the pillows are heavily fractured, a pillow breccia may result (Pl.XIX) with angular fragments of basalt scattered through the matrix.

The matrix of both pillows and pillow breccia is a combination of small basalt fragments and a tuffaceous material. The tuff is green in colour being composed of chlorite, with lesser amounts of red iron oxides and possibly some pink quartz. The appearance of the matrix resembles the descriptions of aquagene tuffs described by Carlisle (1963) in British Columbia and by Sigvaldason (1968) from the subaquatic flows of Iceland.

Both authors indicate a formation of both pillow breccias and aquagene tuffs, initiated by molten lava flowing into a body of water. Immediately globose pillows are formed with an outer semi-plastic crust forming a seal to liquid lava within. Each pillow thus becomes an isolated, closed system in which lava cools and solidifies. During solidification, magmatic gas segregation occurs and these gases are confined within the pillow crust. Should the internal gas pressure exceed the confining pressure, then the pillow will shatter. At the same time as pillow and pillow breccia formation, lava between the pillows is being quenched to form a glass. The rapidity of cooling, however, tends to shatter the glass and so an aquagene tuff results, the glass fragments later devitrifying.

The infrequency or absence of vesicles in the pillows of the Arkose Lake area suggests that there was little gas in some of the basalt flows which formed pillows. This may account for the presence of some pillows in an environment

Pl. XVIII. Radial fractures in a near spherical, pillow, structure, in pillow lava, (area III) Majoque Lake Formation.

Pl. XIX. Pillow breccia set in hyaloclastite matrix (area I), Majoque Lake Formation.

which was subaerial as indicated by the other flow types.

b. Flow Directions Within the Basalts

Structures such as ropes, stretched amygdales and flow-orientated phenocrysts can be used to indicate flow directions of the volcanics. The data obtained are plotted in figures XVI and XVII. The data for orientated phenocrysts indicate a scattered distribution (figs. XVI a & b). However, the data for rope structures and stretched amygdales have been subdivided into both area I and area II (see below) (fig. XVII a & b). Very little information was obtained in area III. The data is remarkably consistent considering that these flow structures are controlled by local flow within a main flow. The ropes give a true direction whilst the amygdales are two-directional structures. The flow direction in each area appears to be south-southeast, indicating that the basalts have originated from a source to the north of the area (fig. VIII).

III. The Sediments of the Majoque Lake Formation

The sediments of the Majoque Lake Formation consist of thin units up to 50 metres thick. Six units occur within the area but the highest stratigraphic unit was only mapped for a short distance at the western part of the southern boundary of the area (Grid. Ref. 026 004) before it strikes southeast out of the map area. Each unit is given a letter and they are referred to as Band A, Band B, etc. (see fig. VI).

For the ease of description, it is proposed to subdivide the outcrop of the Majoque Lake Formation in the area into three structural areas referred to as I, II and III. They are: I. The area of the northern syncline.

II. The area of thrust faulting to the north and northwest of Club Lake.

Fig. XVI. Distribution of plagioclase phenocrysts in basalts of the Majoque Lake Formation.

a)

—— Represents a two-directional reading.

All directions corrected for dip of beds and plunge of folds in the field.

b)

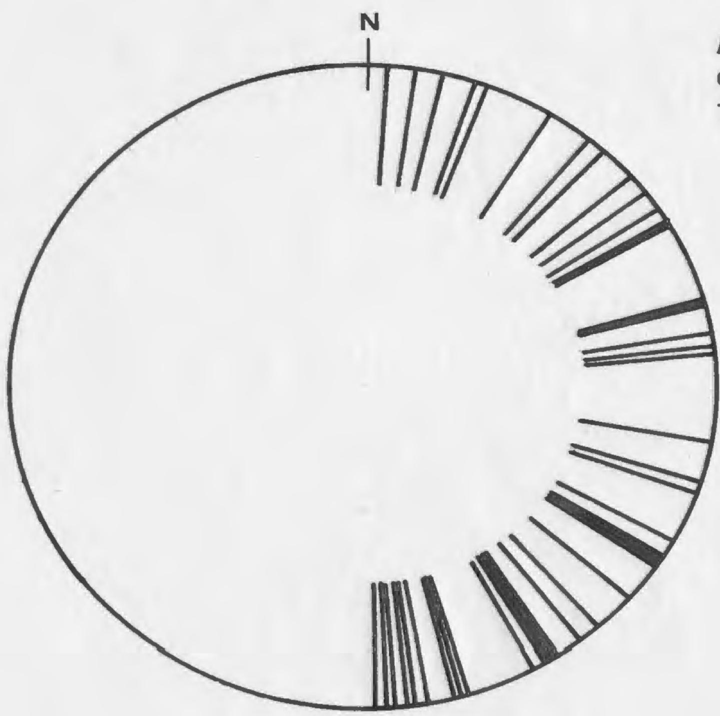
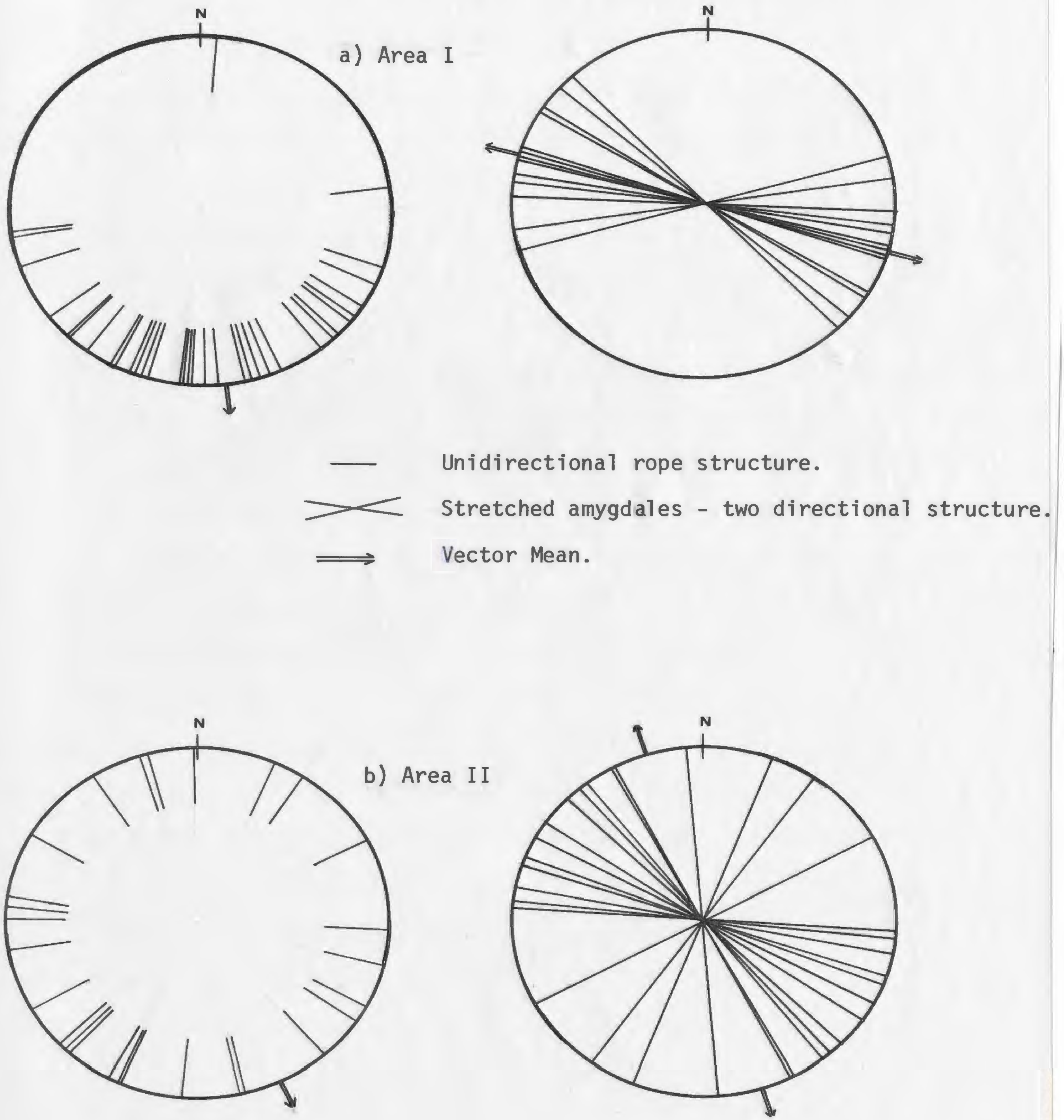


Fig. XVII. Distribution of directional flow structures in basalts of the Majoque Lake Formation.



III. The southward-dipping succession south of Arkose and Club Lakes.

The bands have a lateral extent of several miles but only Band C has been traced along strike from the eastern to the western limits of the area. Bands B, D, and E all thin out along strike and eventually disappear within the area. D and E thin out westwards whilst B thins to the east. Band A appears to be persistent from the western limit almost to the eastern margin of the area.

Table I gives the thickness variations for the Bands A, B, C, D and E. Band A (fig. XVIII) which occurs 7 to 15 metres above the contact of the Arkose Lake and Majoque Lake Formation is relatively thin throughout. However, within area I its sedimentary character changes radically from that elsewhere in the Arkose Lake Area (see later). None of the other bands occur within area I. Band C persistently thickens from east to west in area III and it is the thickest mapped. A sediment band comparable in composition and sedimentary structures to those mapped in area III also occurs in area II (fig. XIX a & b). Its thickness is comparable to that of Band C and as Band B is relatively thin whenever it was located, the band in area II is correlated with Band C in area III. This correlations implies that Band B has thinned out and perhaps disappeared to the north.

Usually only a single unit of sediment is exposed in outcrops but several exposures on Band C, D and E (Grid. Refs. 126 029, 160 025 and 118 023, respectively) show that they may contain two units of sediment which are separated by a thin basalt flow. It is the upper of the two sediment units that is generally exposed as the lower one and very often the basalt flow is covered by talus debris. Beneath the upper unit of sediment, the tops of the basalt flows are deeply weathered to a brown-red, fine-grained, lateritic deposit (see later). The laterite also occurs beneath the sediment of Band A and below the lower

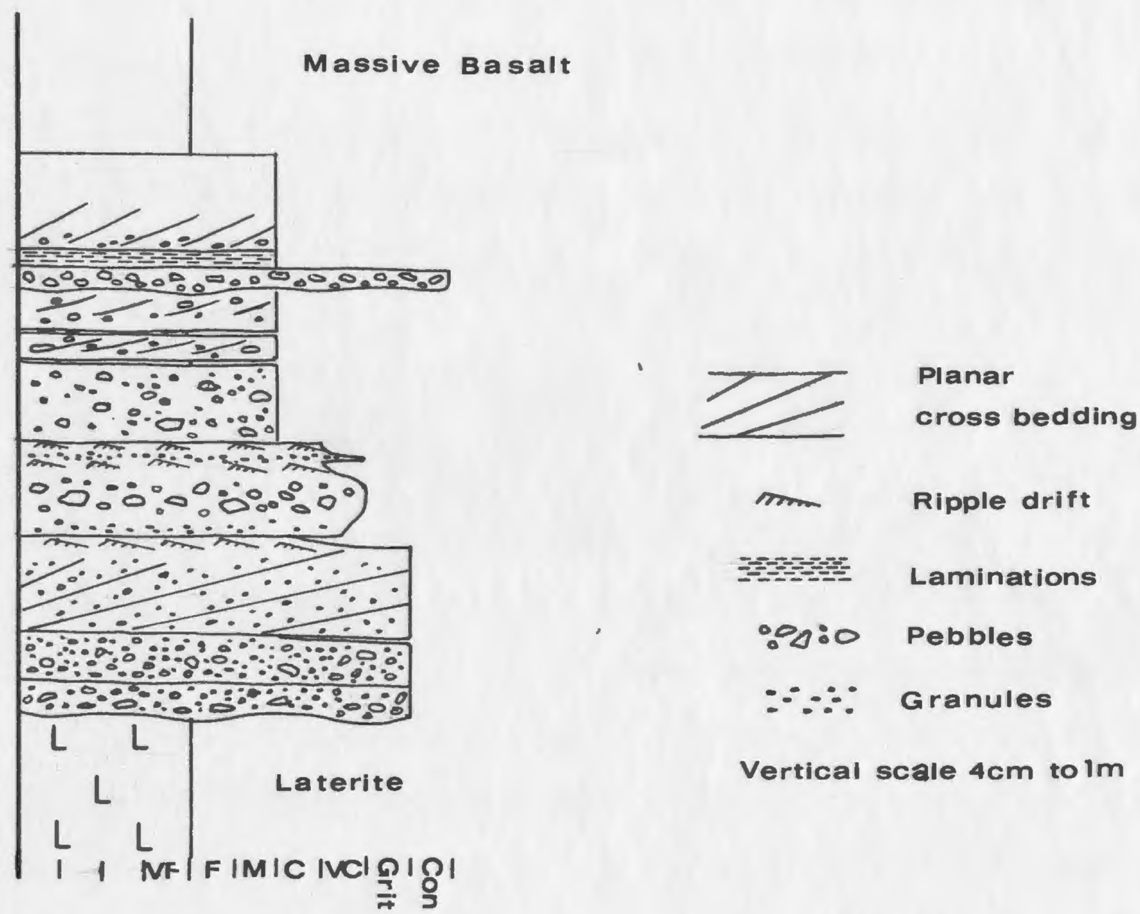


Fig. XVIII. Section 4 - Sedimentary section in Sediment Band A, area III.

sediment units of Bands C, D and E.

a. General Lithologies

The sediment bands of the Majoque Lake Formation consist of intercalated conglomerates, arkosic to quartzose grits, coarse and very coarse arkosic to subarkosic sandstones, some medium sandstones and occasional red coarse silt lenses and very fine sandstone. The lithologies are dominated by conglomerates and the coarser sandstones. Within a band, there is a general fining upwards of component grains and this is especially noticeable in the pebble sizes of the conglomerates.

1. Conglomerate

The conglomerates are composed of pebbles usually from 1/2 cm. to 2 cm. in diameter but pebbles of 5 cm. diameter are not uncommon. Pebble counting was undertaken in the field. The counts recorded the ten largest pebbles, and their lithologies and an overall modal pebble count for an area, half meter square. The results of the largest pebbles recorded show that the coarsest pebble sizes in Band C are fairly uniform (about 2.5 to 3.5 cm.) except in the extreme western part of the area where the coarsest pebbles increase up to 6.1 cm. (see table I and Fig. VIII). This increase corresponds to the westward thickening of Band C. The size of the coarsest pebbles in Band E also increases westwards but it is not certain if there is a corresponding increase in the thickness of the band. The pebble counts show that the pebble types are dominated by a few lithologies. Of these white quartz which may attain up to 86% in extreme cases, is the most abundant clast type, followed by feldspar which can form up to 54% of a pebble unit. Purple and red quartz may individually form up to 20% of the counts.

TABLE I

Band Thickness and Pebble Size Variation for Sediment Bands of the Majoque Lake Formation

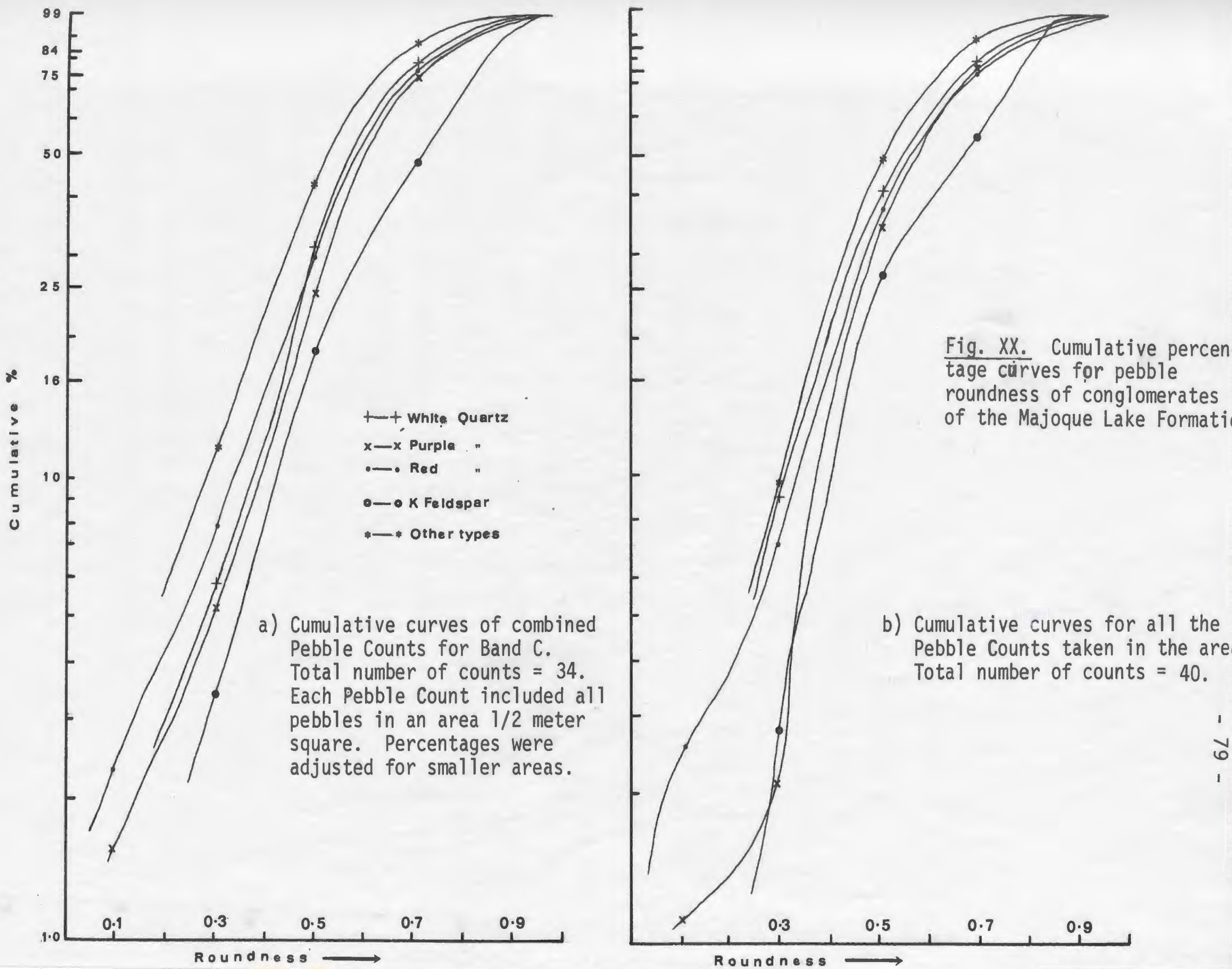
BAND A						
Area I	East		Centre		West	
Band Thickness	1.20m.		5.85m.		--	
Area II						
Band Thickness	--		--		4.5m.	
Area III						
Band Thickness	3.5m.		1.95m.	1.8m.	1.8m.	
Maximum Pebble Size	2.3cm.		--	0.7cm.	3.0m.	
Band B						
Area III						
Band Thickness	--		--		2.0m.	
Band C						
Area II						
Band Thickness	14.1m.		9.5m.	8.75m.	6.2m.	
Maximum Pebble size	1.0cm.		1.9cm.	3.5cm.	3.0cm.	
Area III						
Band Thickness	3.2m.	4.0m.	9.5m.	11.5m.	14.5cm.	13.5m.
Maximum Pebble Size	2.3cm.	2.4cm.	3.0cm.	5.5cm.	3.5cm.	4.5cm.
Band D						
Band Thickness	1.35m.					
Band E						
Band Thickness	4.72m.		4.5m.		5.25m.	
Maximum Pebble Size	2.5cm.		4.0cm.		5.0cm.	

These five pebble types are supplemented by minor percentages of grey quartz, bluish white opalescent quartz and epidote which is often veining or veined by quartz. Occasionally jasper, red chert, basalt, anorthosite,granite and sandstone pebbles are found. Table II shows the various percentages of pebble types for each pebble count recorded and the averages for each band and for all the counts as a whole are also presented. The counts show that the major and minor pebble types are consistent for each band except Band A. In Band A, the usual pebble types are supplemented by minor percentages of granite gneiss, rhyolite, rhyolite porphyry, feldspar porphyry, laterite and arkosic sandstone.

The feldspar pebbles are usually fresh, unaltered pink to salmon pink in colour. They are sometimes bleached creamy-white on weathered surfaces and Mann (1959) suggested that they are kaolinised. Some feldspar pebbles have been altered and are pale green in colour suggesting sericitisation. Other feldspar pebbles show a deep red, iron-oxide rich centre surrounded by an iron-free, pink outer rim. Most of the feldspar occurs as small pebbles of about 0.5 cm. diameter; large sizes are uncommon.

The pebbles were also analysed for roundness and sphericity in the field using the chart of Krumbein (1941). The roundness results were computed and plotted as cumulative curves (Figs. XX). Separate curves show values for quartz and feldspar. The results indicate that although the pebbles cover the complete range of degrees of roundness, the quartz pebbles are generally less well rounded than the feldspars and both groups have a high percentage of angular and subangular pebbles.

However, although the cumulative curves for sphericity indicate a large percentage of spherical pebble shapes, such data collected for sphericity is treated with caution because pebble shapes involve three dimensional measurement



a) Cumulative curves of combined Pebble Counts for Band C. Total number of counts = 34. Each Pebble Count included all pebbles in an area 1/2 meter square. Percentages were adjusted for smaller areas.

b) Cumulative curves for all the Pebble Counts taken in the area Total number of counts = 40.

Fig. XX. Cumulative percentage curves for pebble roundness of conglomerates of the Majoque Lake Formation and Krumbein's chart and the smooth, glaciated outcrops of the Arkose Lake area only show pebble shapes in two dimensions.

In the field, general observations showed that quartz occurred in all of the Zingg (1935) shapes with rods and spheres dominating. The feldspar pebbles however, are predominantly blades with a prismatic form. Quartz pebbles appear to show poorer rounding compared to the feldspars and the latter were often angular and showed very little modification to their original crystal shape. Drake (1970) has drawn attention to structural controls of pebble shapes whilst Sames (1966) believes that only those lithologies that contain no structural, igneous, metamorphic or sedimentary textural controls and are relatively resistant to abrasion are useful environmental indicators. Thus, the shape and roundness of the quartz pebbles will provide the most significant environmental evidence although the presence of angular, prismatic feldspar pebbles is also important, since feldspars are relatively easily broken compared to quartz. The presence of pebbles showing very little abrasion suggests rapid weathering, transport and deposition of the conglomerates. Some of the quartz pebbles however, show driekanter shape suggesting wind faceting typical of an arid or semi-arid climate.

The conglomerates are poorly sorted. The larger pebbles (1 - 2 cm. or greater) are usually set between more numerous, smaller pebbles of approximately 0.5 cm. diameter. The conglomerate matrix is usually a poorly sorted grit to coarse sandstone mixture with a dark, clay matrix binding the coarser factions. Opaque ore minerals are scattered through the sand faction of the conglomerates.

2. Grits and Sandstones

Poorly sorted, often pebbly arkosic to quartzose grits and medium to very coarse sandstones are intercalated with the conglomerates. The sandstones and grits are red, reddish brown and yellowish white in colour. Dark reddish-brown, iron oxide stains occur in patches throughout the sandstones and grits where haematite has been heavily concentrated. The sandstones and grits are composed of similar major constituents as the conglomerates. The coarser sediments are generally poorly sorted and clay matrix is abundant. Opaque ore grains are scattered throughout the poorer sorted sediments. The medium sandstones are usually better sorted and often show heavy mineral laminations. Thin red, green and grey, coarse silts and very fine sandstone mixes occur as thin lenses 4 cm. to 25 cm. thick within the coarser sandstones.

All these lithologies are present in all the bands. However, the character of Band A is different in area I than in area II and III where the lithologies described above occur (fig. XVIII). In area I, Band A is a fine-grained, pink quartzite which is locally cherty in appearance and may be stained green. At localities (Grid. Ref. 130 059) to the southeast of Margaret Lake, the upper contact is locally distorted into small quartzitic dykelets intruding the overlying basalt. This relationship suggests that the rock was an acid intrusion and the outcrops were previously mapped as intrusive sill bodies within the basalts (Knight, 1970). Thin section examination has since shown that the lithologies are sedimentary quartzites. The band is quite thick in the west of area I but thins considerably eastward (Table I).

b. Sedimentary Structures

Within all the bands mapped, there appears to be a close correlation between grain-size of sediment and the type of structure present.

1. Conglomerates

The conglomerates exhibit few internal sedimentary structures. They are massive bedded in units up to 1.3 m. thick (Pl. XX) but occasionally a broad grading from base to top of a bed does occur. The conglomerates lie upon undulose or planar scour surfaces that truncate earlier sediments and structures.

Conglomerates can also form the basal parts of beds which grade up into grits and coarse sandstones which are often pebbly. The conglomerates are thin and structureless but the overlying finer sediments show planar or large and small scale cross-stratification. These conglomerates may be well sorted or poorly sorted.

The massive bedded conglomerates are thought to represent bar deposits of longitudinal type which are associated with braided streams (Doeglas, 1962; Williams and Rust, 1969; Smith, 1970; McDonald and Banerjee, 1971). The bed forms represent dumping of bed load and the planar shape of the forms suggests deposition as plane beds in upper flow regime conditions (Mcdonald and Banerjee, 1971). The well sorted conglomerates probably represent lag deposits and the presence of overlying cross-stratified sands and grits indicates the migration of avalanche bars and large and small scale sand ripples across the top of the pebble deposit.

2. Grits and Sandstones

Cross-stratification is the most common sedimentary structure in the sandstones and grits, but plane beds also occur.

i. Cross-stratification

a. Planar cross-bedding

Planar cross-bedding is the dominant sedimentary structure in the sandstones and grits. It occurs in several associations: (1) In sandstones and grits which

Pl. XX. Conglomerate, Band C (area III), Majoque Lake Formation.

Pl. XXII. Isolated set of small scale trough cross-bedding (ripple drift). Cross-bedding is picked out by heavy mineral laminations.

overlie conglomerates or grits which are massively bedded. The cross-stratification is usually of large dimensions and is difficult to trace because of the two-dimensional nature of the outcrops. The laminae are usually 3 cm. in thickness and apparent dips up to 34^{o} have been recorded.

The origin of these deposits was discussed in the section on conglomerates.

2. As very large scale structures up to 50 - 60 cm. thick comprised of graded and steeply dipping, straight foreset beds up to 6 cm. thick (Pl. XXI). The foreset beds are graded from grit or very coarse sandstone and sometimes small pebble conglomerate at the base of each foreset bed up to very coarse to medium sandstones at the top. The foreset beds which are straight may occasionally curve in a concave fashion as they approach the basal surface of the set. The base of each set is either an undulose or horizontal planar scour which is often overlain by a thin conglomerate or grit.

Graded, straight foreset bedding in such large sets suggests that these deposits formed by avalanche deposition at the downstream end of a transverse bar such as occur in braided stream environments (Doeglas, 1962; Williams, 1966; Smith, 1970).

3. As very low angle cross-stratification which is almost flat bedding in units 20 - 30 cm. thick overlying a basal, flat scour. Internally 5 - 10 cm. beds grade from conglomerate or grit to thin 2 cm. tops of fine or medium sandstone

Low angle cross-stratification which parallels a basal scour has been described by Doeglas (1962) in the Ardêche River in France. There the cobble beds follow the floor of the original channel and it is likely that the deposits result from deposition of bed load in a channel where the channel deepens and flow conditions change.

Pl. XXI. Small cliff section showing low and high angle planar cross-stratification overlying conglomerate bed. Note planar surface between low and high angle planar cross sets, graded foresets in the high angle planar sets and conglomerate truncating high angle planar cross-beds. Band C (area III), Majoque Lake Formation.

b. Trough Cross-bedding

Trough cross-bedding exists only as a minor bed form in the sediments and occurs as both large and small scale structures.

1. Large Scale Trough Cross-bedding

This occurs in grits to medium sandstone. The grits form the basal part of the trough (fig. XIXa) overlying a concave, scoop-shaped scour. Each set is 10 - 15 cm. thick and has a lateral extent up to 50 cm. They may occur in a composite, festooned form for 70 cm. and they overlie the larger scale, planar cross-stratification. Composite and single units occur.

This bed form most likely forms as the result of migrating large scale ripples (Allen, 1963; Harms and Fahnstock, 1965).

2. Small Scale Cross-bedding (Ripple drift)

Four cm. beds of small scale cross-bedding occur in the better sorted coarse to very fine sands. Usually isolated forms occur (Pl. XXII) associated with other bed forms. The cross-stratification is displayed by thin graded laminae where the finer fraction is coloured deep red. Heavy mineral laminations very often are associated with the cross-stratification which they outline.

The small scale cross-stratification overlies both massively bedded horizons which represent longitudinal bars and also large scale cross-bedding. The small scale structures probably represent small scale ripples that migrate across the top of shallow submerged bars and large scale ripples during times of low stream flow.

ii. Massive Bed Forms

These occur in grits which may be pebbly and which may grade up into sandstones. They are similar in form and association to the conglomerates previously described.

iii. Other Bedforms

a. Laminations and ripple drift

Occasional thin lenses of very fine and fine sandstones and coarse siltstones display very fine horizontal laminations and occasionally small scale ripple drift. The lenses can be up to 25 cm. thick but laterally they are cut out rapidly by an overlying downcutting erosion surface. Red silt partings are common at the top of some cross-bedded units. No mudcracking was observed.

b. Flat bedding

Flat bedding occurs in the fine-grained quartzites of Band A in area I. The bedding varies from very thin to laminated (McKee and Weir, 1953) and is difficult to distinguish in outcrop. In thin section, grading on a very fine scale is visible. In the west, occasional grit and coarse sandstone grains occur within the quartzites.

The significance of the quartzites is discussed later.

c. Relationships between different grain-sizes and sedimentary structures

From the detailed sections that were measured throughout the area (figs. XVIII, XIX, and XXI), it is clear that massive bedded, poorly sorted, coarse sediments and better sorted, large scale, planar cross-stratified grits and sandstones form the bulk of the deposits. Although most of the massive beds grade upwards into small or large scale,cross-stratified deposits, there are no clear cyclothemic sedimentation patterns noticeable. Several deposits characteristic of longitudinal or transverse bars may be deposited in successive layers and beds of large scale,trough cross-stratification and occasionally

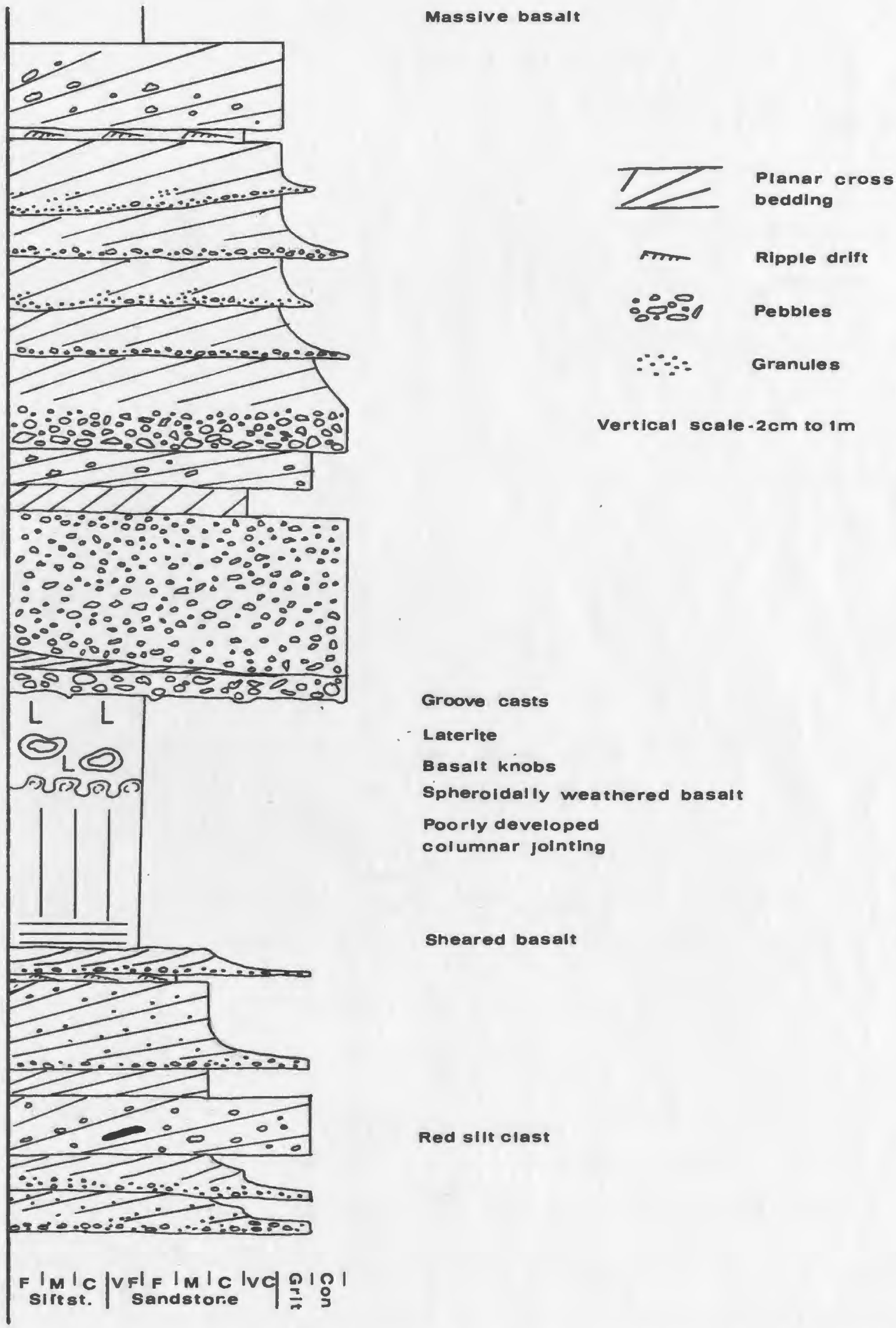


Fig. XXI. Section 12 - Sedimentary profile through Sediment Band E (area III). Majoque Lake Formation.

silt horizons may then occur before the next series of bar type sediments were laid down.

d. Palaeocurrent data

No palaeocurrents were measured except the groove casts which occur at the base of each sediment band (fig. XXII, see pate 95) but from the apparent inclincation of the planar foreset beds, the general current direction is to the south.

e. Nature of the Contacts between the Sediment Units and the Enclosing Volcanic Rocks

1. Upper Contacts of the Sediment Units

The sediment close to the contact of the overlying basalt is baked to a depth of 3 cm. The baked zone weathers to a light colour and quartz pebbles and grains are visibly reddened and resemble red chert as distinct from the white quartz outside the baked zone. In the fresh rock, the matrix of the sediment is dark green and the rocks resemble greywackes in colour and appearance.

The contacts are sharp though undulose on a large scale although sometimes modified by shearing and associated development of veins of quartz and epidote. However, at a locality on Band C in the western part of the area (Grid. Ref. 034 015) pillow structures which intrude and deform the top of the sediment band (Pl. XXII), are developed. The pillows are 35 cm. in diameter and are spherical or irregular in shape. At the immediate contact with the sediment, there appears to be a flow banding within the pillow but this disappears into the centre of the pillow. The pillow intruded pebbly, coarse sandstone with red silt partings which were deformed with intrusion of the pillows (fig. XIXa). Such deformation

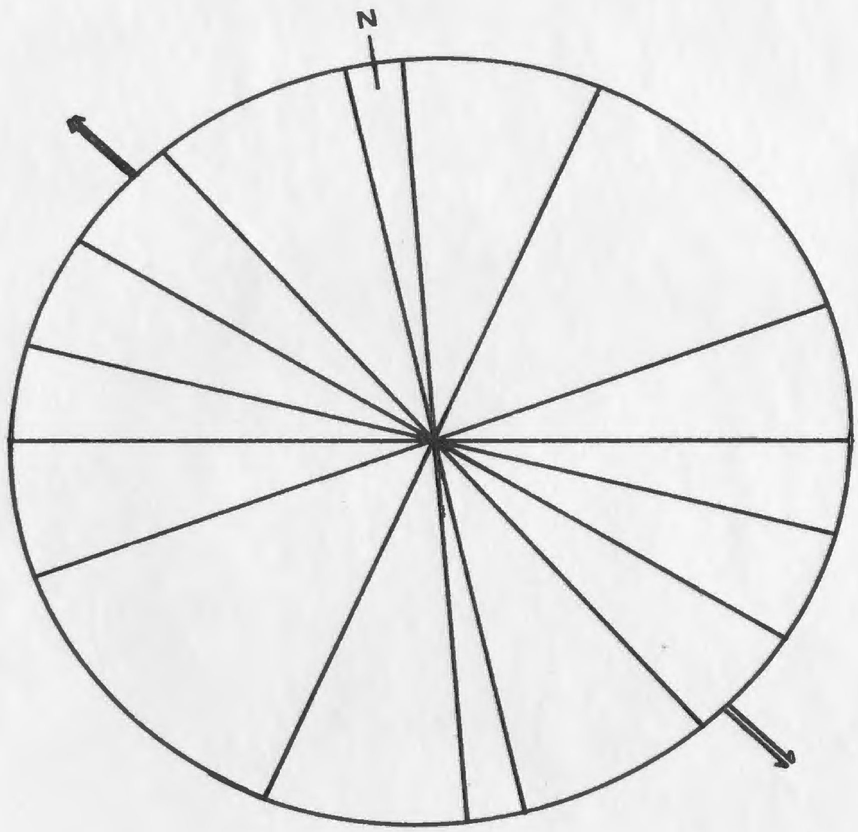


Fig. XXII. Plot of two-directional groove casts-base of Sediment Bands. Majoque Lake Formation.

Pl. XXIII. Basalt pillows intruding the top of Sediment Band C (area III), Majoque Lake Formation.

suggests that the sediment was water laden and directional orientation of the pillows intruding into the sediment suggests that the lava was flowing to the west. It is thus likely that the locality represents an active stream channel at the time of the resumption of volcanism. At another locality on Band C (Grid. Ref. 089 022) an elliptical, scoop-shaped scour (fig. XIXa) was infilled by massive basalt but no intrusion of the sediment took place. In both cases, the basalt immediately above the contact was mixed with some coarse sediment (Pl. XXIII).

The upper contact of Band A in area I is usually a sharp, planar surface (Pl. XXIV). However, in outcrops to the southeast of Margaret Lake (Grid. Ref. 134 060), there is evidence to suggest that the movement of a basalt flow eastwards dragged the sediment upwards to form dykes within the basalt (fig. XXIII). These dykes are 2 - 4 cm. thick and intrude up to 70 cm. into the basalts. The sediment which is fine-grained quartzite does not appear baked in these dykes although there is a distinct green stain to the quartzite at the very contact with the basalts. At one point, a sill-like projection of sediment is taken up within the basalt. It thins from 50 cm. to zero over six metres in an easterly direction. The sediment here was probably partly melted as vesicles occur in a 5 - 6 cm. zone of baking. The basalt in the immediate vicinity of the quartzite is highly vesicular suggesting that there was water in the sediment which was quickly vaporised and the steam trapped in the basalt. The sediment near the basalt displays no internal structures and the contacts with the basalt are very irregular (fig. XXIV).

The basalt flows which overlie the sediment bands are visibly affected in many cases especially where there is a suggestion that water was present, e.g. pillow forms. In many cases, however, the base of the flows is marked by highly

Pl. XXIV. The fine quartzites of sediment Band A, (area I) overlain by fractured, massive basalt.

Pl. XXV. Base of sediment Band E showing conglomerate infilling polygonal cracks in the top of the underlying laterite horizon.

Fig. XXIII. Sedimentary dykelets ramifying into overlying basalt at upper contact of Pink Quartzite and Basalt (Band A, area I) Majoque Lake Formation.

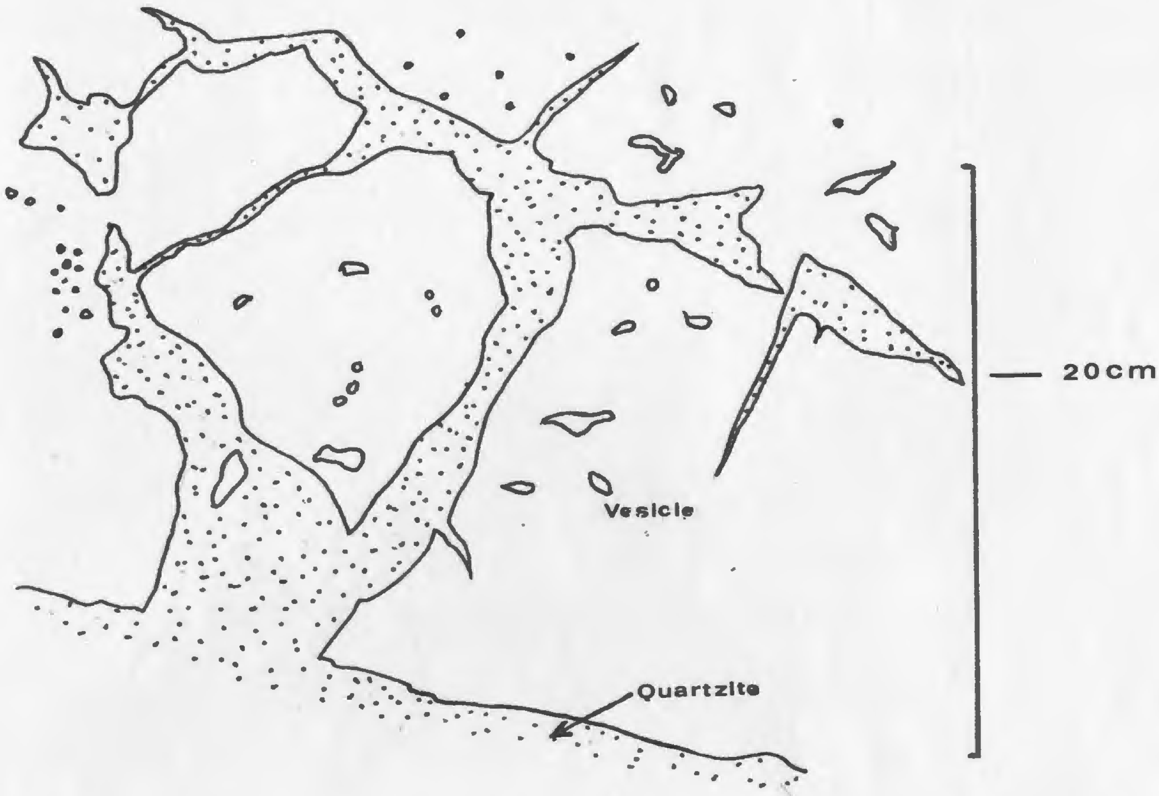


Fig. XXIV. Sedimentary sill enclosed within basalt. Sediment Band A quartzite, area I. Note vesicles in upper part of quartzite sill and vesicle trails in overlying basalt.

vesicular basalt which very often has many cavities. The cavities are irregular in shape and rise in a narrow, near-vertical tube (fig. XXV) which may branch and be infilled by quartz and calcite. The tube-like cavities are 15 to 70 cm. in height. These structures perhaps form because of steam escaping from the underlying sediments which have been heated. They resemble the spiracles described by Waters (1960) from the Columbia River Plateau Basalts.

2. Lower Contacts of the Sediment Units

The bases of the sediment bands generally overlie a fine-grained, red rock which resembles a fine-grained basic tuff but is the weathered top of basaltic flows (see following discussion). The base is generally sharp and planar. However, locally ridges occur on the undersides of the basal beds. The ridges are about 5 - 8 cm. wide and 4 cm. deep. They are sinuous and irregular in direction although showing a general northwest to southeast alignment (fig. XXII). Their directional extent is however, not known due to limitations of exposure. These ridges resemble welt structures described by Friend (1965). In the Arkose Lake area, they represent sinuous depressions cut in the top of the weathered basalt and later infilled by coarse sediment. Thus they may represent irregular rill markings although as they are usually infilled by coarse pebbly sediment they may be formed by scouring of the weathered basalt when the coarse sediment was first brought in over the weathered basalt by currents which must have been in upper flow regime conditions.

Other basal irregularities occur as polygonal structures (Pl. XXV) 4 - 10 cm. across and approximately 1 cm. deep. These may represent shrinkage or mudcracking of the top of the weathered basalt.

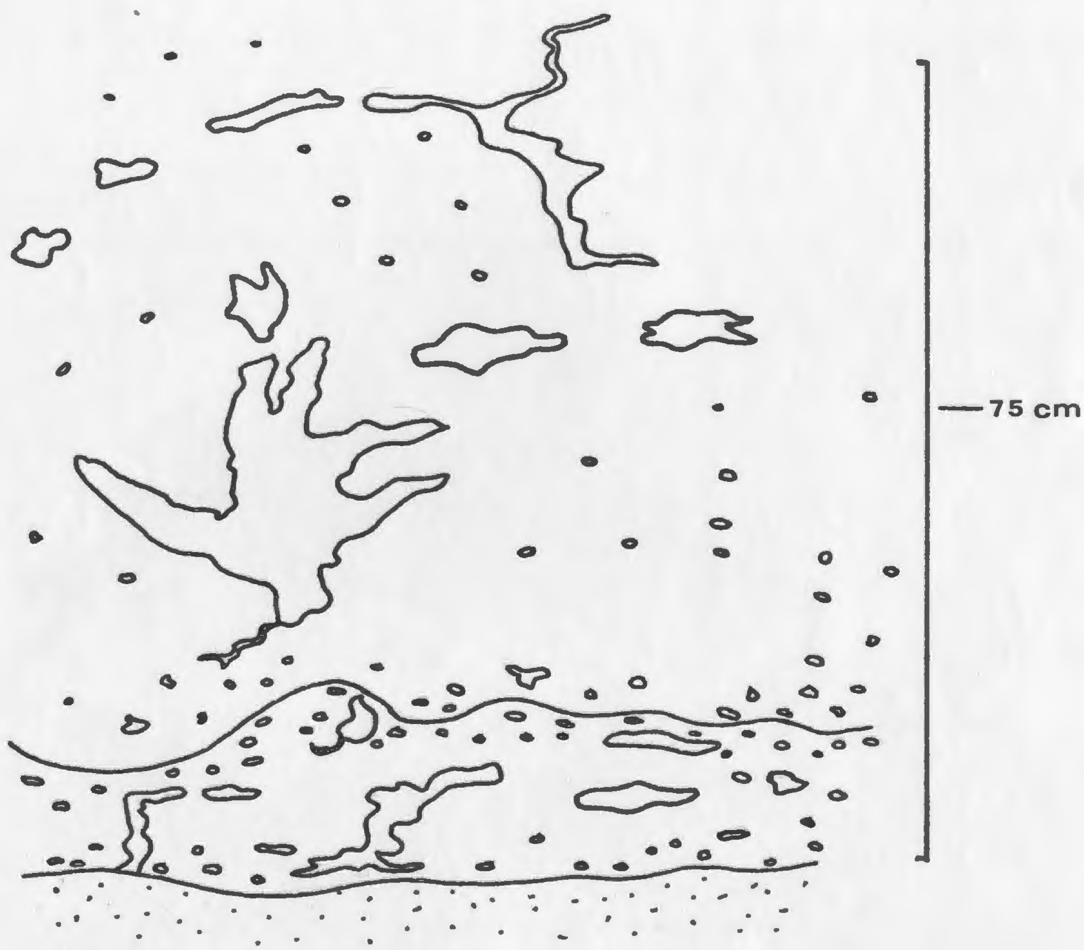


Fig. XXV. Vertical, irregular and branching tubes at the base of a basalt flow which overlies quartzites of Sediment Band A (area I), Majoque Lake Formation.

IV. The Nature of the Weathered Basalt (Laterite)

The weathered basalts form deposits up to 2 - 3 metres thick although only 1/2 to 1 metre is usually exposed. It is generally structureless although it encloses pods of massive, red-weathered basalt and is often mottled by dark brown spots. At one locality, (Grid. Ref. 118 023) where the weathered basalt passes down into unweathered basalt (fig. XXI and Pl. XXVI) knobs of unweathered basalt up to 15 cm. across are enclosed in the weathered rock. Similarly, bulbous projections form the top of the unweathered basalt with weathered material occurring between each bulb. The basalt both in the knobs and at the top of the unweathered part of the flow shows spheroidal shell weathering. Beneath the weathered top, the basalt is massive and in places poorly developed, columnar jointing occurs. Where two sediment units occur separated by a basalt flow, the unweathered basalt varies in thickness from 1.3 metres for that in Band E to 5 metres for Band C. The weathered horizons are formed beneath all the sediment units including both upper and lower sediment units of Band C, D and E.

The field relationships presented above (especially the spheroidally weathering basalt and basalt knobs enclosed within the weathered material and the presence of mottling) indicate that the deposits are lateritic soils rather than basic tuff horizons. Brückner (1955) shows spheroidal weathering of basic rocks in Ghana associated with deep red, lateritic profiles whilst Reiche (1962, page 72) indicates mottling to be common in many laterites. Moreover, an origin as basic tuffs is thought unlikely since they occur so consistently beneath deposits of sediment. Lateritic horizons are not uncommon in other basalt successions of subaerial origin and have been recorded from the Deccan Flood Basalts, the

Tertiary Plateau basalts of Western Scotland (Richey, 1948), the Columbia River Plateau basalts (Waters, 1961) and the Lighthouse Cove basalts of Northern Newfoundland (Williams and Stevens, 1971).

Many of the laterite soils become rich in detrital material such as quartz and pink feldspars as the base of overlying sediment is approached. The top 30 - 50 cm. of the lateritic soils may also show horizontal and ripple drift lamination indicating that active streams were reworking the sediment prior to the influx of extra-basinal material. Beneath Band A in the vicinity of Club Lake in area III, the laterite soil which occurs elsewhere beneath the band is absent. Instead, a bedded rock showing compositional and grain-size banding occurs. The rock comprises beds of 2 - 12 cm. thick composed of a lower layer of red-brown, grit sized fragments set in a red, fine-grained matrix overlain by a fragment-free, red, fine-grained layer. In some cases, the bedding is inclined and planar cross-stratification occurs. The cross-stratification parallels a planar scour surface which truncates earlier bedding. The total thickness is 1.8 metres and it overlies, although no actual contact was seen, dark grey, massive basalt. This lithology can traced along strike for up to 4 kilometers.

CHAPTER IV

MINERALOGY AND PETROLOGY

Sedimentary and volcanic rocks of both formations were studied using standard petrographic procedures. The mineralogy of sediments and volcanics is described whilst the sediments were also analysed petrographically using the following methods.

1. Integrated point counting to obtain modal analyses.

2. Visual measurements of grain-size of sand faction measuring only the maximum diameter with an objective of known diameter. Only sand grains greater than 0.05 mm. were measured so that clay and silt factions of the sediments were ignored.

3. Visual measurements of roundness of sand grains using the chart of Krumbein (1941).

The formations will be dealt with separately.

A. The Arkose Lake Formation

1. Mineralogy

The sediments of the Arkose Lake Formation consist of sandstones and grits which are compositionally subarkoses and feldspathic greywackes (Pettijohn, 1957). Table III shows the modal analyses of the sediments and separates the Lower Member sandstones from the Upper Member.

The sediments are composed of quartz, feldspar, a few rock fragments which are predominantly of polycrystalline quartz, minor heavy minerals and

TABLE III

Modal Analysis of the Sediments of the Arkose Lake Formation

Sample #	Qtz.	K.F.	Plag.	R.F.	Opaque Minerals	Heavy Minerals	Mica	Matrix
1. Lower Member								
a.Eastern Area								
1K 020	77.5	9.3	0.5	0.1	0.2	--	--	13.6
1K 030	63.3	20.6	0.2	5.5	--	--	--	12.5
1K 262	67.61	9.25	--	3.83	0.39	1.8	0.39	18.3
b.Western Area								
1K 336	71.81	20.24	1.77	0.27	0.4	--	--	5.4
1K 338	58.93	15.73	0.19	4.89	0.19	1.23	--	12.95
1K 341	66.5	6.53	0.09	2.50	5.9	0.97	--	16.95
1K 342	56.1	4.14	1.57	7.08	1.08	0.09	--	29.14
2. Upper Member								
1K 078	76.1	5.3	0.6	0.8	0.5	0.1	--	16.6
1K 136	86.8	11.5	0.5	0.5	--	0.1	--	0.7
1K 214	87.4	6.1	0.2	2.7	0.7	0.2	--	2.6
1K 220	59.86	15.03	0.09	2.43	1.17	1.18	--	21.69
1K 223	63.1	19.9	0.8	1.5	2.1	0.1	--	11.9
1K 253D	69.5	12.7	0.02	5.2	--	--	0.06	12.5
1K 279	49.5	15.7	0.7	5.48	1.9	0.09	1.9	25.0
1K 288	60.1	6.7	1.1	9.8	2.2	0.1	0.2	17.2
1K 366	75.8	3.6	--	4.9	0.2	0.6	0.8	9.4

Qtz = Quartz
KR = Potash Feldspar
RF = Rock Fragments

Each modal analysis comprises 1000 points.

and a varying amount of clay matrix.

a. Quartz and Polycrystalline Quartz

Quartz occurs in unicrystalline and polycrystalline form. The former occurs in all grain-sizes but the latter is generally restricted to the coarser sand-sized particles.

Unicrystalline quartz displays ubiquitous undulatory extinction and minor development of deformation lamellae may occur in some of the larger grains. The larger grains also show vacuole trails and fractures which may be tinted red by haematite.

Polycrystalline quartz occurs in several forms characterised by the number of crystals and form of the crystalline texture. They are:

Type I. - Particles composed of large crystals with two or three crystals per grain (Pl. XXVII). Grain boundaries are usually straight or slightly sutured. The extinction is undulatory.

Type II - Particles made up of a large number of large or small crystals. The crystals are anhedral with sutured boundaries but may sometimes be subhedral. Very often, the large crystals have a slight or pronounced elongation which is not related to the cleavage developed during deformation of the area. When small crystals make up the grains, there is a pronounced alignment of the long axes of these crystals (Pl. XXVIII). Usually the shape of the grains is controlled by the crystal fabric. In a number of grains, recrystallisation at the boundaries and within the large

Pl. XXVI. Basalt knobs (k) enclosed in laterite (l) which overlies unweathered basalt (UB)

Pl. XXVII. Polycrystalline quartz sand grain composed of large crystals with slightly sutured boundaries. X 38.

Pl. XXVIII. Polycrystalline quartz sand grain which displays numerous, aligned quartz crystals. X 38.

Pl. XXIX. Photomicrograph of myrmekitic texture in polycyrstalline quartz grain. X 160.

elongated crystals occurs. The recrystallised quartz in finely crystalline with polygonal shapes.

Undulatory extinction occurs in all forms of Type II.

Type III. - An isolated occurrence of quartz displaying myrmekitic like textures but not involving feldspar (Pl. XXXIX).

Type IV. - A single grain of sedimentary quartzite showing sharp angular to rounded grains with authigenic quartz overgrowths.

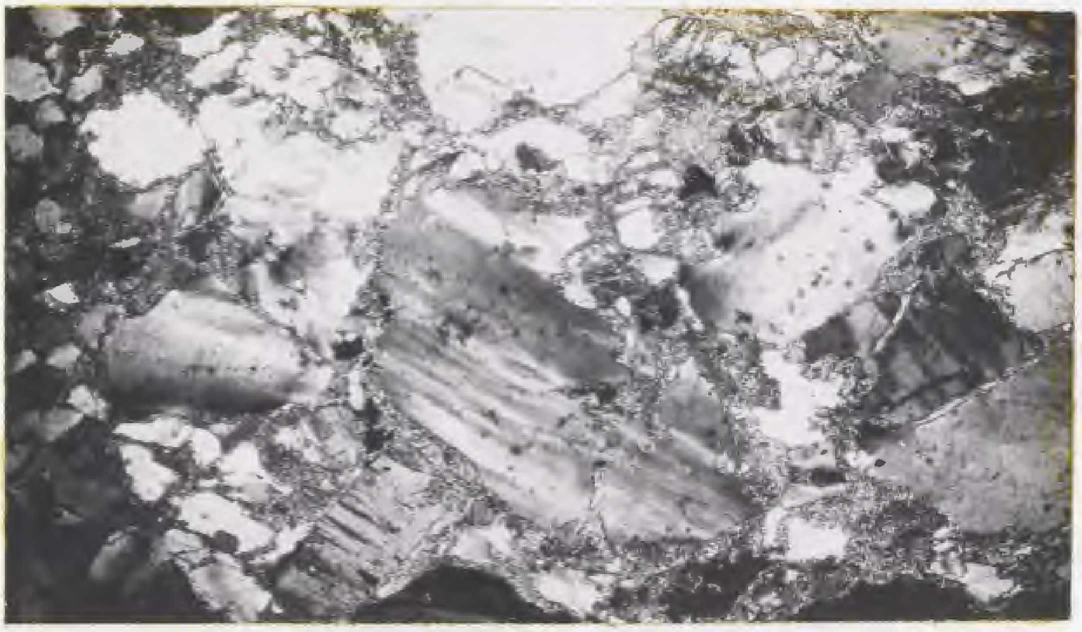
The individual quartz grains show varying amounts of resorption solution and boundary modifications. Where they are closely packed and grains touch one another, boundaries are sutured (Pl. XXX) and authigenic quartz overgrowths are common (Pl. XXXI). Where clay matrix separates quartz sand grains, the grains show varying amounts of corrosion with some grains replaced by clays as either a thin layer around the edge of the grain, or as deep re-entrants (Crook, 1968) or as appendages (Crook, 1968) (Pl. XXXII).

Features such as undulatory extinction, polycrystalline quartz types and corrosion have been studied by a number of authors and have been shown to be useful indicators of source rock and depositional environment (Fol, 1961; Blatt and Christie, 1963; Connelly, 1965; Crook, 1968; Cleary and Connelly, 1971).

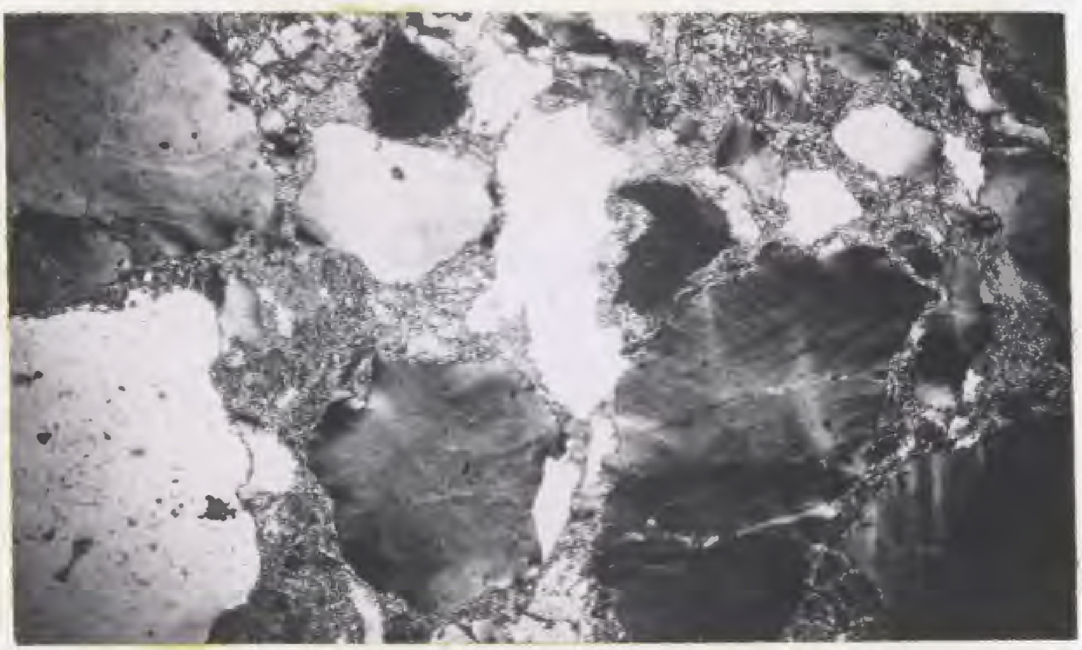
Undulatory extinction in the Arkose Lake sediments cannot be safely used as an indicator of source rock since the rocks of the area have been deformed and the undulatory extinction probably results primarily from this deformation. However, the polycrystalline quartz is indicative of both

Pl. XXX. Photomicrograph of sutured contact between adjacent quartz sand grains. X 40.

Pl. XXXI. Photomicrograph of authigenic quartz overgrowth. X 38.



Pl. XXXIIa. Photomicrograph of re-entrants in several quartz sand grains infilled by clay minerals. X 38.



Pl. XXXIIb. Photomicrograph of quartz appendage upon a quartz sand grain. X 38.

source rock and maturity of sediment. Polycrystalline quartz of Type I and Type III is typical of a plutonic granite and granite gneiss source (Folk, 1961; Cleary and Connelly, 1971) although Type I may also be derived from quartz veins. Type II, however, indicates derivation from granite gneiss and quartz-rich metamorphic rocks. High percentages of polycrystalline quartz typify immature sediments (Blatt and Christie, 1963; Cleary and Connelly, 1971). It is also apparent that the percentage of polycrystalline quartz present in the sandstone is dependent upon the grain-size of the samples. Connelly (1965) has shown that polycrystalline quartz predominates in the coarser sand grains and this appears to be true in this study since there is a greater amount of such quartz in the coarser sediments of the Lower Member in the western part of the area (Table III, sample 1K 342, 338, 336).

The presence of corrosion of the sand grains in sediments has been studied by Crook (1968) and Cleary and Connelly (1971) and may indicate weathering of the sediment following deposition and also initial weathering of the source rock. Saprolite soils derived from a granite, gneiss and schists yield such corroded grains in the Southern Appalachians (Cleary and Connelly, 1971). However, grain corrosion also occurs in poorly sorted sandy sediments (Crook, 1968) and has been found in upper parts of palaesol soils of a pediment and in coastal plain sediments (Cleary and Connelly, 1971). All three represent insitu weathering of a soil profile.

Although such corrosion features exist in the sediments of the Arkose Lake Formation, it is prudent not to place too much emphasis upon them. In sediments, so old as the ones dealt with here, the corrosion could also have occurred by insitu weathering, by diagenesis during lithification or after lithification and during deformation.

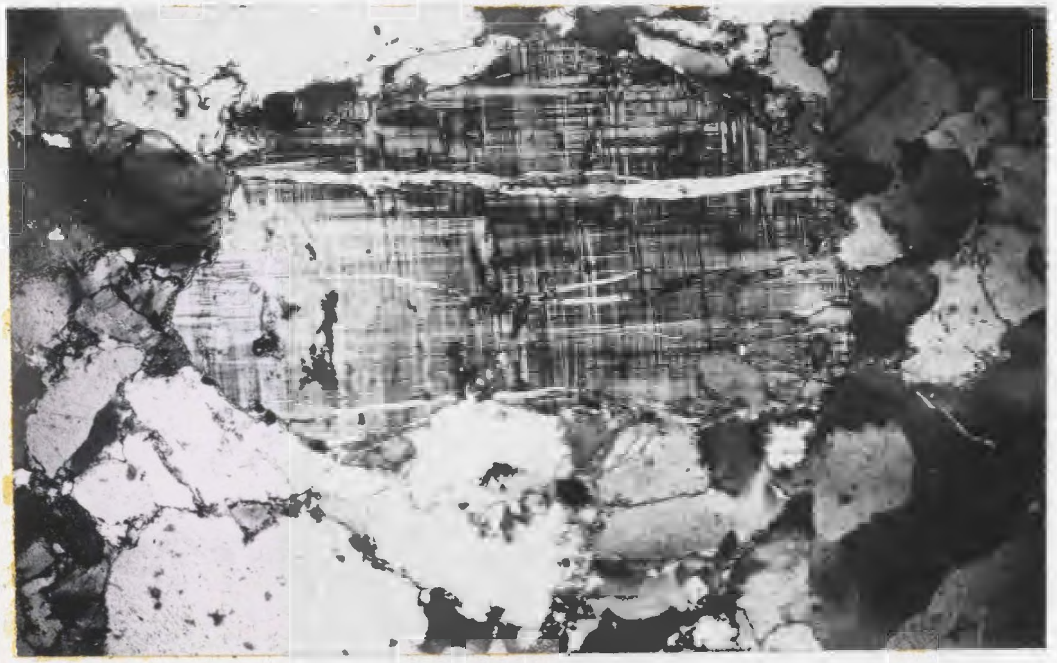
b. Feldspars

Several varieties of feldspar occur in the sediments of the Arkose Lake Formation.

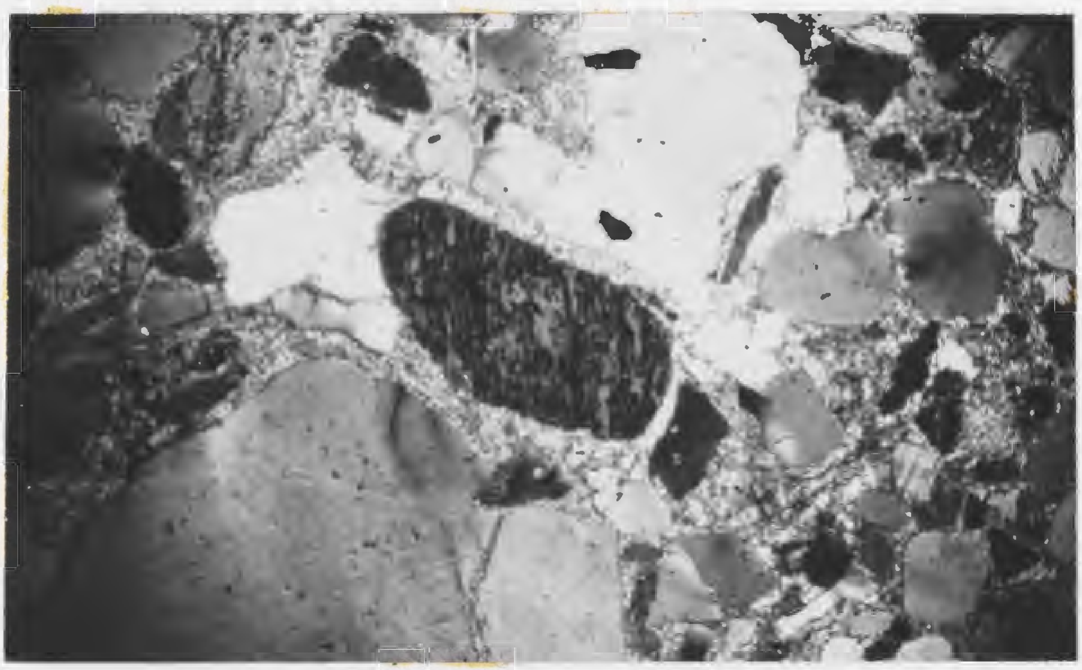
Type I - Microcline occurs as fresh, unaltered grains throughout the formation although occasionally some are slightly sericitised. Sections show good cross hatched and spindle-shaped twinning (Pl. XXXIII). Microcline is more common in the fine to coarse sandstones and is confined to the sand matrix of the conglomerates and grits which occur in the formation.

Type II - Antiperthites with subsidiary perthites and microperthite are most common in grades coarser than coarse sandstone and vary from fresh (Pl. XXXIVa) to highly altered (Pl. XXXIVb). The alteration is dominantly sericitisation and appears to be partly post-depositional, occurring especially along the cleavage planes.

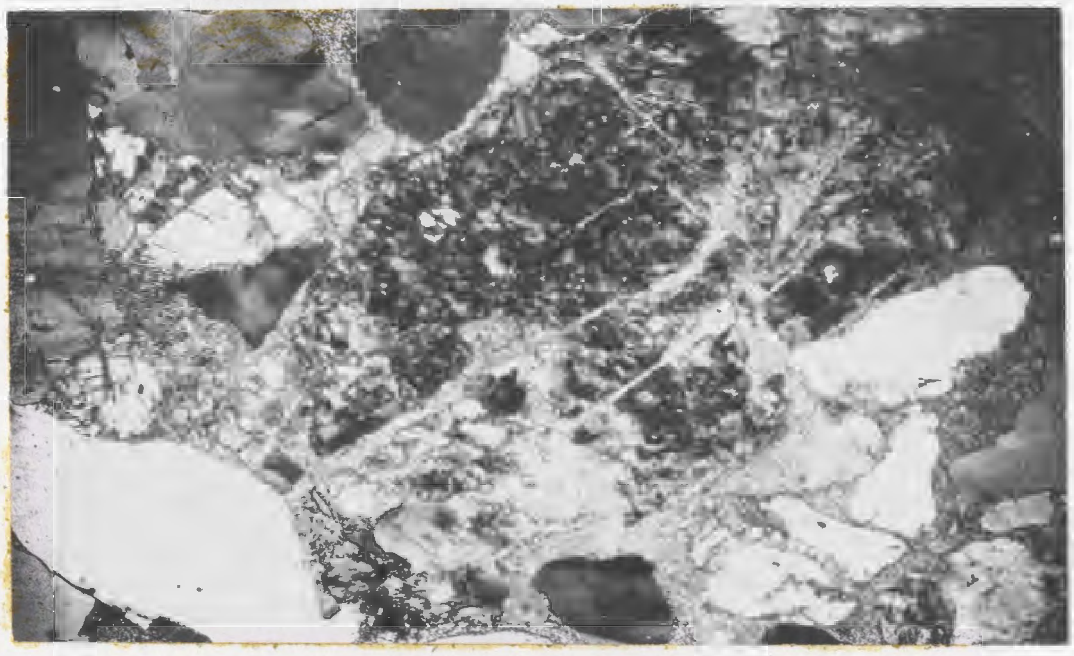
Type III - Orthoclase occurs as both clear and turbid grains (Pl. XXXV). In the latter case, the turbidity appears to be related to a brown tint due to finely disseminated haematite. Folk (1961) indicates that such brown tinting is caused by the presence of vacuoles. Occasionally, the feldspars are partially altered to magnetite and haematite. The alteration may occur in the centres of the grains especially along cleavages or it may affect the edges of the grains. In the latter case, the surrounding matrix



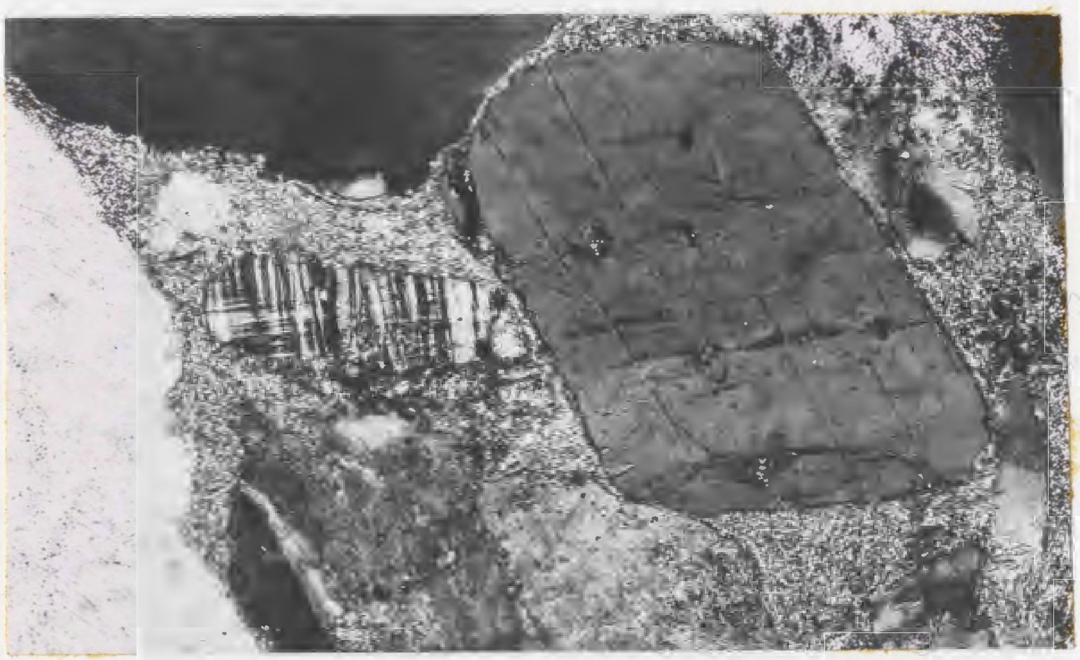
Pl. XXXIII. Photomicrograph of sand grain of unaltered microcline displaying cross-hatched twinning. Fractures are associated with deformation of the sediment. X 38.



Pl. XXXIVa. Photomicrograph of sand grain of unaltered perthite in poorly sorted sandstone. X 38.



Pl. XXXIVb. Photomicrograph of large perthite grain which is heavily sericitised especially along its cleavage. X 38.



Pl. XXXV. Photomicrograph of only slightly corroded sand grain of orthoclase. The grain shows very little rounding of the original prismatic crystal form. Large amount of clay matrix and microcline sand grain displaying spindle shaped twinning. X 160.

is also replaced suggesting post-depositional or lithification origin. In the former, however, the replacement may be inherited from the source rock.

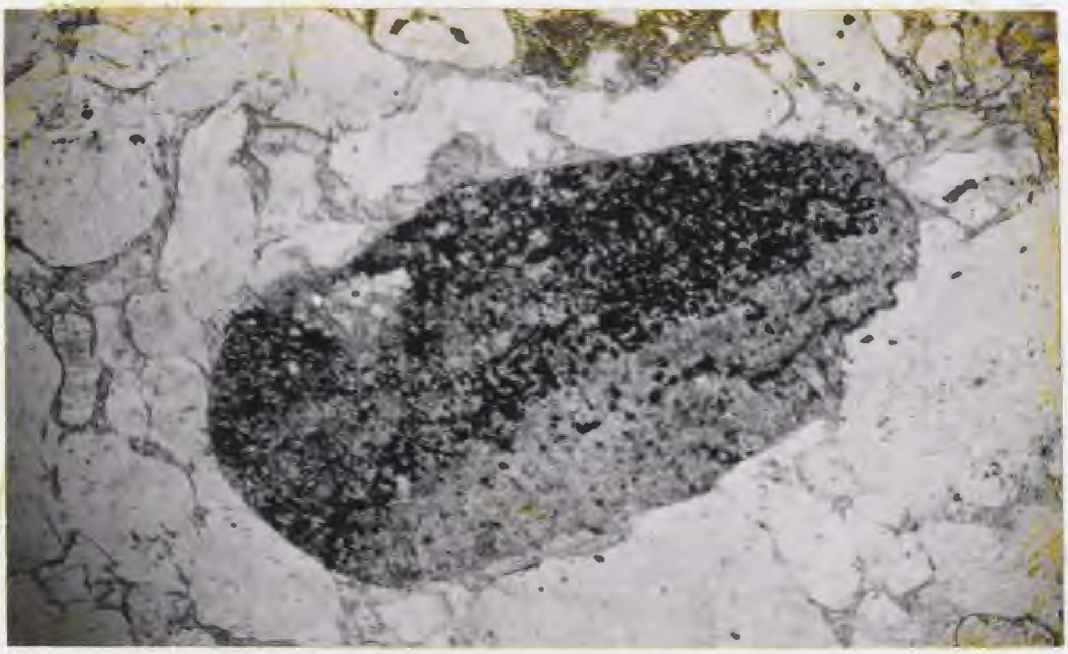
Type IV - Plagioclase occurs as very fine and fine sand grains. It shows albite twins and based upon this twin law may be either albite of composition An_3 or andesine of An_{35}.

c. Rock Fragments

Rock fragments other than polycrystalline quartz are very infrequent and are usually of cryptocrystalline chert. A grain of banded chert-ironstone (Pl. XXXVI) occurs with cryptocrystalline quartz interlayered with bands composed of small grains of magnetite. Occasionally, jasper grains showing red colouration and cryptocrystalline textures also occur (Pl. XXXVII).

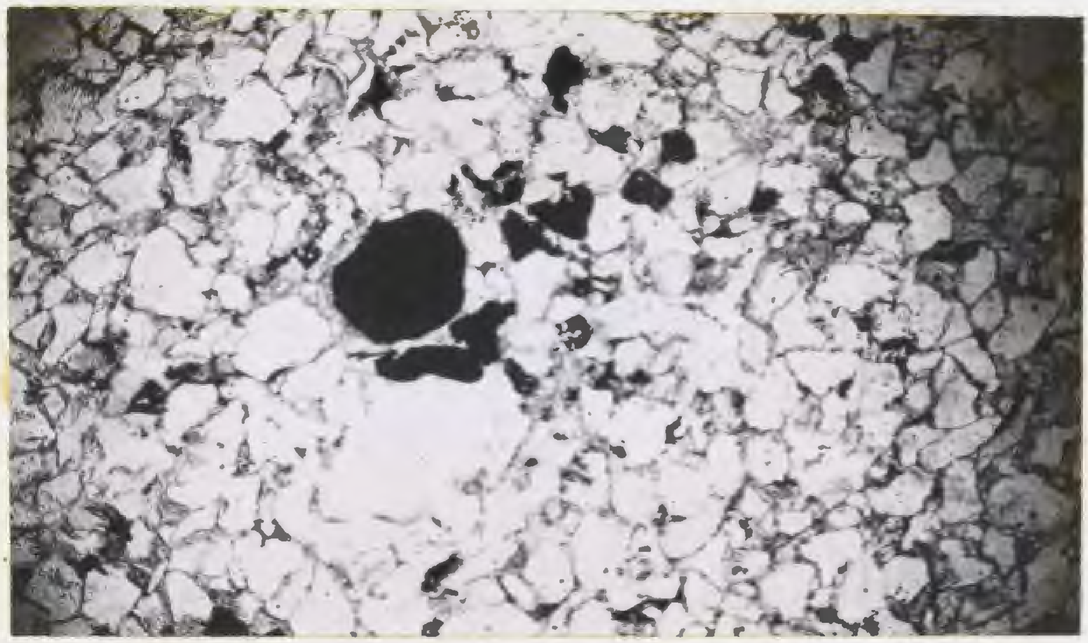
d. Heavy Minerals

The Arkose Lake Formation sediments are not rich in heavy minerals. In the Lower Member near Arkose Lake, only a few scattered grains of zircon and magnetite occur. In the sandy matrices of conglomerates of the western part of the area and the sandstones of the lowest horizons of the Lowest Member, heavy minerals are more abundant. They include magnetite, zircon and occasional epidote grains (Pls. XXXVIIIa, b & c). The magnetite is well rounded to angular and prismatic and may be rimmed by a leucoxene-haematite alteration zone. The zircons may be well rounded but often are prismatic or angular, broken fragments.



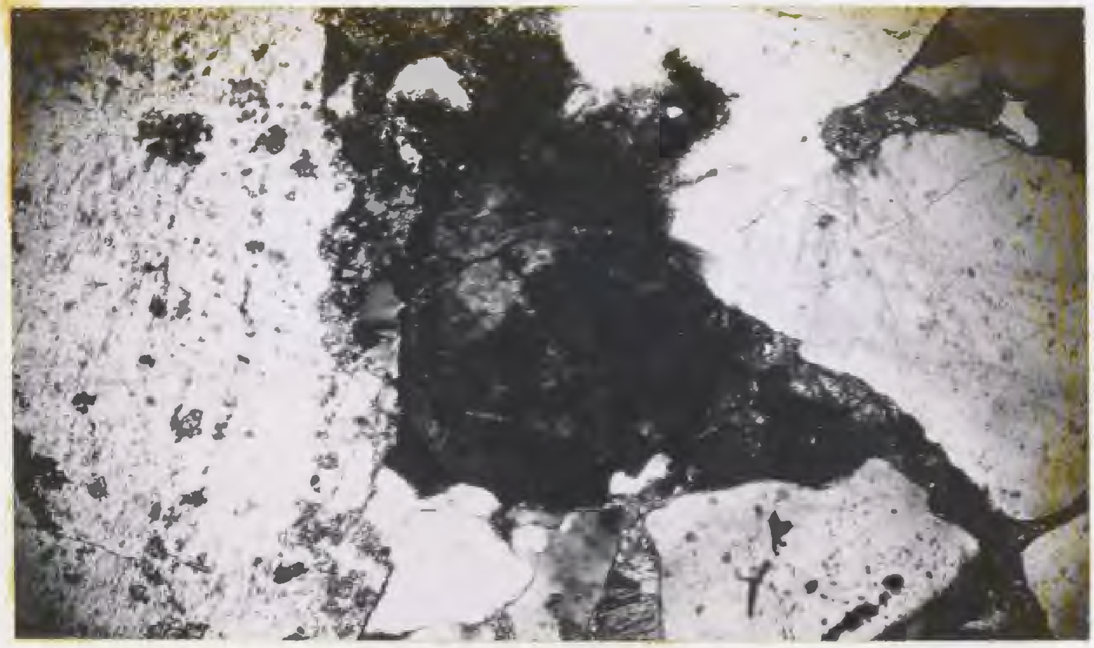
Pl. XXXVI. Photomicrograph of sand grain composed of cherty-ironstone. (Plane polarised light.) X 51.

Pl. XXXVII. Photomicrograph of sand grain of jasper. X 38.

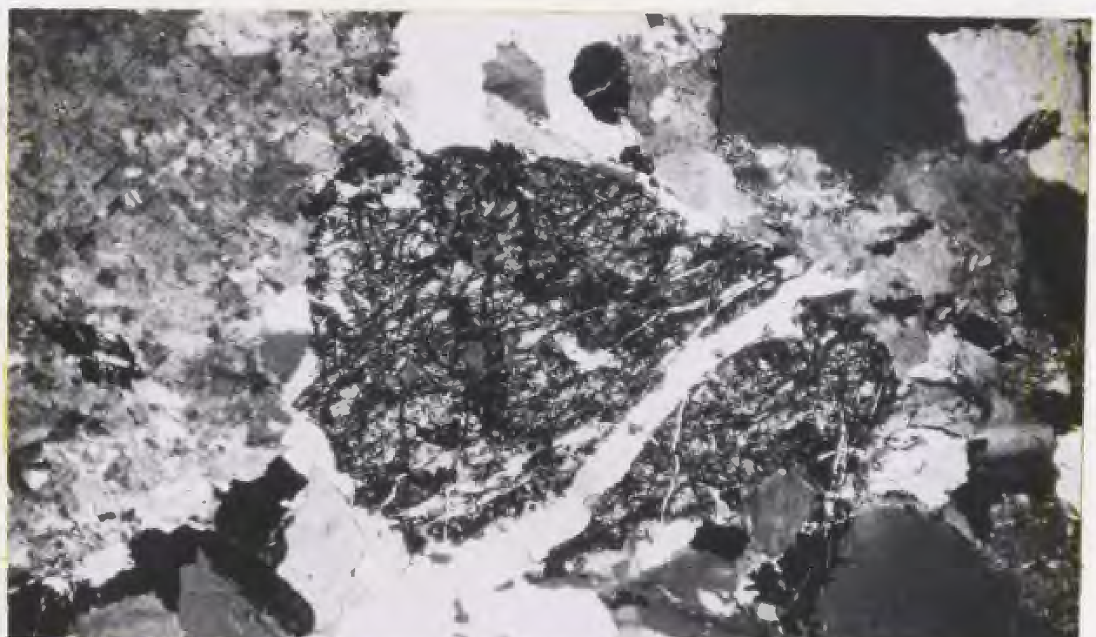


Pl. XXXVIIIa. Detrital magnetite grains associated with angular quartz grains.(Plane polarised light) X 38.

Pl. XXXVIIIb. Small, angular fragment of detrital zircon associated with quartz, feldspars and clay matrix. X 38.



Pl. XXXVIIIc. A rounded grain of detrital epidote (dark area) associated with quartz, perthite and clay matrix. X 38.



Pl. XXXIX. A rounded pebble of epidote and quartz cut by a later vein of quartz. X 5.

e. Matrix and Cement

Many of the sandstones, grits and conglomerates possess a large amount of clay matrix (Table III). The clay matrix is very fine-grained but the birefringence of the clay plates suggests sericite or illite and the in situ breakdown of perthite grains to sericite suggests that possibly sericite is the main clay sized mineral. In the sediments of the western part of the area, occasional clusters of chlorite occur. Minor amounts of muscovite also occur but it is probable that they are secondary not detrital minerals.

Cryptocrystalline quartz occurs in patches within the clay matrix. Iron oxides especially haematite and limonite also cement the rocks and the outlines of the sand grains are commonly picked out by the oxides.

2. Statistical Analysis of the Arkose Lake Formation

The grain size and roundness of sand sized particles was measured for the sediments of the Arkose Lake Formation. One hundred grains were measured per thin section. The grain size data was subdivided into 0.1 mm. size intervals and size was plotted against cumulative percent on logarithmic graph paper which also converted the millimeter scale to phi scale (fig. XXVIa, b, & c). From the cumulative curves* produced measures of inclusive graphic standard deviation (σ^1), inclusive graphic skewness (Sk_1), simple mean grain size (M_z), simple sorting measure (So_s) and simple skewness measure (α_s) were computed (Table IV for equations). The first four measures are those used by Folk and Ward (1957) whilst the last two measures were devised by Friedman (1967). The results of the calculations were given in Table V which also includes sediment modes which were taken directly from the cumulative curves.

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*Because of the poor sorting and feldspathic composition of the sandstones, no conversion of thin section data to sieve-size equivalents (Friedman, 1958) was considered necessary. Since the curves represent percentage number, not volume percent, it is appropriate to point out that comparison of this data with that of other similar studies may not be appropriate (see page 121).

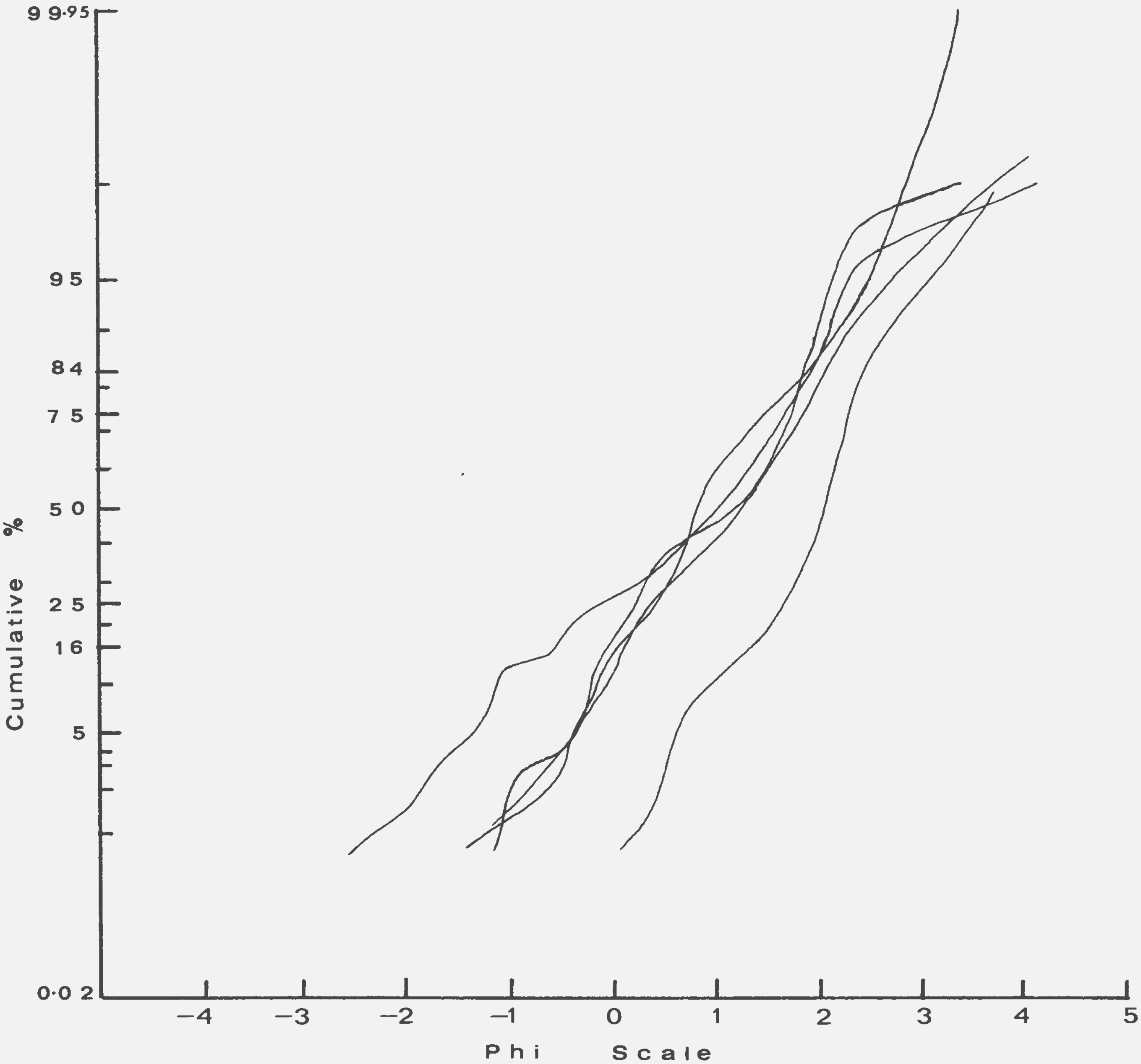


Fig. XXVI. Cumulative Percentage curves for grain size analysis of sandstone of the Arkose Lake Formation.

a) Lower Member - Eastern part of the Arkose Lake area.

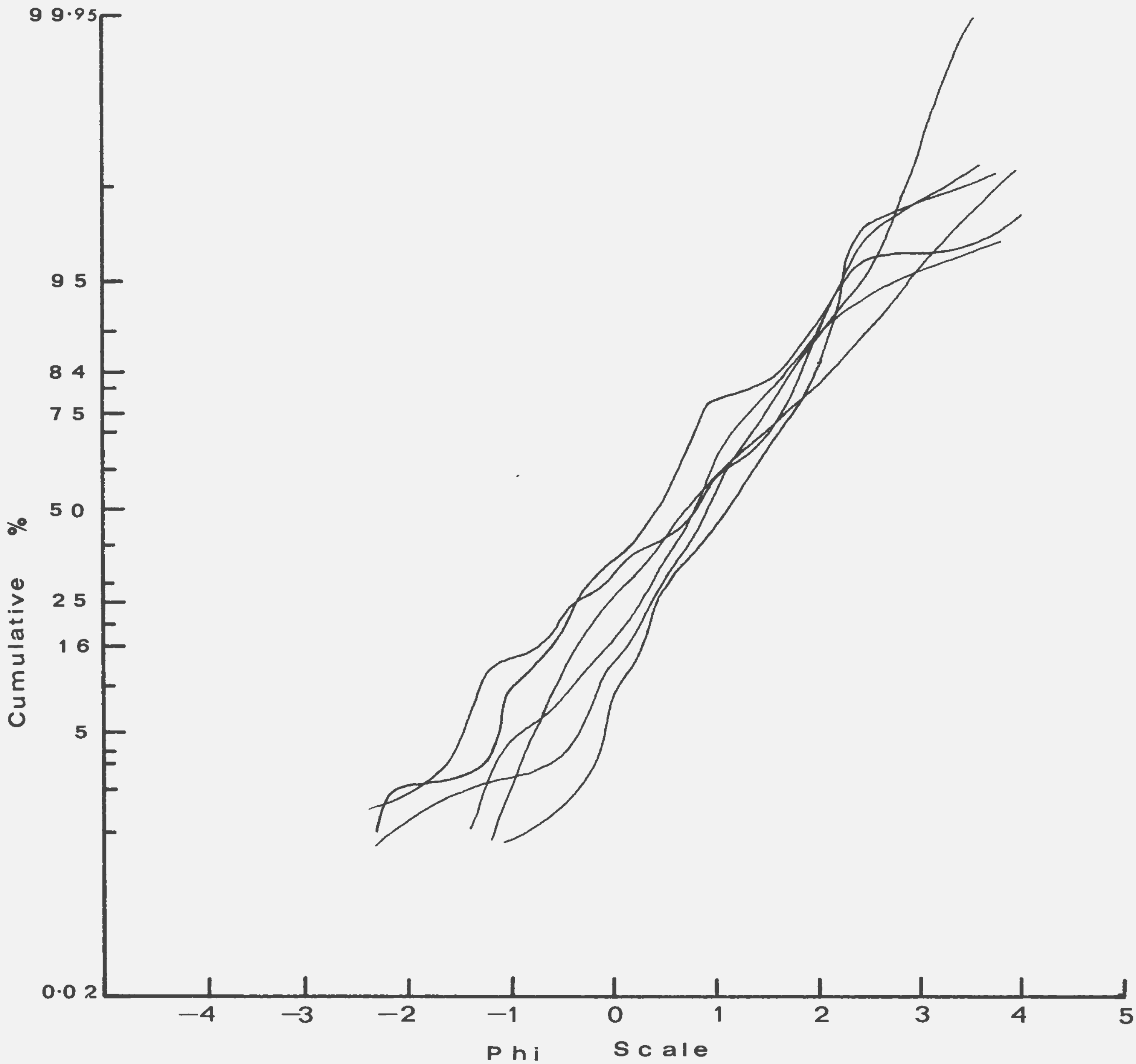


Fig. XXVI b. Lower Member - Western part of the Arkose Lake area.

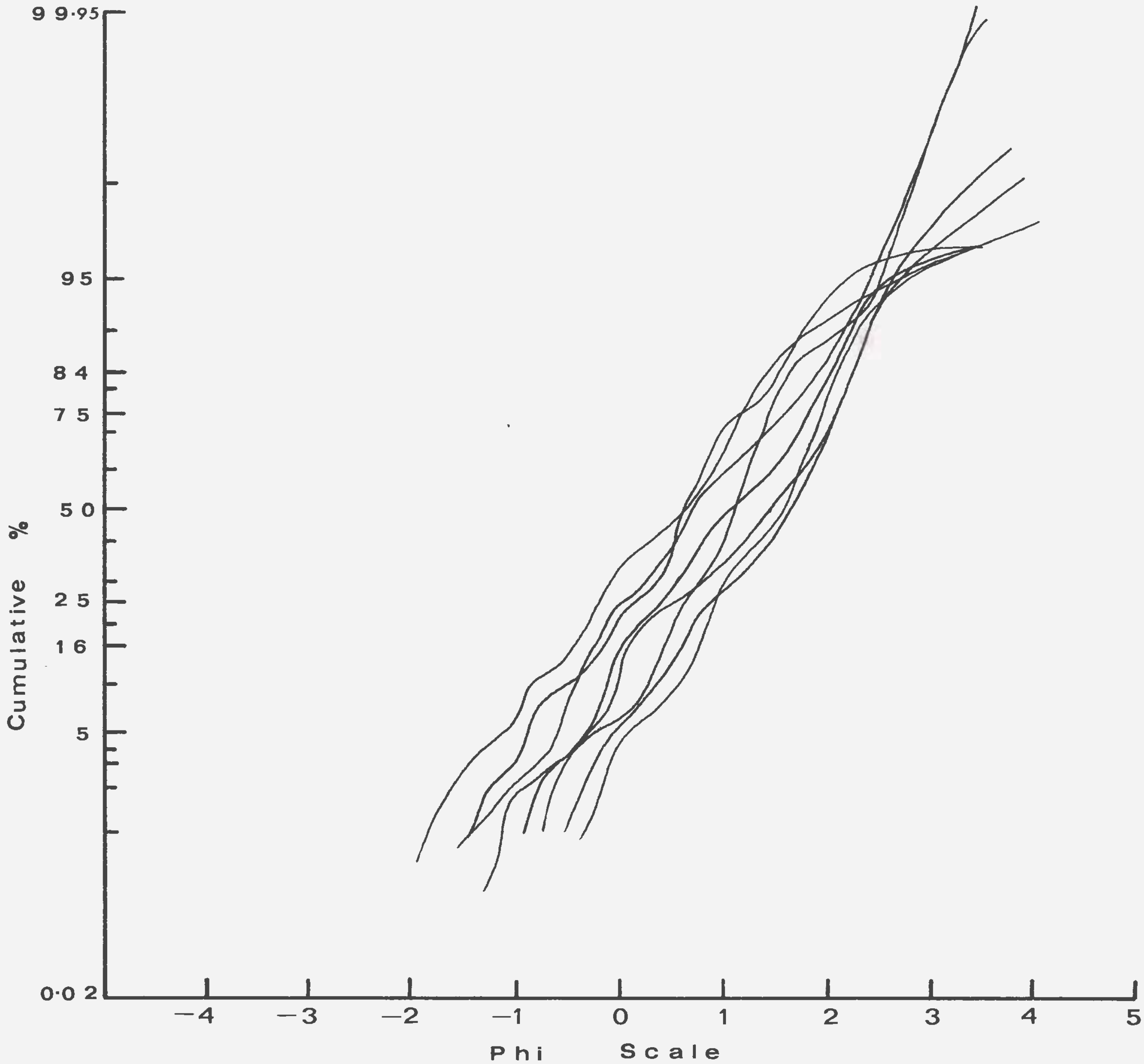


Fig. XXVI c. Upper Member.

TABLE IV

Equations of Measures of Sorting for Sediments

1. Mean Size $Mz = \frac{\phi 16 + \phi 84 + \phi 50}{3}$

2. Inclusive Graphic Standard Deviation $\sigma^1 = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$

3. Inclusive Graphic $Sk_1 = \frac{\phi 16 + \phi 84 - 2\phi 50}{2(\phi 84 - \phi 16)} + \frac{\phi 5 + \phi 95 - 2\phi 50}{2(\phi 95 - \phi 5)}$

4. Graphic Kurtosis $Kg = \frac{\phi 95 - \phi 5}{2.44\ (\phi 75 - \phi 25)}$

5. Simple Sorting Measure $So_s = 1/2\ (\phi 95 - \phi 5)$

6. Simple Skewness Measure $\alpha s = (\phi 95 + \phi 5) - 2(\phi 50)$

Measures 1 to 4 are those of Folk and Ward (1957), 5 & 6 are those of Friedman (1967).

TABLE V

Analytical Results for the Sediments of the Arkose Lake Formation

1. Lower Member

a) Eastern Area

Sample #	Primary Mode	Secondary Mode	σ^1	Mz	Sk_1	So_s	S
1K 003	C	M-7	0.997	1.1	-.146	1.52	- .25
1K 006	M	C	0.65	1.98	-.159	1.27	- .35
1K 030	M	C	1.187	0.86	-.25	1.85	-1.1
1K 262	M	C	.878	1.08	-.245	1.75	-0.6
1K 262A	C	M	.927	0.95	0.236	1.45	0.7

b) Western Area

Sample #	Primary Mode	Secondary Mode	σ^1	Mz	Sk_1	So_s	S
1K 336	C	VC	1.14	0.83	0.194	1.8	0.8
1K 338	C	VC	1.08	0.53	0.050	1.7	0.2
1K 339	C-M	VC	1.16	0.73	-.135	1.85	-0.7
1K 341	M	C	.771	1.666	-.094	1.65	-0.3
1K 342	C	M	.636	0.983	0.084	1.4	0.3
1K 343	C	-	1.268	1.15	.279	0.8	0.2

2. Upper Member

Sample #	Primary Mode	Secondary Mode	σ^1	Mz	Sk_1	So_s	S
1K 072	7M	C	1.02	1.26	0.239	1.55	-0.5
1K 136	C	VC	1.054	1.03	-0.585	1.95	-1.0
1K 214	M	C	.861	1.23	.071	1.4	1.25
1K 220	M	-	.74	1.5	- .271	1.35	-0.3
1K 220A	M	F	0.821	0.55		1.85	-0.7
1K 279	C	M-VC	0.98	0.85		1.55	0.5
1K 288	C	M-VC	0.917	0.683		1.57	1.15
1K 366	M	-	1.124	1.13		1.85	-0.8

Unfortunately the validity of this data and that for the Majoque Lake Formation must be questioned because of the general inadequacy of petrographic analysis of grain-size. As previously stated only sand grains larger than 0.05 mm. diameter were measured in the thin sections. The silt faction and clay matrix were not measured and therefore the curves only show sorting and skewness for the sand faction. Consequently, the results obtained are not directly comparable to those of studies of recent sediments such as that of Folk and Ward (1957). Nevertheless, the data is indicative of the state of the sand faction and can be extrapolated with some degree of confidence to the rock as a whole. The adding of silt and clay factions to an already moderately to poorly sorted sand will only serve to increase that poor degree of sorting. Likewise with skewness, the introduction of a substantial fine faction to the sediment will serve to convert many negatively skewed sediments into the field of positive skewness.

The modal data (Folk, 1961) confirms the field observations of coarsening of sediments in the lower member from east to west. Primary modes and secondary modes are predominantly coarse and very coase respectively in the west as compared to medium and coarse in the east. The sandstones of the Upper Member have fine to coarse primary modes.

The sediments are moderately to poorly sorted with skewness divided equally between positive and negative values. Many of the sands are only just negatively skewed and if it was possible to measure the fines it is likely that many more sands would be positively skewed. The results that were obtained can be explained by inspecting the secondary modes of the samples, where if the secondary mode is coarser or finer than the primary mode then the sands are negatively or positively skewed respectively.

The importance of these measures is that they can be characteristic of the depositional environment. Moderate to poor sorting and positive skewness is typical of river sands, some deltaic sands and some deeper water marine sands (Folk and Ward, 1957). However, deepish water marine sands and deltaic sands can be eliminated by virtue of the facies present. Friedman's (1967) plots of simple skewness measure (αS) vs. simple sorting measure (So_s) and skewness (Sk_1) vs. standard deviation (σ_1) are used in order to substantiate the petrographical conclusions that the sands represent river deposits. The plots (Fig. XXVIIa & b) show that all the sands fall within the field of river sands. Mean size, standard deviation and skewness were also plotted upon the diagrams of Folk and Ward (1957) but no trends such as were obtained by those workers on the Brazos River existed in the Arkose Lake sediments. This is to be expected however, because of the random sampling of the area, the lack of a complete suite of grain-sizes (i.e. lack of silty rocks) and also the inadequacies of the measuring technique.

3. Roundness Data

The roundness data obtained using Krumbein's (1941) visual method was subdivided using the classification of Powers (1953). Except for two analyses, the majority of grains fall within the subrounded to subangular classes. In the other two samples, rounded grains form a substantial part of the sample. Of the extremes of very angular and well rounded in a sample, there are usually more of the former. Such sands with low roundness are typical of river sands. Russell and Taylor (1937) showed that the Mississippi River sands showed very little rounding along the length of the river. Abrasion

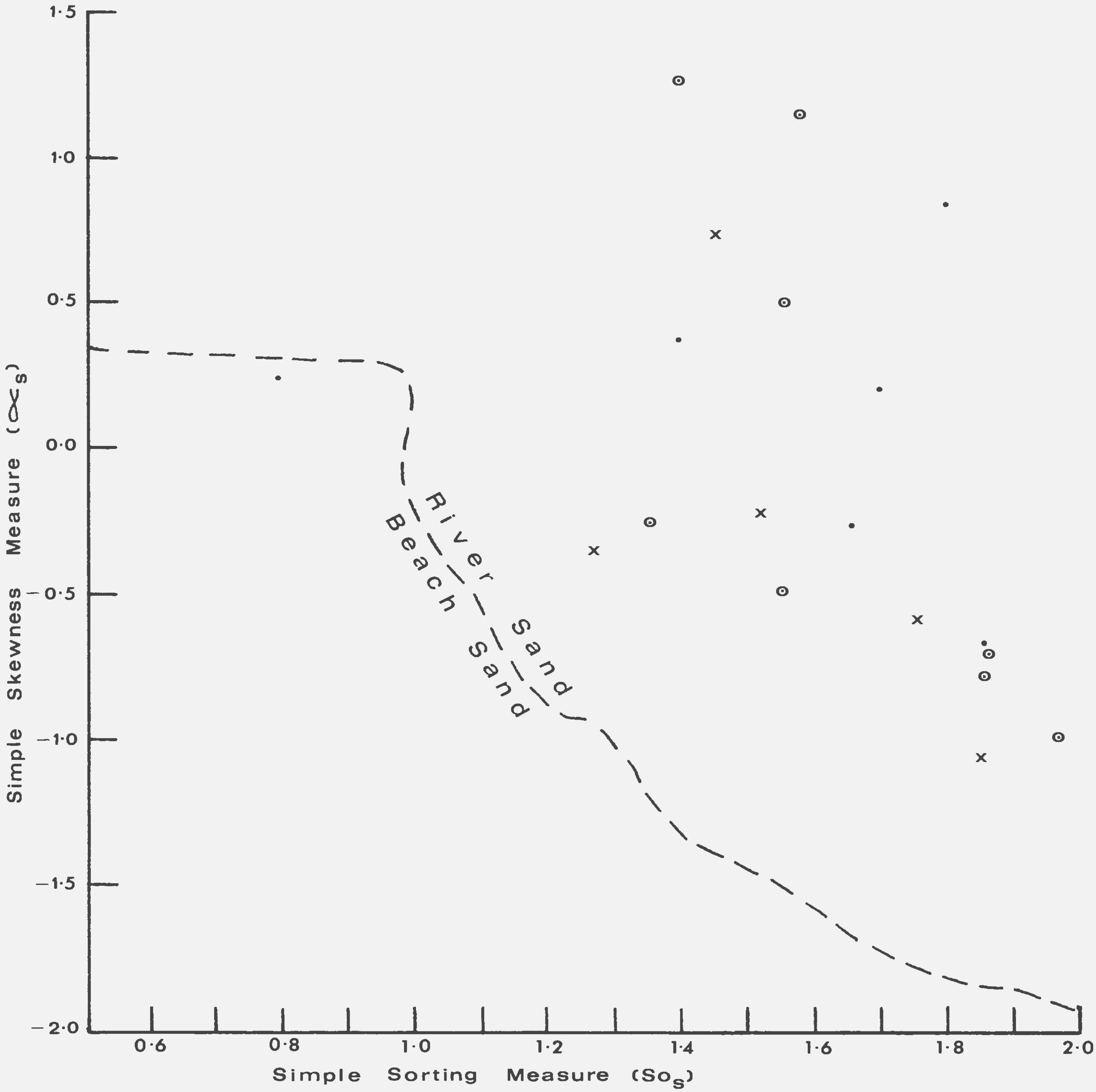


Fig. XXVII a. Friedman Plot (1967) of Simple Sorting Measure vs Simple Skewness measure to distinguish river and beach sands. (Symbols as in fig. XXVIIB.)

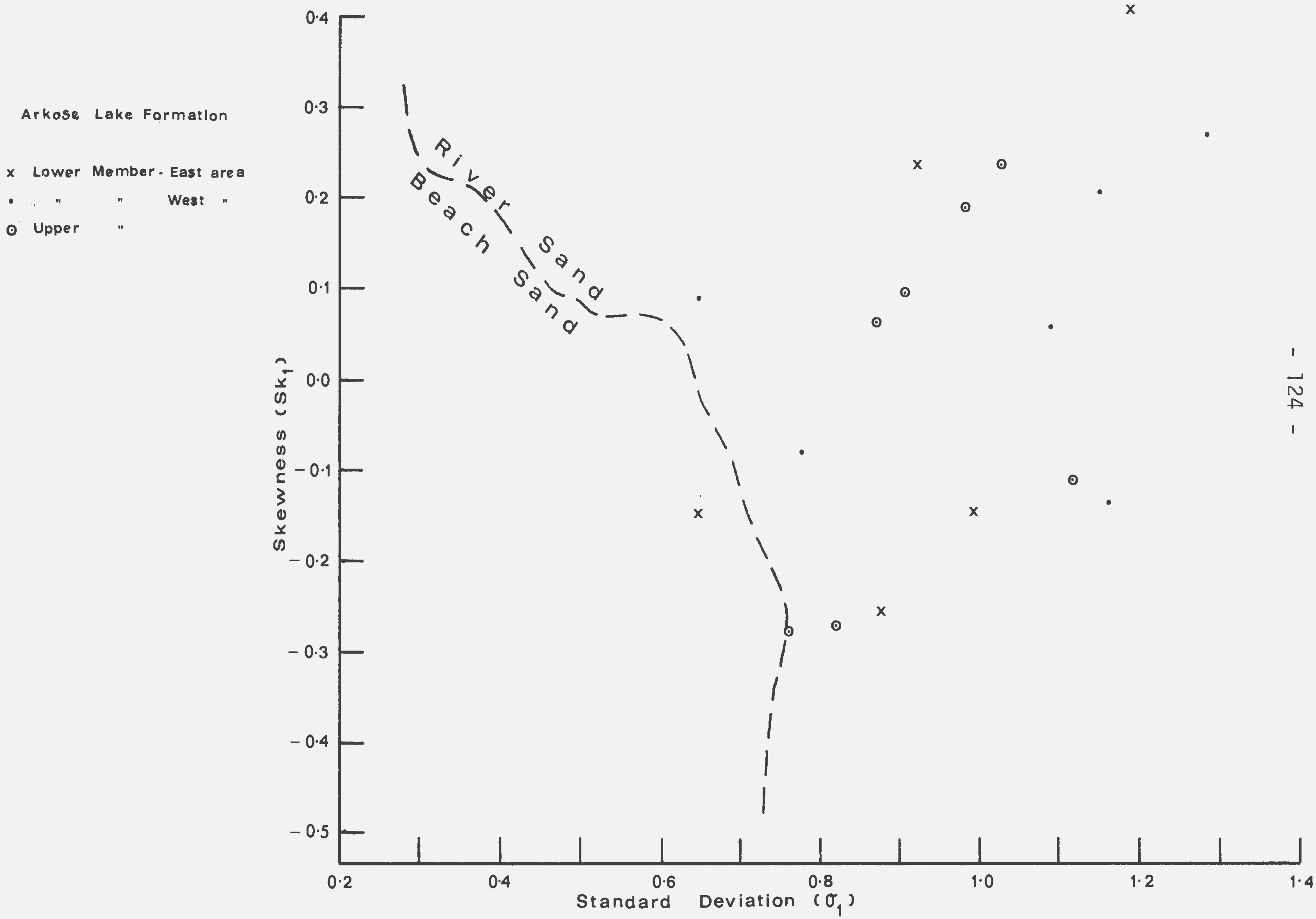


Fig. XXVII b. Friedman Plot (1967) of Standard Deviation vs Skewness to distinguish river and beach sands.

in a beach environment would be expected to raise the roundness values of the sediment.

B. The Majoque Lake Formation

1. The Sediments

a. Mineralogy

The sediments of the Majoque Lake Formation vary in composition. Subarkoses are the major sandstone type with minor arkose, subgreywacke and protoquartzite (Pettijohn, 1957) also present (Table VI). The components of the sediments are described in order of grain size with pebble types of conglomerates described first followed by grits and sandstones which includes the matrices of the conglomerates.

1. Pebble Types

a. Quartzite pebble types

i. Pebbles of a single crystal of quartz - These display undulatory extinction and often display deformation lamellae, abundant vacuole trails and fine fractures. One quartz pebble enclosed a lath of apatite.

ii. Pebbles of polycrystalline quartz - These are composed of either:

a. A few large crystals which are subhedral or anhedral with straight or sutured boundaries.

b. A large number of large but slightly to pronouncedly elongated crystals which have sutured, irregular boundaries. Some of these pebbles show recrystallisation of quartz with numerous, small polygonal crystals scattered through the crystals.

TABLE VI

Modal Analyses of the Sediments of the Majoque Lake Formation

Sample #	Qtz.	K.F.	Plag.	R.F.	Opaque Minerals	Heavy Minerals	Micas	Matrix
Band A (area I)								
1K 286A	78.7	8.0	0.3	1.3	--	0.1	11.7	--
Band C (area III)								
1K 113	60.3	20.3	0.3	3.2	--	13.4	--	3.1
1K 166	65.8	17.2	0.5	10.0	2.8	4.0	--	--
1K 309	47.9	20.11	0.58	7.94	3.47	7.16	0.2	12.6
1K 322	78.4	7.6	--	7.2	1.4	0.8	--	4.8
(area II)								
1K 268	66.2	17.7	6.0	0.9	0.8	1.4	0.4	7.0
1K 286	69.8	14.4	--	2.1	3.8	0.6	0.1	8.6
Band E								
1K 141	56.3	25.8	1.0	21.5	1.6	0.5	--	4.0
1K 186	55.7	11.3	0.3	21.5	4.3	5.7	0.1	2.4

Qtz = Quartz
KF = Potash Feldspar
RF = Rock Fragments (Mostly polycrystalline quartz.)

Each modal analysis comprises 1000 points.

c. A large number of small crystals whose long axes are arranged in schistose fashion.

All of the above polycrystalline types display undulose extinction.

iii. Pebbles of cryptocrystalline quartz - These chert pebbles are not very common and may be tinted red by haematite.

iv. Quartz-epidote pebbles (Pl. XXXIX) with crystalline epidote cut by a number of thin veins of quartz.

b. Feldspathic Pebble Types

i. Antiperthitic, perthitic and microperthitic feldspars in order of abundance all occur as pebble types. They are commonly heavily sericitised especially along the cleavage planes, whilst those which are fresh usually have a fine sericitised rim.

ii. Microcline pebbles are not so abundant as perthites. They are usually fresh but may sometimes have a sericitised rim.

iii. Orthoclase pebbles which are turbid and untwinned occur only infrequently. They are often almost completely replaced by magnetite which in turn is altered to haematite. The replacement by magnetite also affects the clay matrix but not quartz grains in the area surrounding the feldspar so that the process occurred after deposition.

iv. Polycrystalline pebbles are composed dominantly of perthitic feldspars enclosing small euhedral crystals of Carlsbad twinned plagioclase and some crystalline epidote (Pl. XL). Some of the perthites also contain irregularly shaped patches of exsolved quartz and some microcline. Occasionally, microcline with poorly developed

Pl. XL. Photomicrograph of part of a pebble of perthitic feldspar enclosing carlsbad twinned plagioclase (PL) and epidote (E). X 5.

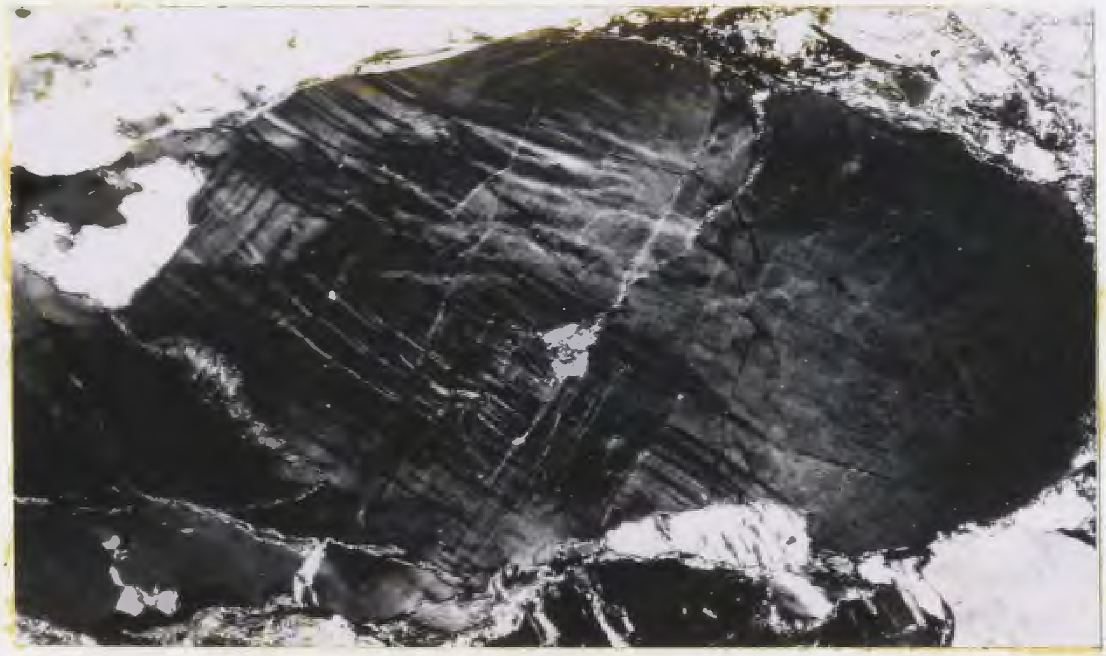
Pl. XLI. Photomicrograph of rounded pebble of microcline enclosing irregular areas of quartz (Q). X 5.

twinning and patches of indistinct perthitic texture encloses polygonal quartz which may show deformation lamellae (Pl. XLI). The microcline is sericitised and chlorite occurs in patches through these pebbles.

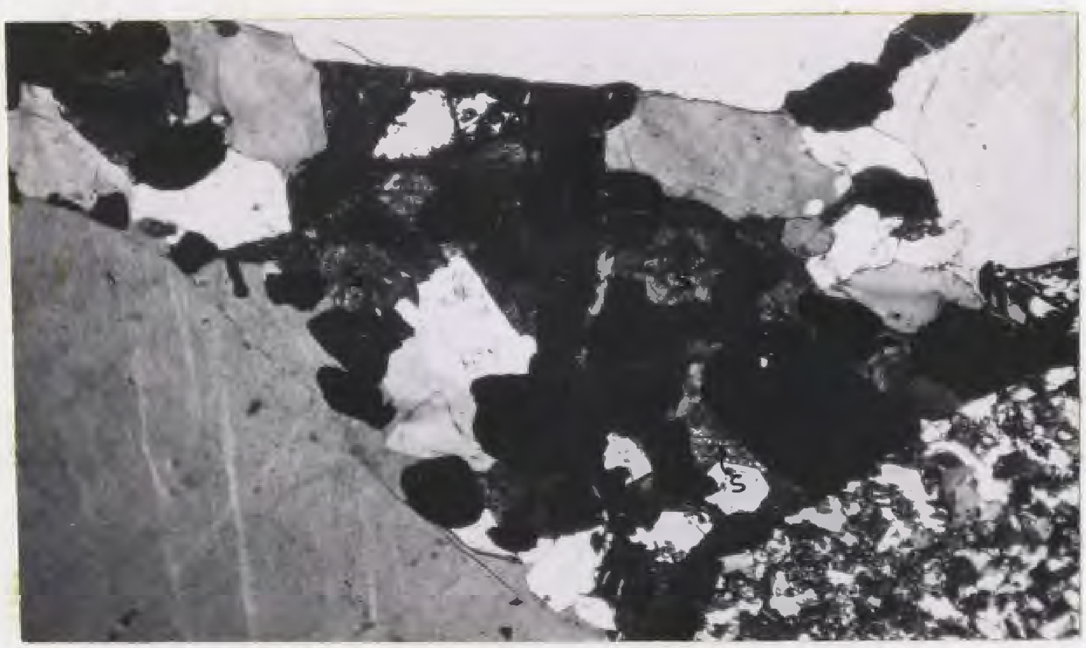
2. Grits and Sandstones

The detrital components of the grits and sandstones and the sandy matrix of the conglomerates are compositionally the same as the pebble types described above. Quartz of various types, perthitic and microcline feldspars are the main components. The microclines which are more abundant and generally fresh with only slight alteration but the perthites may be fresh or heavily altered. The quartz shows undulose extinction and in the larger grains, deformation lamellae occur (Pl. XLII). Grain boundary modification also occurs.

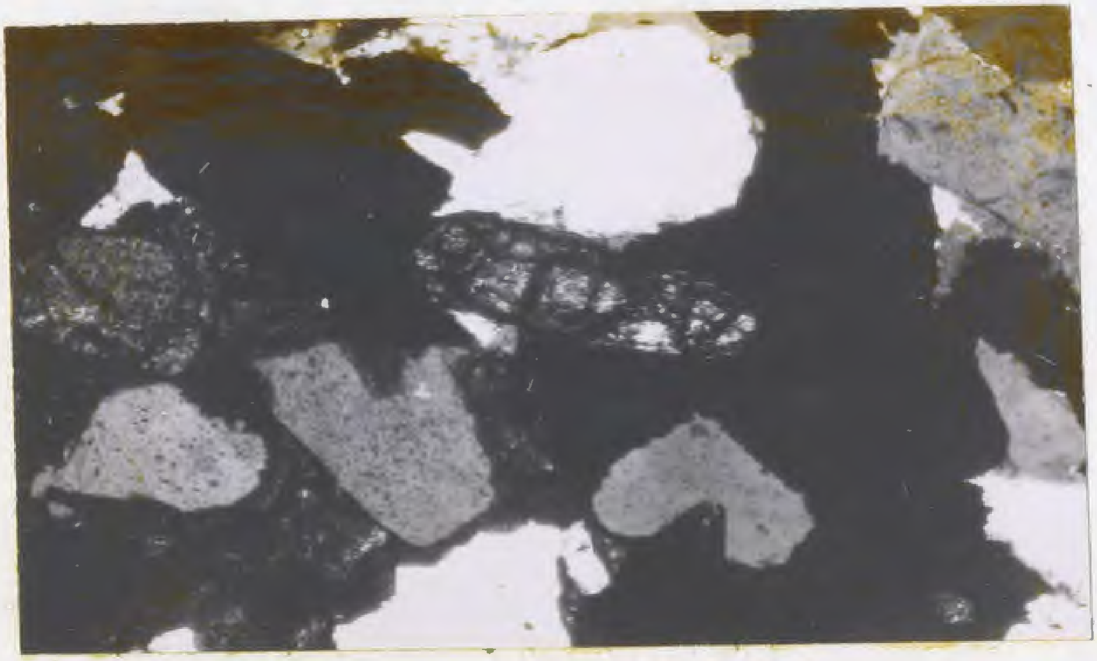
All the sands, grits and sandy matrices of conglomerates are characterised by detrital heavy minerals and by secondary growth of these minerals. In the conglomerates and some of the sandstones, the heavy minerals generally occur randomly but thin, 1 mm. laminae of heavy mineral concentrates may occur in ripple-drifted or trough cross-bedded, well sorted, fine to medium sandstones. The heavy minerals can form up to 75% of such laminae, and are associated with quartz, alkali feldspar and clay matrix. They consist of magnetite, zircon, sphene and epidote (Pls. XLIIIa, b & c). Magnetite is usually dominant whereas the other three minerals can be abundant or absent. Of these, zircon is the most persistent throughout the sediments although epidote of detrital and secondary origin forms a major component of some of the fine sands of Band A in area I.



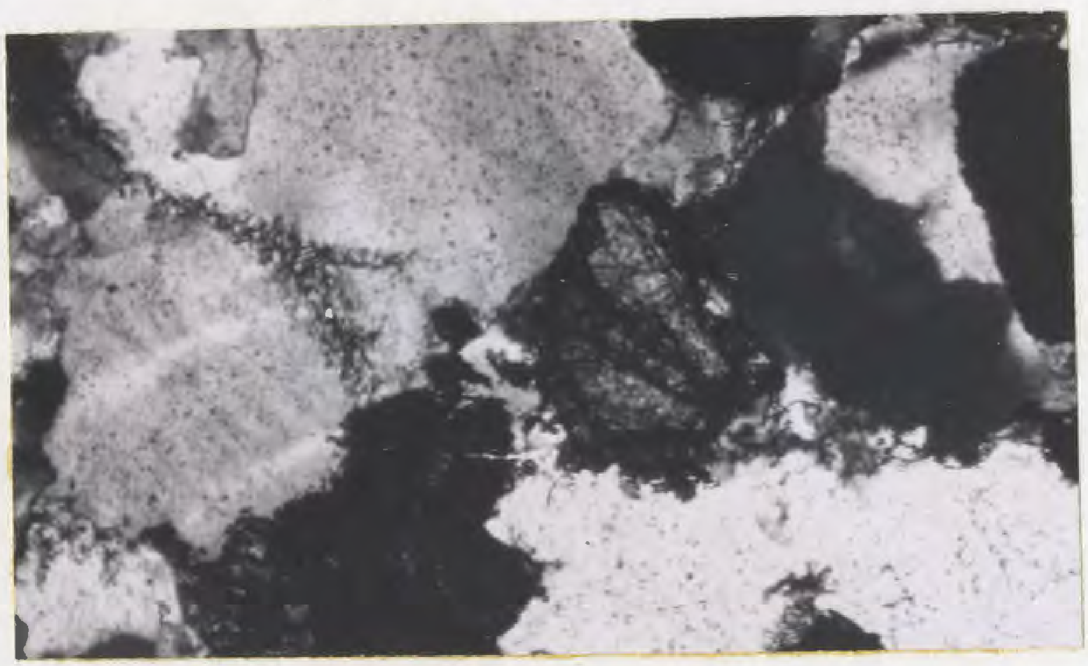
Pl. XLII. Sand grain of quartz displaying quartz deformation lamellae and undulose extinction. X 38.



Pl. XLIIIa. Concentration of heavy minerals in conglomerate matrix. Black grains are magnetite cemented by secondary sphene (s) which displays prominent partings. X 38.



Pl. XLIIIb. Moderately rounded, prismatic grain of zircon associated with magnetite (black), quartz (white and grey) and detrital epidote (dark grey). X 100.



Pl. XLIIIc. Sand grain of detrital epidote associated with quartz (light areas) and magnetite (black). X 64.

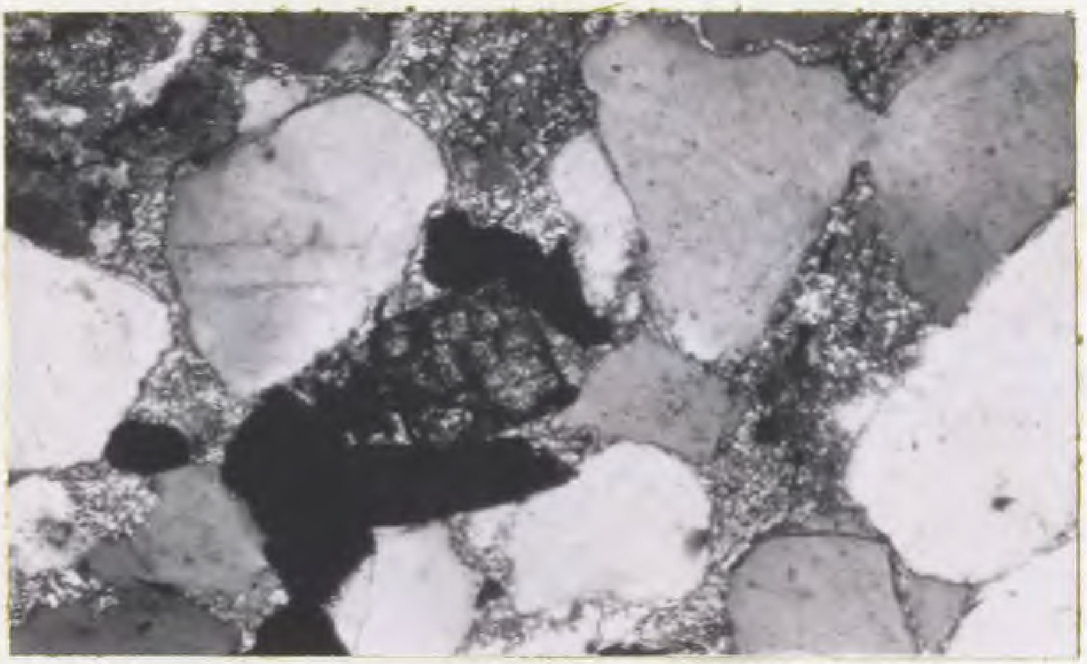
The magnetite grains vary from angular to rounded. The zircons may be well rounded but are usually elongate prisms or broken fragments. Detrital sphene and epidote are commonly difficult to distinguish since the detrital grains are enclosed within secondary growths of the same mineral. Secondary sphene occurs as rhombic crystals (Pl. XLIV) and as a cement which is brown, cloudy, and displays prominent partings. It is usually associated with detrital sphene and magnetite. The magnetite is often altered to haematite and leucoxene suggesting that it is titaniferous. The sphene is also altered to leucoxene. Detrital epidote occurs as poorly rounded grains which may show twinning. It is however, often more abundant as a secondary mineral, occurring as large masses of crystalline epidote surrounding detrital quartz and associated with secondary cryptocrystalline quartz and calcite. In this association, the epidote may replace and intrude into quartz grains.

The calcite usually occurs as patchy cement but occasionally replaces the rim of a feldspar grain. Epidote may also occur as a cementing agent in the quartzites of parts of Band A in area I (Pl. XLV).

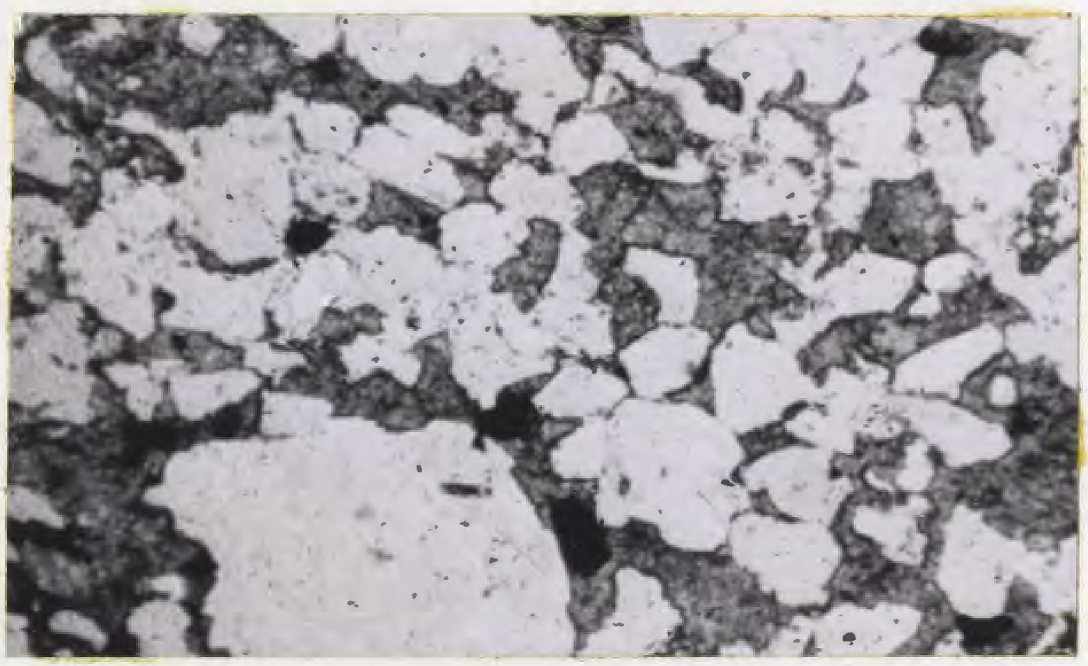
Clay matrix occurs in all the lithologies but varies in quantity. It is most abundant in the conglomerates but is reduced by the growth of secondary minerals. Sericite or illite is the main-clay-sized mineral and is often associated with substantial amounts of chlorite. Within the clay matrix large flakes of sericite occur which are probably secondary. Cryptocrystalline quartz, haematite and to a lesser extent limonite are the chief cementing agents. Both clay matrix and rims of grains are stained by iron oxides.

b. Statistical Analysis of the Majoque Lake Formation Sediments

The sediments of the Majoque Lake Formation were analysed in the same



Pl. XLIV. Rhomb of secondary sphene associated with detrital quartz (white and light grey), magnetite (black) and clay matrix. X 60.



Pl. XLV. Secondary epidote cementing quartz sand grains and some magnetite in fine quartzites of Band A (area I). (Plane polarised light) X 64.

way as those of the Arkose Lake Formation and the results are shown in figures XXVIIIa, b & c, XXIXa & b, and XXXa & b and table VII. The sediments can be subdivided into two groups. i. The coarse sediments that occur throughout the bands in areas II and III.

ii. The fine-grained quartzites of Band A in area I.

1. Group i

The sandstones and grits analysed are moderately to poorly sorted with σ^1 values ranging from 0.659 to 1.28. One sample of very coarse sandstone in Band E has σ^1 value of .475 which is well sorted (Folk and Ward, 1957). Like the Arkose Lake Formation, this group has equal numbers of positively or negatively skewed sediments. With the addition of the silt and clay factions to the sands and grits, it is probable that many of the sediments would become positively skewed.

The standard deviation, skewness and mean size were plotted upon diagrams used by Folk and Ward (1957) (fig. XXIXa & b). The plots show trends similar to those presented by these co-workers. The trends show that for mean-size of Ø = 1 to -2, the sediment is well sorted. However, as the sediment becomes finer, its sorting becomes poorer and the number of important modes increase. However, with continuing decrease of grain-size the sorting improves to moderately sorted. Skewness also reacts to this change of grain-size. The coarser sediments because of the poor sorting and the presence of a dominant fine component in the tail of the curve, give positive skewness. The negative skewness is just attained as the sediments improve their sorting and the grain-size decreases and the coarse components control the asymmetry of the tail.

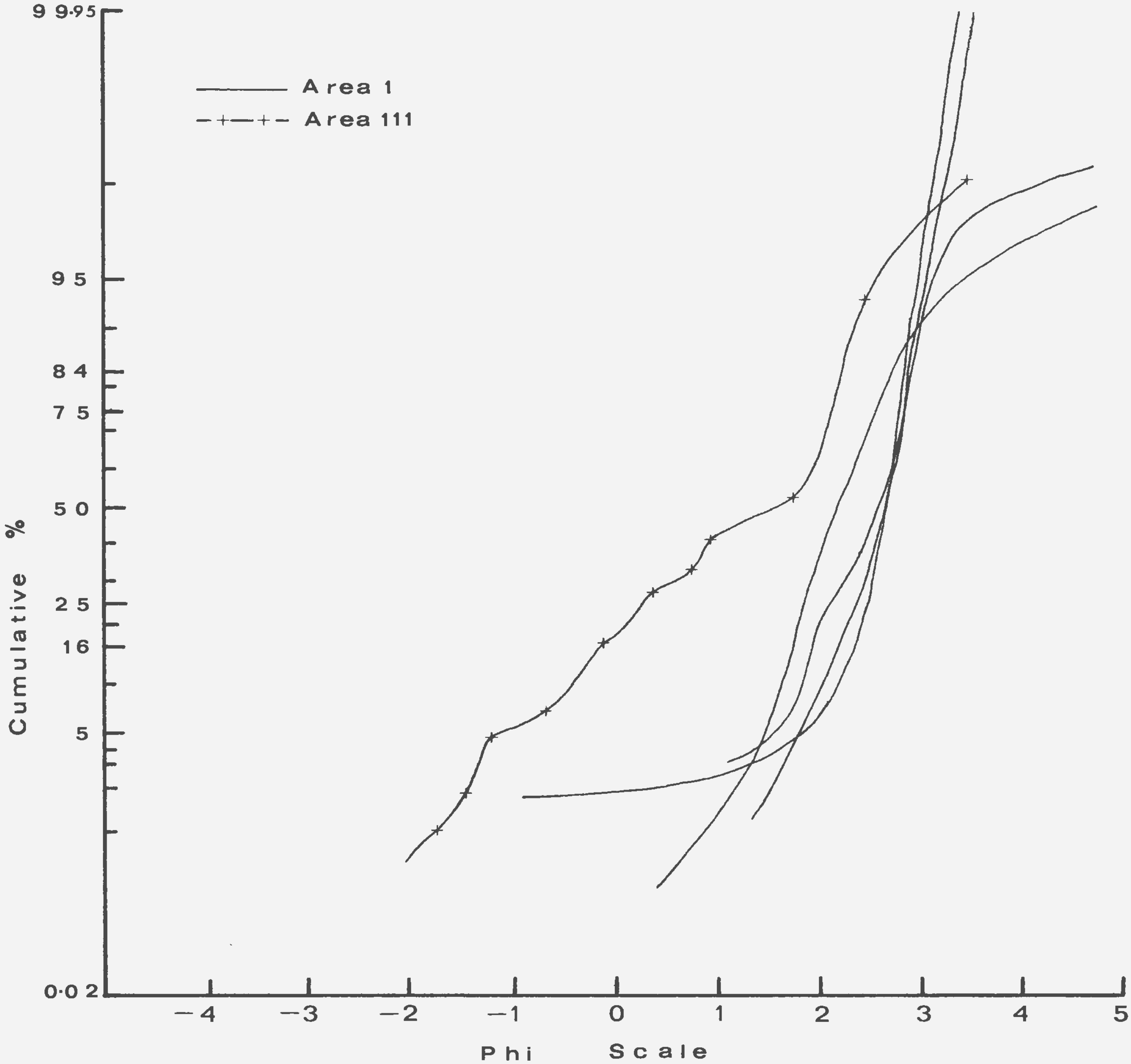


Fig. XXVIII a. Cumulative Percentage curves for grain-size analysis of sandstones of the Majoque Lake Formation.

a. Band A - area I and III.

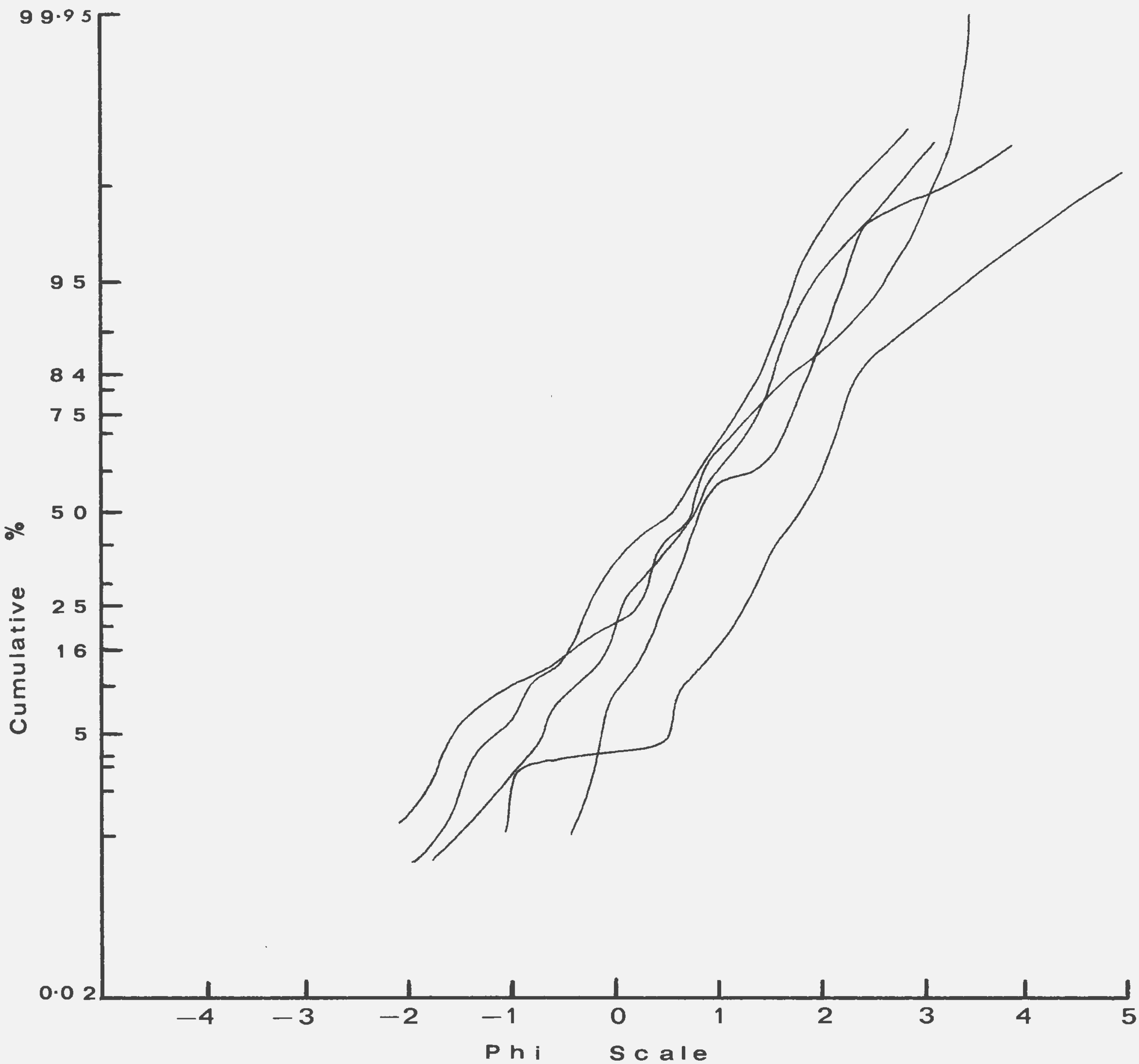


Fig. XXVIII b. Band C - area III.

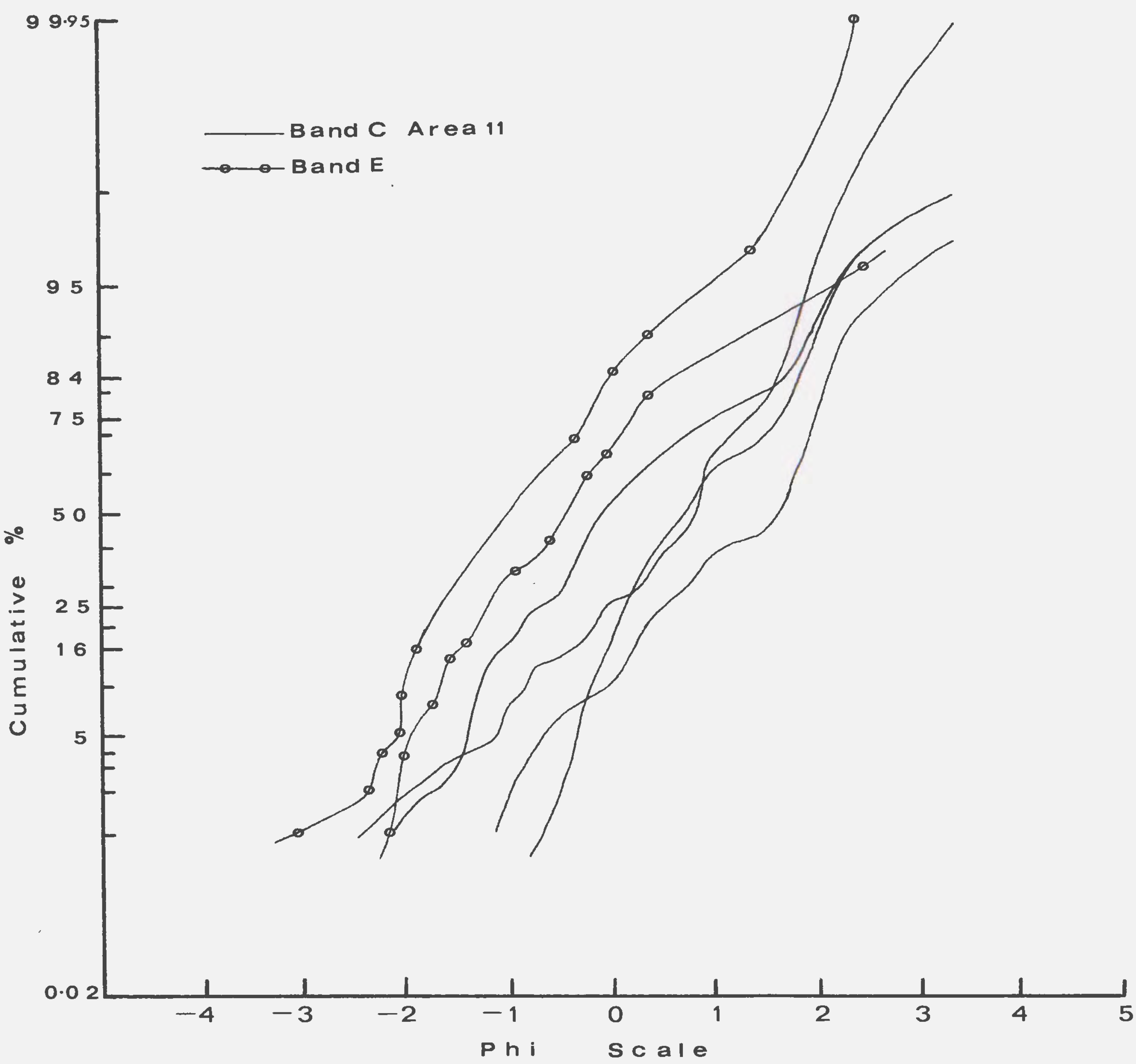


Fig. XXVIII c. Bands C (area II) and Band E (area III).

TABLE VII

Analytical Results for the Sediments of the Majoque Lake Formation

Band A	Primary Mode	Secondary Mode	σ^1	Mz	Sk_1	So_s	s	Kg
1K 134 (Area III)	F	C-M	1.191	1.33	-0.561	1.95	-2.1	-
1K 286A(Area I)	F	M	0.475	2.51	-0.42	0.8	-0.65	1.12
1K 287 (Area I)	F	-	0.33	2.58	-0.58	0.6	-0.6	1.09
1K 300 (Area I)	F	-	0.282	2.61	-0.27	0.6	-0.5	1.20
1K 331 (Area I)	F	M	0.535	2.25	0.211	0.97	0.51	1.13
Band C (Area III)								
1K 050	C	-	1.128	0.73	-0.011	2.15	-0.31	
1K 113	C	M	0.659	0.9	0.163	1.1	0.2	
1K 116	C	M	0.927	0.88	0.021	1.95	-0.1	
1K 166	VC-C-M	-	0.93	0.58	-0.168	1.5	-0.7	
1K 194	M	F	0.814	1.75	-0.057	1.5	0.3	
(Area II)								
1K 234	CMF	-	0.88	0.9	0.156	1.3	0.4	
1K 236	C	-	0.99	1.4	-0.383	1.7	-1.2	
1K 237	VC	-	1.28	0.23	0.242	1.85	0.9	
1K 263	C	M	0.988	0.8	-0.21	1.57	-0.85	
Band E (Area III)								
1K 141	C	VC	1.17	-0.46	0.226	2.97	1.05	
1K 152	VC	C	0.475	-1.3	0.173	1.55	0.9	

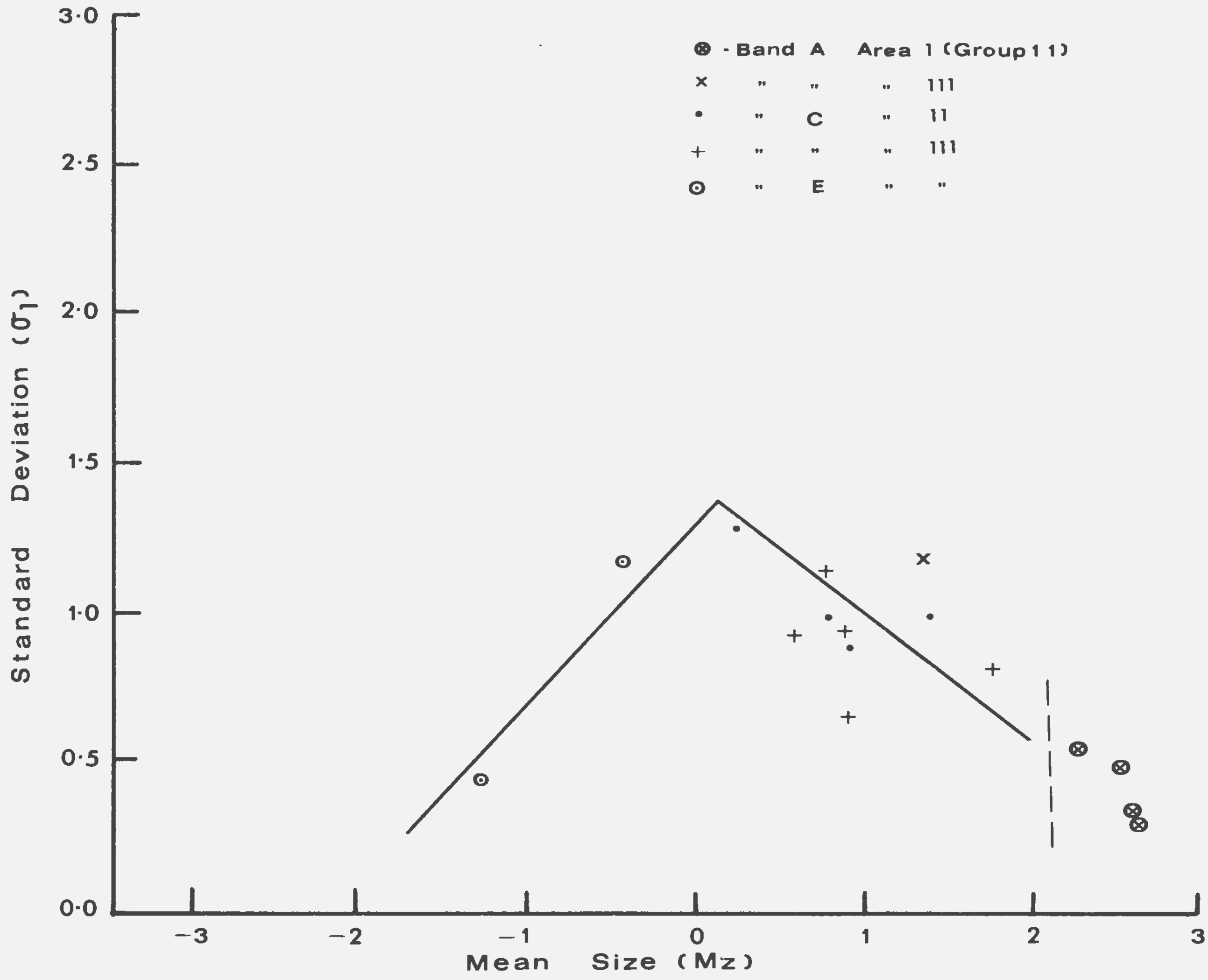


Fig. XXIX a. Plot of Standard Deviation vs Mean Size after Folk and Ward (1957)

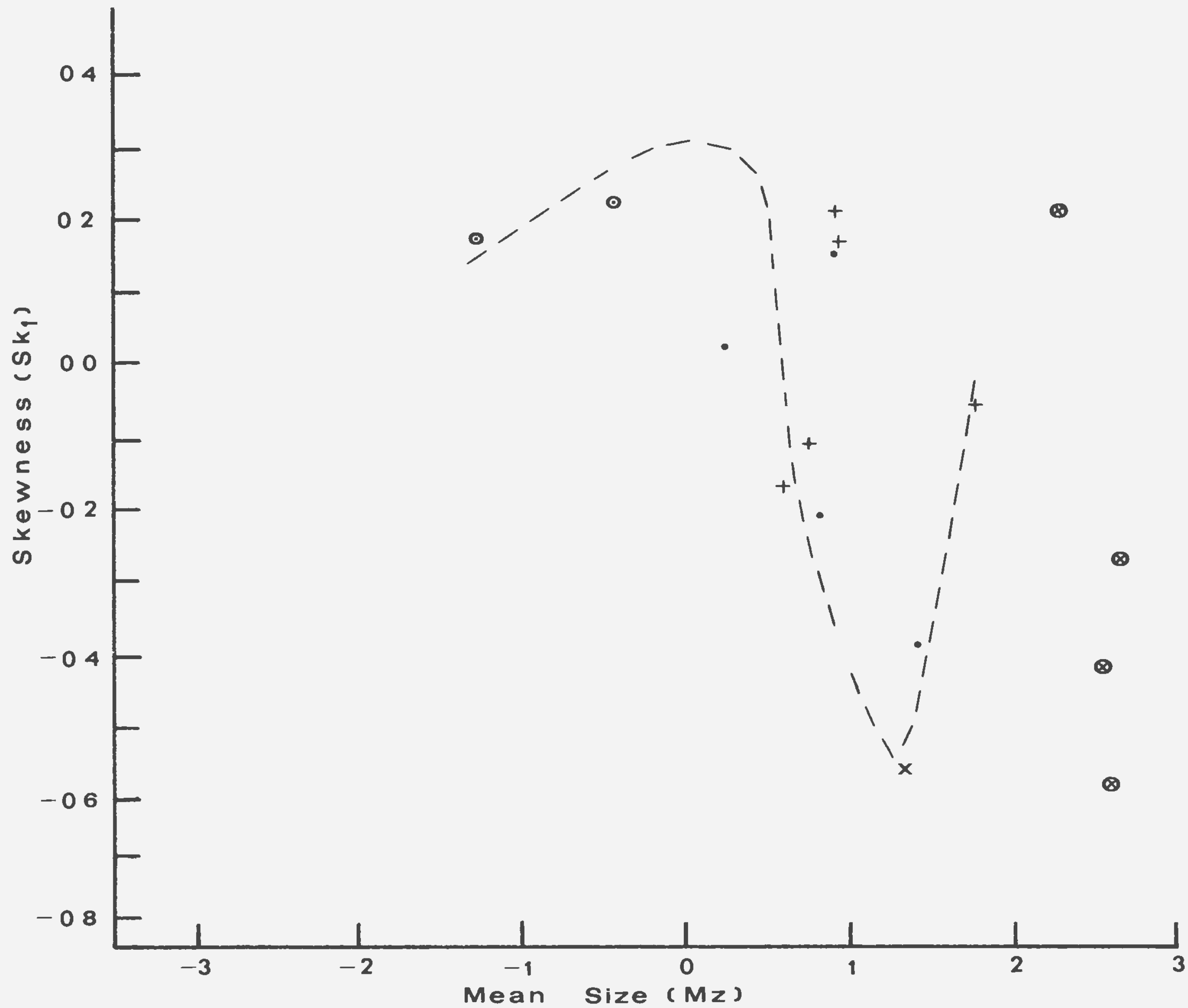


Fig. XXIX b. Plot of Skewness vs Mean Size after Folk and Ward (1957).

This variation in measures corresponds to deposition in differing flow regimes. The better sorted grits occur as massive bed forms associated with channel bars in higher flow regime conditions which would tend to remove much of the finer faction. Within planar cross stratified sandstones, the low flow regime conditions will not remove the finer sand so effectively and the poorer sorting will be increased as a result of downslope slippage of deposited sediment upon the avalanche face of a migrating sand bar. With lower flow regime conditions, finer, better sorted sands would result by initial deposition and also by reworking of earlier deposits.

Plots of standard deviation vs mean size and skewness vs. mean size show trends like those of Folk and Ward (1957). Standard deviation vs. skewness was also plotted but no comparable trends were found.

Friedman's plots (1967) to distinguish river and beach sands were also used and all points plot within the field of river sands (Fig. XXXa & b).

2. Roundness Data of Group I

The roundness data for group i of the Majoque Lake sediments was subdivided in a similar fashion to that for the Arkose Lake Formation. The sediments are subrounded to subangular although there are three samples which contain a large percentage of rounded grains. Usually however, the extremes of roundness in a sample are dominated by angular grains. This data is consistent with that of river-lain sediments.

3. Group ii

The statistical data for Group ii is accepted without the reservations for the other sediments analysed. This is because the sediments are well sorted with little or no matrix (see modal analysis 1K 286 A- Table VI), and for this

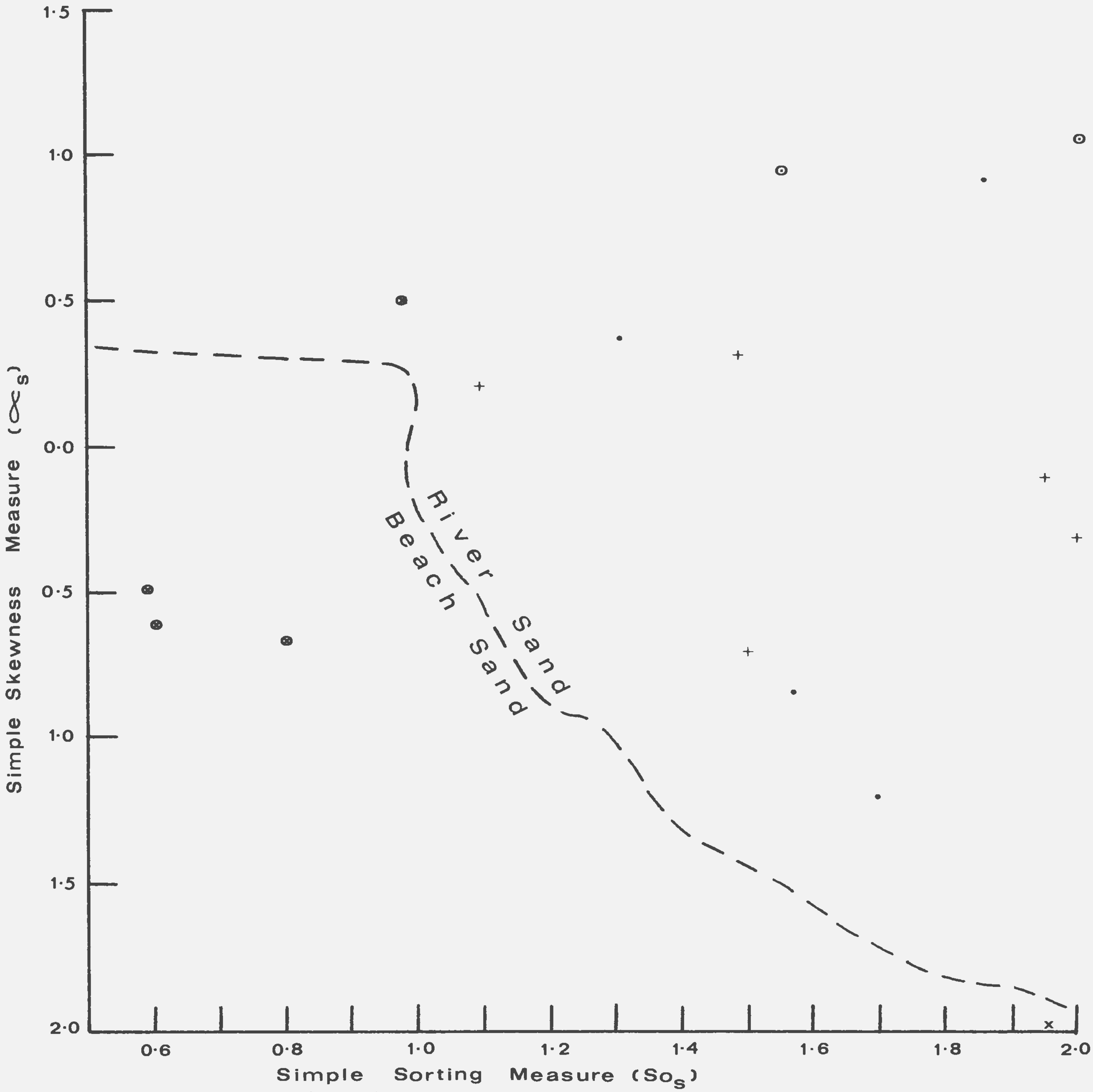


Fig. XXX a. Friedman Plot (1967) of Simple Sorting Measure vs Simple Skewness Measure to distinguish river and beach sands.

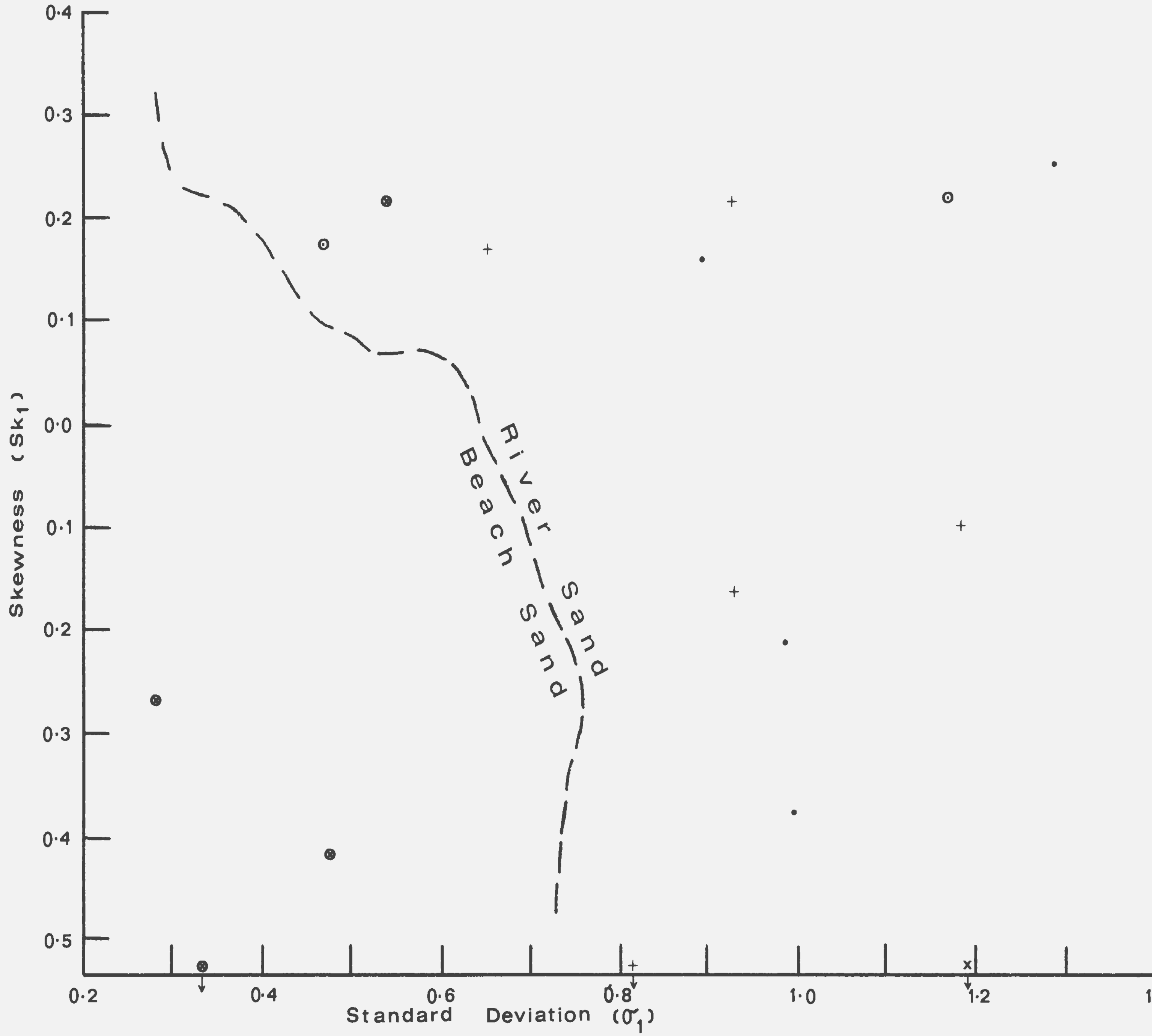


Fig. XXX b. Friedman Plot (1967) of Standard Deviation vs Skewness to distinguish river and beach sands.

reason kurtosis was also computed.

The fine sands of area I are extremely negatively skewed except for one sample which is positively skewed. All the sands are well to very well sorted and show leptokurtic values although one of the samples fall marginally into the mesokurtic field of Folk and Ward (1957). Plotted upon Friedman's diagrams (Friedman, 1967) they plot within the field for beach sand.

Several studies to distinguish beach and dune sands have been undertaken (Mason and Folk, 1958; Shepard and Young, 1961; Friedman, 1961) since the two are difficult to distinguish apart. Comparison with the results of these works shows that the group ii sands have closer affinities to beach sands than to dune. Beach sands are almost always negatively skewed since the fines are removed by wave action (Mason and Folk, 1958; Friedman, 1961) whereas dune sands have a higher percentage of clay admixed (Shepard and Young, 1961). Sorting of dune sands is usually better than in beach environment (Mason and Folk, 1958) whilst kurtosis values are similar.

Three of the fine sands of area I analysed are considerably more negatively skewed than any of the sands analysed by Mason and Folk, 1958 and Friedman, 1961, and this is probably the result of the analytical method. The fourth sand which is positively skewed has however, high σ^1 values and thus,it is too poorly sorted to be a dune sand. All the values of standard deviation (σ^1) for the fine sands lie within values (σ^1 = 0.30 - 0.35) of beach sand of Mason and Folk (1958) or are more poorly sorted than these values. One value 1K300 has an σ^1 value which is indeterminate according to the criteria of Mason and Folk.

The analytical approach and subdivisions of Mason and Folk (1958) were questioned by Shepard and Young (1961) as a result of their own grain-size study which could not discriminate between beach and dune sands. Folk (1961) however, attributed this to the method of grain size analysis. However, Shepard and Young did suggest that the dune sands could be distinguished by their higher clay content. Examination of the area I fine sands shows them to be almost wholly lacking in clays (see modal analysis, table VI). They also suggest that dune sand grains are rounder than those of beach sands as suggested previously by Russell (1939), Pettijohn (1956), and Beal and Shepard (1956). If this is true though it has been questioned by Mason and Folk (1958) and Mattox (1955), then it is likely that the fine sands are not dune sands since they are subrounded to subangular.

Thus, it is apparent that the analytical evidence, the mineralogy and roundness data, presented above suggest a beach sand for the fine sandstones of group ii. Flat bedding which is the main sedimentary structure is also typical of beach deposition. Alternatively, the sands may be a water-lain deposit of wind blown sand. The thin flat bedding indicates that the waters were probably relatively quiet. Sorting was however, poorer because of the introduction of small amounts of coarse detritus which resulted in negative skewness.

II. Volcanic Rocks

a. Mineralogy

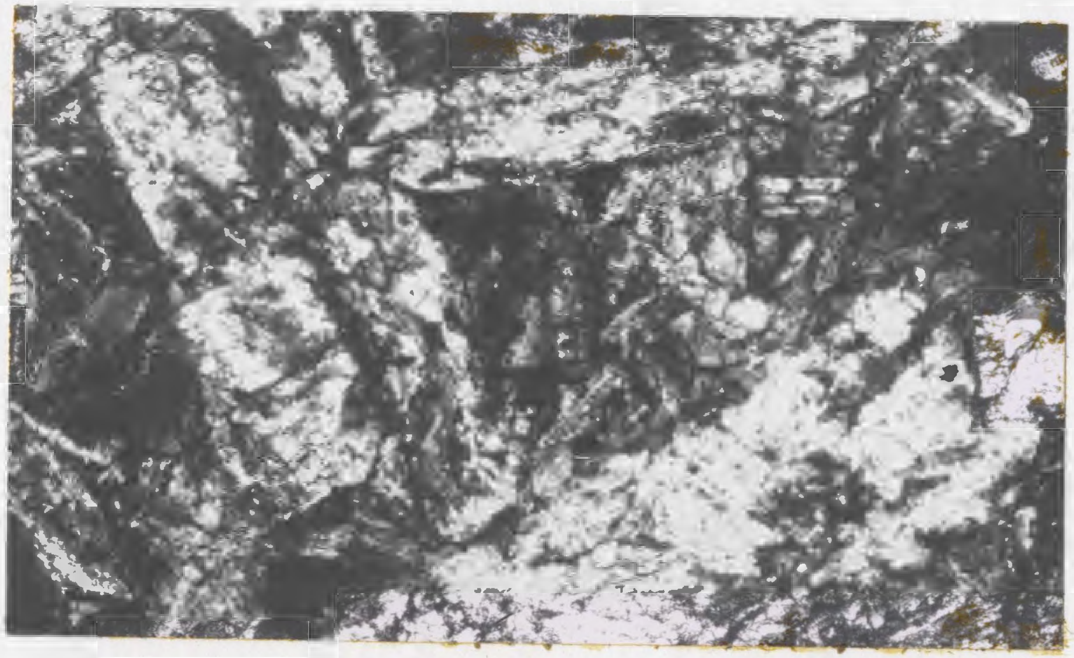
The volcanic rocks of the Majoque Lake Formation are composed of two main primary mineral phases, plagioclase and clinopyroxene set in a groundmass of glass, microlites, pyroxene granules, skeletal ores and rare alkali feldspar.

Alteration and growth of secondary minerals are common throughout.

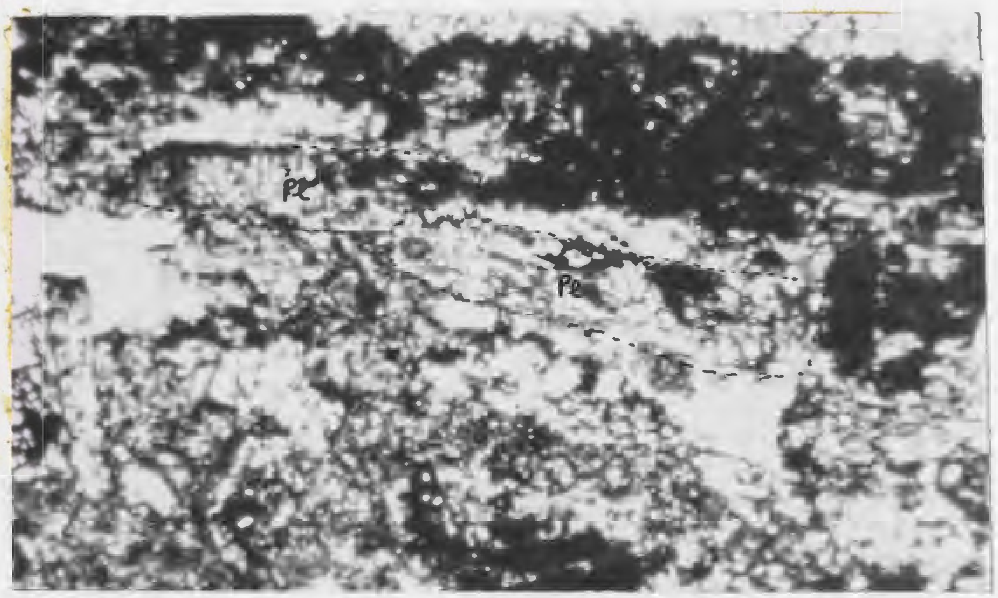
Plagioclase usually occurs as three general types. Type i) Phenocrysts of 1 - 1½ mm. in length are common and occur as laths which show albite and combined carlsbad-albite twins. Occasionally, pericline twins also occur. The phenocrysts are usually highly saussuritised and locally sericitised (Pl. XLVI). Their composition varies from An_{54} to An_{62}. Type ii) Smaller phenocrysts up to 4mm. long with both albite and carlsbad twins occurring between the larger phenocrysts. They are saussuritised and sericitised but to a lesser degree than the larger feldspars. Their composition is An_{52}. Type iii) Very small, anhedral crystals of albite twinned plagioclase occur in the interstices between the larger grains. They are not very common and are little altered and have a composition similar to type ii.

Besides the three types of plagioclase described above, some flows contain large 1 - 1½ cm. long phenocrysts of plagioclase. These crystals are so highly sericitised and saussuritised that it is almost impossible to distinguish them in thin section and their composition is now known. They are often bent due to flow and contact with other crystals (Pl. XLVII).

Clinopyroxene is the only primary mafic mineral phase identifiable with certainty. It is usually pale brown in colour and may be slightly pleochroic with α - colourless, β - purply-brown and γ - pale brown. It is optically positive with an optic angle of 48^{o} and the $\gamma \wedge Z$ extinction angle varies from 38^{o} - 42^{o}. The purplish brown colouration suggests that the pyroxene is titaniferous and the low 2V probably indicates the presence of octahedrally coordinated titanium (Deer et al, 1967, p. 124) in the pyroxene structure. Since the 2V is too high for



Pl. XLVI. Laths of sericitised plagioclase (Type 1) (white areas) set in fine groundmass of plagioclase microlites, skeletal magnetite and other secondary minerals. X 160.



Pl. XLVII. 1 cm. long, broken plagioclase phenocryst (Pl) set in fine groundmass of microlites, glass and alteration products. X 8.

subcalcic augite, the pyroxene is regarded as being titaniferous augite. The pyroxenes occur as irregular,1 mm. phenocrysts intergrown with and enclosing types i and ii plagioclase or as irregular, incomplete crystals of 0.2 mm. in size. It is unusual for two forms of pyroxene to occur in the same rock.

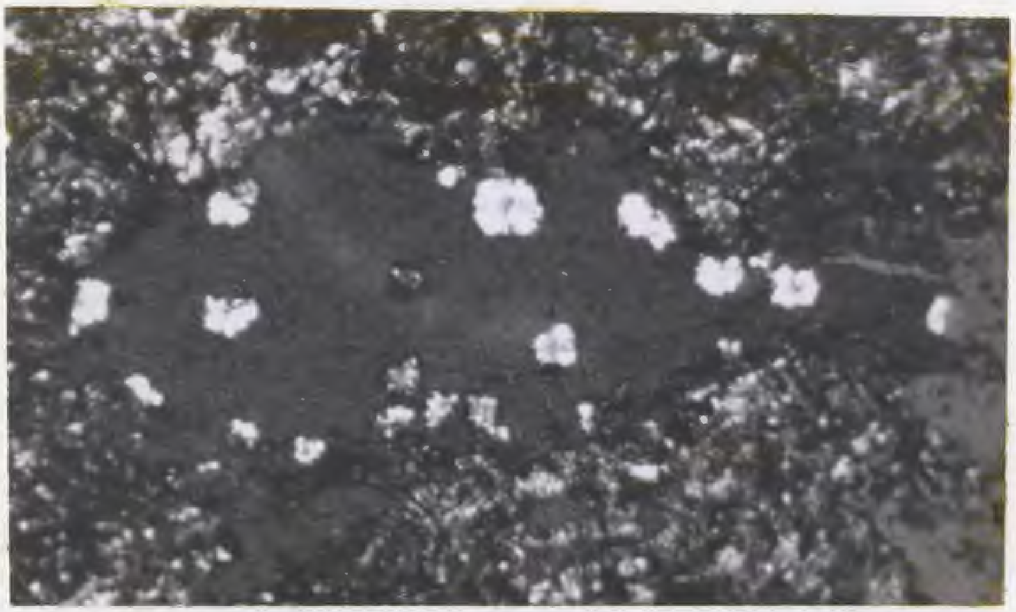
Skeletal magnetite which is probably titaniferous as it is purplish in reflected light occurs in acicular and dendritic forms and as rounded specks throughout the pyroxenes. It may also occur as small euhedral phenocrysts up to 0.5 mm. in size and may form intergrowths with small plagioclase laths.

A single occurrence of amphibole was recorded in the volcanics. The amphibole which is a prism, 2-3 mm. long was altered at its rim to chlorite and clinozoisite. It occurs with glomeroporphyritic clusters of 1-2 mm. long plagioclase laths set in a groundmass of granular clinopyroxene and sericitised plagioclase. The amphibole which is of an unknown type may be a primary volcanic mineral or may represent a cognate xenolith.

Within the groundmass, there are a wide variety of minerals present. Plagioclase microlites 0.1 mm. in length occur with brown granular clinopyroxene, skeletal magnetite which may be altered to haematite, sphene and occasionally some orthoclase feldspar. Cloudy or brown glass occurs in varying amounts depending upon the location of the sample within a flow. Glass was very common in the vesicular tops of flows though relatively scarce in centres of thick columnar basalt flows.

The vesicles of flows are infilled by various mineral associations.

1. Chalcedonic outer rims surrounding chlorite speckled throughout by sphene.
2. Chlorite and chabazite (Pl. XLVIII).
3. Calcite.



Pl. XLVIII. Chabazite spherulites enclosed in chlorite in amygdale. X 51.

Pl. XLIX. Chlorite pseudomorphing possible original nepheline crystal. X 204. (Plane polarised light)

4. Chalcedonic rims enclosing chlorite which rims on epidote-pyrite association.

5. Vesicles containing an inner zone of chabazite which encloses chlorite, sphene and some calcite. The chabazite is surrounded by an outer zone of quenched pyroxenes and small plagioclase microlites enclosed in a dark grey glass (fig. XXXI). Many of the quenched pyroxenes show curly, feathery forms that resemble perlite textures (fig. XXXI). The outer zone also has a thin layer of magnetite which lines the wall of the vesicle. These vesicles are very common in an oxidised top of one flow and they resemble structures described by Smith (1967) in basaltic lavas in New South Wales, Australia. The vesicles which in the latter case occur in pillow lavas are called 'segregation vesicles'. The presence of basalt crystal phases within the vesicles is attributed to partial crystallisation of a basalt liquid and vesicle formation at one confining pressure with final crystallisation at an increased confining pressure. The relative decrease in internal vesicle pressure compared to confining pressure caused the basalt liquid to seep into the vesicle until internal vesicle and confining pressure became equal. In the case of the 'segregation vesicles' of the Majoque Lake basalts, it is unlikely that such a process as Smith described occurred as confining pressures were not likely to change in an environment of continental basalt eruption. However, cracking of the vesicle wall would release the gas in the vesicles lowering

pressure. As a result, basalt liquid would flow into the vesicles until a new bounding surface formed to prevent further infill of the vesicle. The usual minerals would then infill the vesicle after final solidification.

The volcanic rocks are altered throughout the chlorite which is especially common as a replacement mineral. It occurs in large patches replacing glass and enclosing plagioclase laths. The chlorite is usually associated with small horse-shoe shaped patches of very fine-grained secondary quartz, which is possibly chalcedonic and small spherulites of sphene.

Chlorite also pseudomorphs primary mineral phases. Plate XLIX shows a euhedral hexagonal mineral possibly originally nepheline pseudeomorphed by chlorite.

A fibrous green mineral with low birefringence possibly antigorite is associated with scattered fine-grained magnetite in some samples. It's presence suggests that olivines were also present in some of the flows.

Within the zones of the non-oxide rings in the basalts magnetite occurs in irregular patches and as spidery, fibrous developments surrounding silicate crystals. The magnetite which is often altered to haematite is especially concentrated at the outer zone of the iron oxide ring whilst away from the outer zone the magnetite is less dense and of a spidery form. Magnetite and haematite also penetrate cleavage and fractures on the nearby plagioclases and pyroxenes.

b. Textures in the Volcanic Rocks

The pyroxenes and plagioclase phenocrysts occur together in poikilitic and ophitic intergrowths (Pl. L). Where there is abundant glass, intergranular textures occur with granulose pyroxenes clustered about the plagioclase

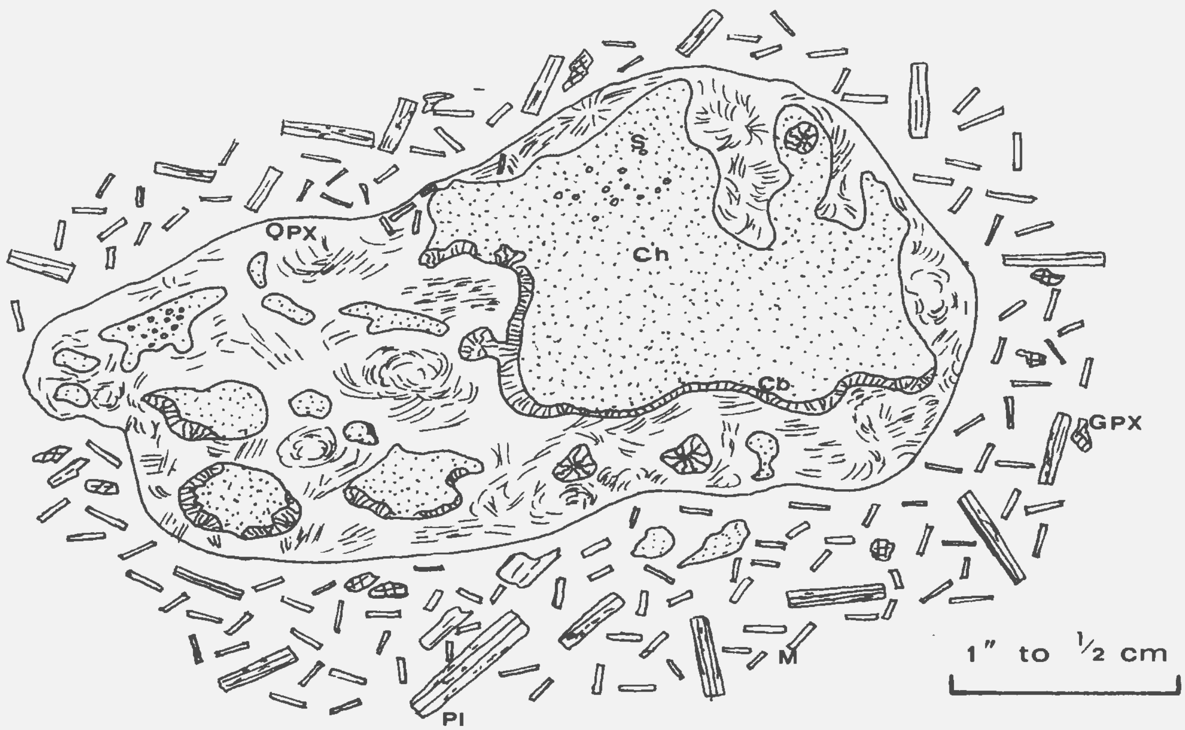
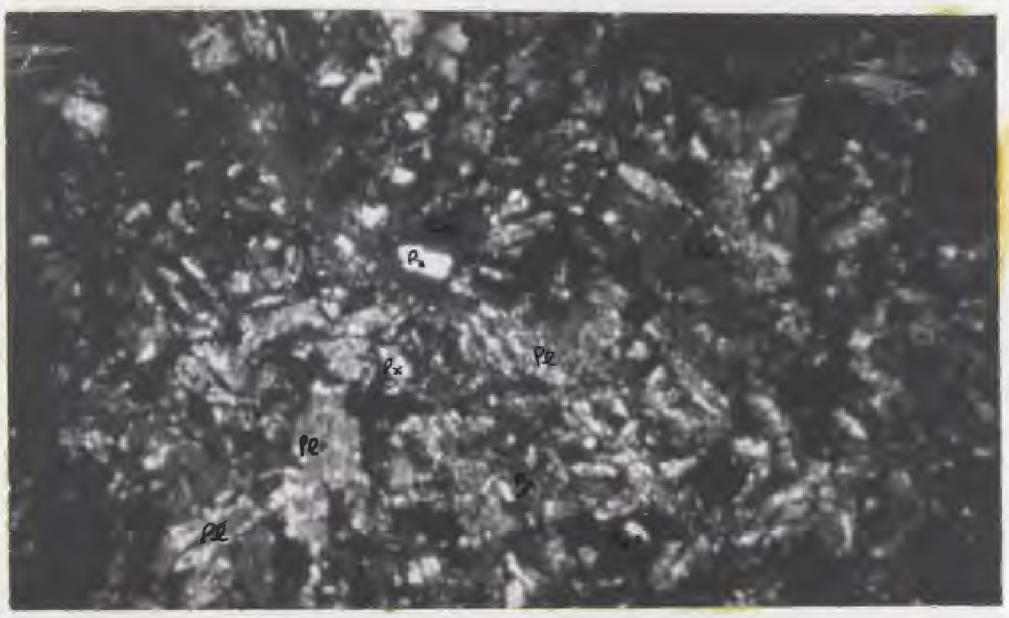


Fig. XXXI. Amygdale containing an inner zone of chabazite (Cb) enclosing chlorite (Ch) which contains small spherulites of sphene (S), and outer zone of quenched, acicular pyroxenes (QPx) which display perlitic textures in a glassy groundmass. The amygdule is enclosed within basalt composed of plagioclase laths (Pl) and microlites (M), with a few scattered granules of pyroxene (GPx) set in groundmass of glass and alteration products.

Pl. L. Large pyroxene crystal (white) ophitically enclosing small laths of plagioclase. Some small magnetite phenocrysts also occur (black). X 38.



Pl. LI. Granular pyroxene (Px) associated with plagioclase laths (Pl) and groundmass chlorite (Ch). X 38.

laths (Pl. LI). Although difficult to distinguish in aphyric hand specimens, many of the volcanics show flow alignment of the feldspars. Where glass content is low or absent, pilotaxitic textures may occur. In the deeper parts of thick columnar basalt flows, flow textures are sporadically developed. Areas of local flow alignment are intermixed with areas of randomly oriented plagioclase phenocrysts. The flow fabric is thought to result from small, localised convection cells occurring in a stationary lava flow. This convection flow could either locally destroy earlier developed flow fabric formed whilst the flow was in motion or could produce flow alignment of the plagioclases within the area affected by the convection cells. Such cells could have been large but were more likely small being controlled by local pockets of greater heat within the flow.

c. Sequence of Crystallisation

From the relationships suggested by the textures in the volcanics it is apparent that plagioclase of An_{54-62} was first to crystallise. Crystallisation of this phase continued for some time until it was joined by clinopyroxene. Plagioclase and pyroxene continued to crystallise together and final plagioclase composition reached An_{50-52}. Other late phases are granular pyroxenes, magnetite and orthoclase. Many of the basalts show quench features with the pyroxenes only incompletely developed and abundant glass present.

d. Chemistry of the Majoque Lake Basalts

Seven samples of basalt were analysed for ten major elements (Table VIII). The data obtained was plotted in Kuno's plots (1960 and 1967) of Al_2O_3 - total alkalis - silica (Fig. XXXIIa & b) and total silica against total alkalis respectively. CIPW norms and Poldervaart's Index (1964) were also calculated (Table IX)

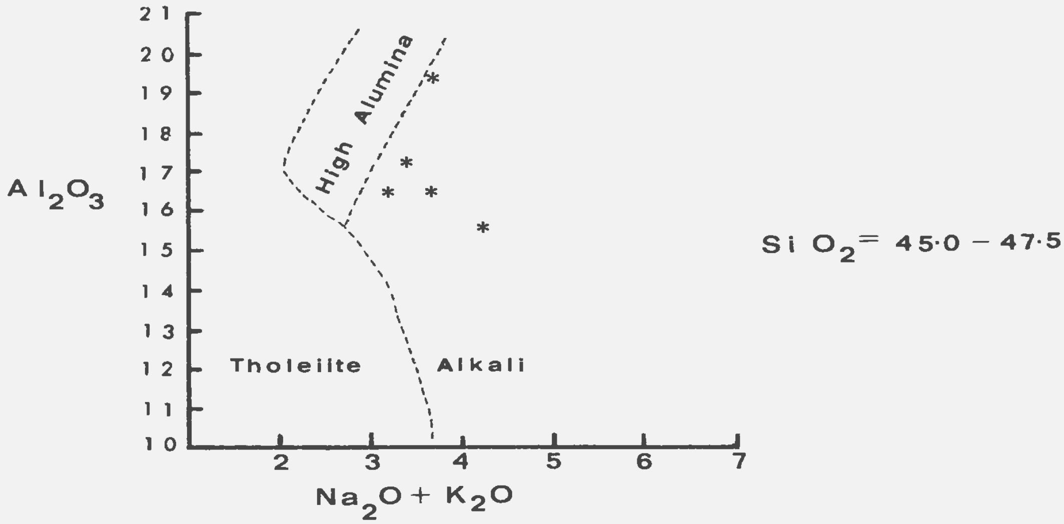
TABLE VIII

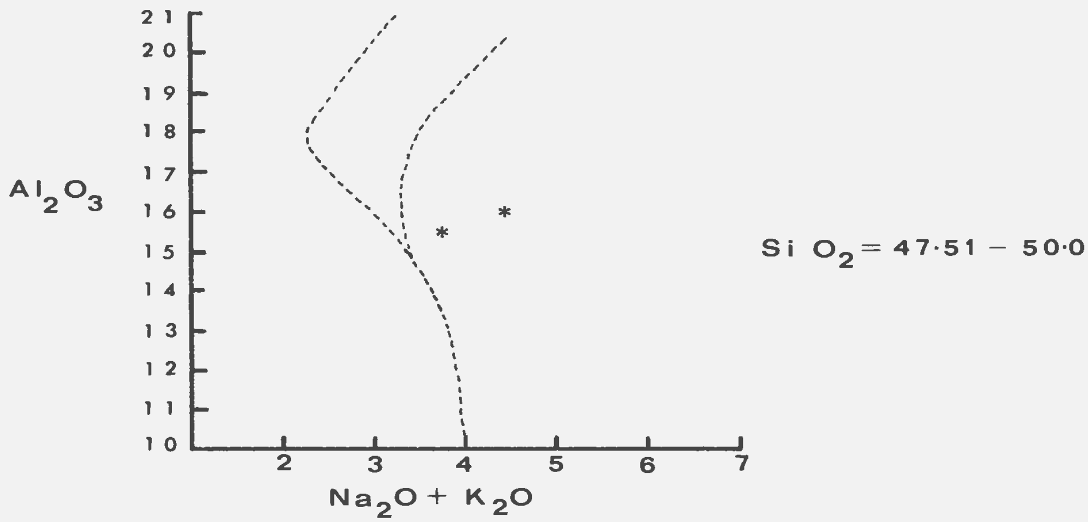
Chemical Analyses of Majoque Lake Formation Basalts

Sample #	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Loss by Ignit.
1K 032	45.0	1.83	17.2	10.9	0.21	7.28	7.81	3.02	0.34	0.24	3.99
1K 074	48.0	1.85	16.1	12.9	0.21	6.69	6.82	3.84	0.60	0.32	3.6
1K 115	46.8	2.30	15.7	14.8	0.20	5.38	7.91	2.95	1.18	0.44	2.43
1K 119	45.5	1.30	19.3	9.0	0.17	6.88	9.05	2.88	0.79	0.22	4.95
1K 122	46.0	1.90	16.5	13.3	0.22	6.39	8.12	2.88	0.25	0.26	3.06
1K 176	47.8	1.78	15.5	12.9	0.21	5.57	8.59	3.26	0.49	0.25	3.06
1K 304	46.0	2.05	16.5	12.9	0.18	6.17	8.61	3.24	0.33	0.27	3.34

Basalts analysed using Perkin-Elmer 303, Atomic Absorption Spectrophotometer, by G. Andrews at Geochemistry Laboratory, Memorial University of Newfoundland.

Fig. XXXII a. Plots of total alkalis vs Alumina vs silica for basalts (after Kuno, 1960).





b. Plot of total alkalis against silica for basalts (after Kuno, 1967).

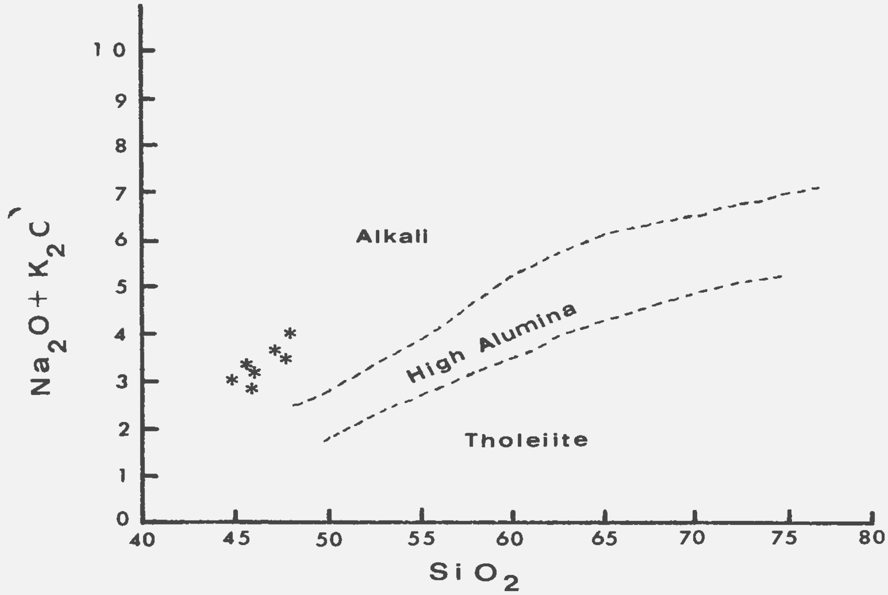


TABLE IX

C.I.P.W. Norms of Majoque Lake Basalts

Sample #	Or	Ab	An	Di	He	En	Fs	Fo	Fa	Mt	Ilm	Ap	Ag	Hyp	Ol	Poldervaar Index
1K 032	2.16	27.49	34.83	2.79	1.40	6.98	4.01	7.86	4.98	3.12	3.74	0.59	4.19	11.0	12.84	0.97
1K 074	3.68	33.75	25.89	3.39	2.43	4.88	4.01	7.6	6.88	3.01	3.65	0.77	5.82	8.90	14.49	2.06
1K 115	7.24	25.89	27.09	4.32	4.52	5.16	6.20	4.71	6.23	3.0	4.53	1.05	8.85	11.36	10.94	0.81
1K 119	4.97	25.95	39.83	3.69	1.52	0.35	0.16	11.33	5.89	3.08	2.63	0.54	5.21	0.52	17.23	3.06
1K 122	1.56	25.78	27.56	3.44	2.87	8.52	8.17	4.7	4.97	2.32	3.81	0.63	6.31	16.7	9.68	-0.421
1K 176	3.04	28.95	27.1	6.86	5.95	7.10	7.07	2.99	3.28	3.04	3.54	0.60	12.82	14.17	6.28	0.501
1K 304	2.05	28.8	31.0	5.64	4.26	3.83	3.31	6.79	6.49	3.04	4.09	0.65	9.90	7.15	13.28	1.98

The basalts are characterised by high aluminium content which in two cases (1K 032 and 1K 119) is high enough to fall in the high-alumina basalt field of Kuno (1960). They are also relatively richer in total iron and poorer in CaO than average world alkali and tholeiite basalts (Mason, 1967, Table VI, page 224) whilst the Na_2O content is comparable to that of alkali basalts.

The CIPW norms calculated from the oxides indicate that the basalts are normative in hypersthene and olivine even though both phases are apparently absent in the rocks themselves. The amount of each normative mineral varies greatly and two groups occur.

i. those with hypersthene and olivine in nearly equal quantities.

ii. those with olivine greater than hypersthene.

The presence of hypersthene in the norm would place the basalts in the tholeiite field of Yoder and Tilley (1962) but since there is high normative olivine, they must be olivine tholeiites. Kuno (1967) and Poldervaart (1962 and 1964) however, regarded the classification of Yoder and Tilley's as too rigid since basalts which are obviously alkali do not possess normative nepheline. Kuno's plots of 1960 and 1967 (figs. XXXII) compiled from Japanese basalts show that the Majoque Lake basalts are such a case as they all plot within the alkali basalt field. Similarly, calculation of Poldervaart's Index (Poldervaart, 1964) indicates that all but one (IK 122) of the basalts analysed are alkali basalts whilst 1K 122 is an olivine tholeiite.

e. Discussion

Mineralogically, the Majoque Lake volcanics in the Arkose Lake area are uniform with mineral assemblages typical of basaltic rocks. It is, however, difficult to assign the basalts to either the alkali or tholeiite fields. Various authors have proposed distinctive features between the two groups. Kuno (1960) distinguishes tholeiites from alkali basalts by the presence or absence respectively of olivine showing a reaction with pigeonite. Yoder and Tilley (1962) distinguish the two groups on the greater variety and composition of pyroxenes in tholeiites. Tholeiites can contain augites, subcalcic augites and orthopyroxenes, plagioclase of approximately An_{50} and iron oxides as essential mineral phases. Alkali basalts are distinguished by the presence of titaniferous or high calcic augite, no orthopyroxene, plagioclase of about An_{50} with zoning towards calcic anorthoclase and olivine. The presence of exsolution lamellae in the pyroxenes is also regarded as characteristic of tholeiites. Macdonald and Katsura (1964), based on volcanics from Hawaii, propose that alkali basalts contain titan-augite, groundmass olivine and interstitial alkali feldspars.

In the Majoque Lake basalts, the mineralogy indicates that the volcanics are alkali. The main pyroxene is augite which is thought to be titaniferous. No exsolution phenomena are present in the pyroxenes. Other features that favour alkali basalts are the presence of groundmass alkali feldspar and possible nepheline and groundmass olivine that have since been completely replaced.

The mineralogical evidence of general alkali basalt affinity for the Majoque Lake basalts is generally supported by the analytical data although the calculated norms indicate that they are olivine tholeiites.

Baragar (personal communication) has systematically analysed the basalts of the Majoque Lake Formation outside the Arkose Lake area. Normatively, they are similar to those of the Arkose Lake area although some of the basalts are nepheline normative. As a result, Baragar suggests that the basalts may form a transition group between alkali and tholeiite basalts. Since the Al_2O_3 content of the basalts is relatively high they may in fact be transitional basalts, similar to the transitional high-alumina basalts of Kuno (1960).

The above conclusions and data, however, indicate that the Majoque Lake basalts are distinctly different from basalts of other plateau basalt provinces. The mineralogy of the basalts resembles that described by Washington (1922) for the Deccan, Oregan, Thulean (Brito-Arctic) and Siberian Provinces. More detailed work however, on the Oregon Province (Columbia River Plateau Basalts) by Waters (1961) and on the Faroes Islands (Noe-Nygard et al, 1968) of the Brito Arctic Province shows that the basalts mineralogically are quire different from those described by Washington. The Deccan basalts which are tholeiitic, appear to have mineralogy similar to the Majoque Lake basalts with plagioclase as phenocrysts and in a groundmass which is compositionally similar (West, 1958). The Deccan, Oregon and the Icelandic and Faroes Island basalts of the Brito-Arctic provinces are all tholeiite basalts. However, plateau basalts of Skye, Rum and Mull of the Brito-Arctic Province, contain substantial quantities of alkali-olivine basalts (Stewart, 1965). In each case, basalt magmas of tholeiitic and alkali type are thought to be primary. The extensive thicknesses of the basalts of the Majoque Lake Formation would suggest a primary transitional magma lying close to or on the diopside-olivine-albite critical plane of undersaturation (Yoder and Tilley, 1962). Only in that way can the quantities of basalts which display such uniformity in both mineralogy and chemistry, be envisaged.

f. Contact effects between sediments and overlying basalts

Baking of the immediately underlying sediment and included sandstone dykelets by basalt flows has caused local recrystallisation of quartz and neocrystallisation of epidote, muscovite and calcite.

Recrystallisation of quartz is best seen in the small dykelets in the basalts of area I where quartz grains display a banded extinction parallel to the margins of the dykelets (Pl.LII). This is regarded as being caused by local stresses at moderate to high temperatures during and immediately after extrusion of the basalt.

Epidote, muscovite and calcite generally replace the clay matrix and occur in coarsely crystalline aggregates of cm crystals. The muscovite may replace veins of quartz sand grains.

Immediately adjacent to the contact, the sediment also contains plagioclase microlites and quenched glass.

Such crystal growth and recrystallisation is obviously the result of contact metamorphism. However, the development of secondary epidote is widespread in the sediments together with other minerals, eg. sphene and chlorite and this may be attributed in part to the heating of the sediments by overlying basalt flows. It is thought that the amount and duration of heat generated by a thick or series of thick basalt flows plus probable migration of magmatic fluids through the unconsolidated sediment might produce the growth of new minerals by replacing the clay matrix. Such mineral growth might be enhanced by the presence of detrital epidote and sphene. However, since chlorite is present the new minerals may be related to the general low grade regional metamorphism of the Seal Lake Basin.

Pl. LII. Photomicrograph of contact in sedimentary dykelets of fine quartzites of Band A (area I) and overlying basalt (upper right). Note the banded extinction parallel to the contact in the quartz sand grains and the dark, glassy, chilled margin of basalt containing some microlites of plagioclase. X 64.

Pl. LIII. Leucoxene pseudomorphs (Black) associated with matted groundmass of clay minerals (white and grey).

III. The Laterites

a. Mineralogy

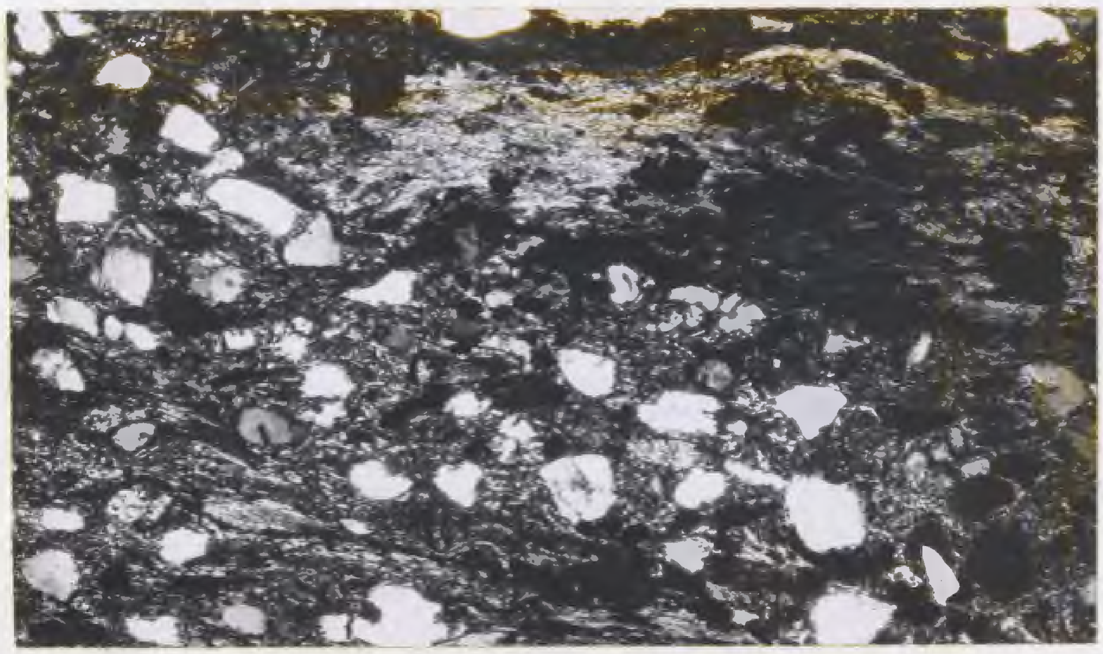
The laterites are characterised by an abundance of amorphous iron oxide which is probably haematite and many fine-grained clay minerals.

The haematite occurs throughout the rock as long thin films, as irregular net-like patches and as large clots almost completely of iron-oxide. Such clots appear to have magnetite associated with them and it is possibly these clots that in part give the rock its speckled appearance.

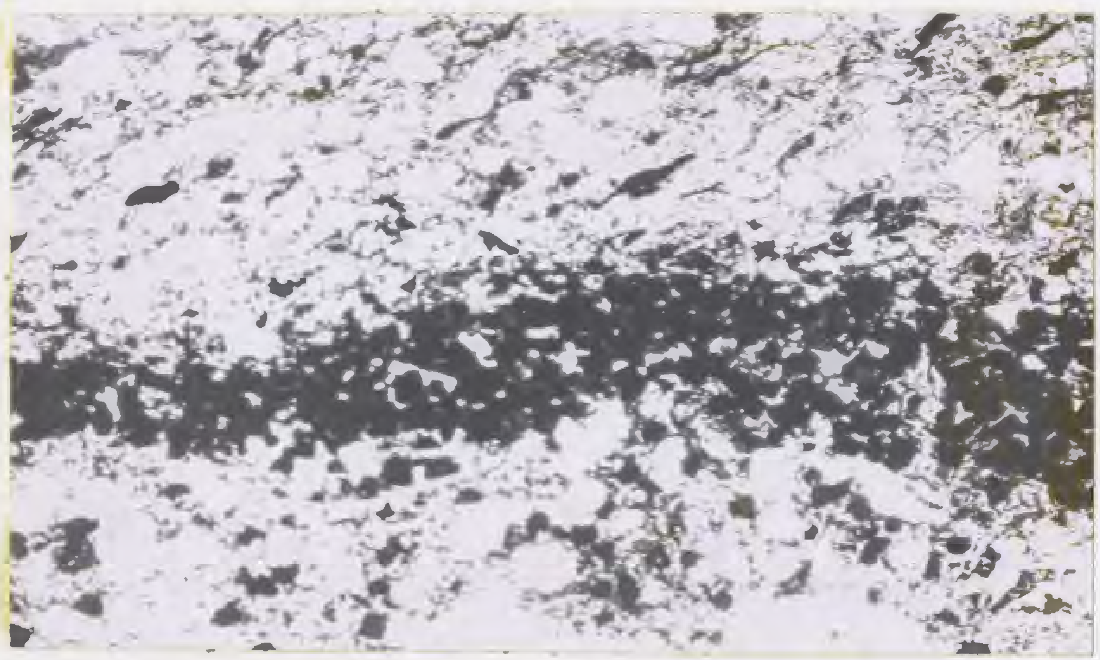
X-ray diffraction analysis using Cu Kα radiation indicates the occurrence of kaolinite, illite, sericite, gibbsite and possibly brucite in the clay mineral faction. Optically these minerals are associated with fibrous chloritic aggregates up to 3 mm. long.

Sphene was recorded in one of the laterite samples and small leucoxene crystals (Pl.LIII) are ubiquitous. The leucoxene is grey-green in colour and white in reflected light and displays concentric oolitic growth that closely resembles the leucoxene described by Loughnan and Golding (1957) from dolerite dykes in Sydney, Australia. They suggested the leucoxene was pseudomorphous after titaniferous magnetite.

When the laterite is reworked (page 98), a bedded rock results. The bedding is represented by thin laminae composed of a lower layer of grit sized fragments (Pl. LIV) grading upwards into heavy mineral concentrations (Pl. LV). The fragments are of typical laterite and are intermixed with detrital fine sand of angular to moderately rounded quartz which is usually slightly corroded at the rims and has occasional deep re-entrants. Polycrystalline and crypto-crystalline quartz grains occasionally occur together with orthoclase, perthite,



Pl. LIV. Photomicrograph of reworked laterite which underlies Band A (area III). A grit sized fragment of clay minerals and iron oxides (top right) occurs together with detrital quartz (white and grey), some detrital magnetite (Black) and fine clay matrix (speckled). X 38.



Pl. LV. Heavy mineral lamination composed predominantly of magnetite which occurs in the reworked laterite underlying Band A (area III). (Plane polarised light). X 38.

zircon, magnetite, sphene and zoisite. This detritus is set in a clay-iron-oxide matrix. The clay minerals are probably illite and are associated with chlorite and secondary quartz and occasionally with spherulites composed of needles of sphene. The upper laminae consists of heavy mineral concentrates and are composed of up to 60% angular magnetite grains (Pl. LV).

b. Evidence of Laterite Deposits and Its Implications

The laterites of the Majoque Lake Formation which might be confused with basic tuffs have been shown to be laterites on the basis of field evidence, petrography and x-ray analysis. Mottling effects on the rocks due to haematite and chlorite clots are described from laterites by a number of authors (La Croix, 1913; Harrossowitz, 1930; Reiche, 1962, p. 72). The presence of a variety of aluminous clay minerals occurring together with gibbsite is typical of lateritic mineral assemblages. Leucoxene pseudomorphs are commonly found in laterite deposits formed from the weathering of basaltic rocks in several areas of the world (Sherman, 1952a; Craig and Loughnan, 1964; Loughnan and Golding, 1957). The titanium is released by oxidation of titaniferous magnetite, and haematite and leucoxene are formed. According to Sherman (1949, 1952b) the presence of high titanium and iron concentrations within laterites is an indication of long, dry climatic periods in which stablisation of the iron by oxidation and titanium by desiccation occurs. Wet climates, however, tend to leach these ions and leave concentrations of alumina. However, from the available data, it is obvious that neither an excessive iron-titanium or alumina concentration occurs in the Majoque Lake laterites and this indicates that alternating wet and dry conditions may have existed at the time of formation.

CHAPTER V

THE STRUCTURE OF THE ARKOSE LAKE AREA

I. General Statement

The rocks of the Arkose Lake area have been deformed with all major structures and bedding striking parallel to the east-west regional trend of the Seal Lake Basin. The structures were formed during one major period of deformation. This deformation produced a number of large folds and some large thrust faults which are significant in terms of the local and the regional stratigraphy. A well developed cleavage cuts the rocks throughout the area and is related to the major structures.

The occurrence of reasonably complex structures in the Arkose Lake area is not indicated by the reports and maps of earlier workers. Mann (1959) shows only a homoclinally southward dipping succession of strata though he briefly noted that some overturned bedding and folds were observed in the Arkose Lake area.

A. Major Structures

Within the Arkose Lake area, there are two structural sub areas in which distinctive styles of deformation have evolved. In the east, a number of large folds form the main structural pattern whilst thrust faults characterise the western area, although at the extreme western boundary of the area, a major fold was mapped.

1. Major Folds

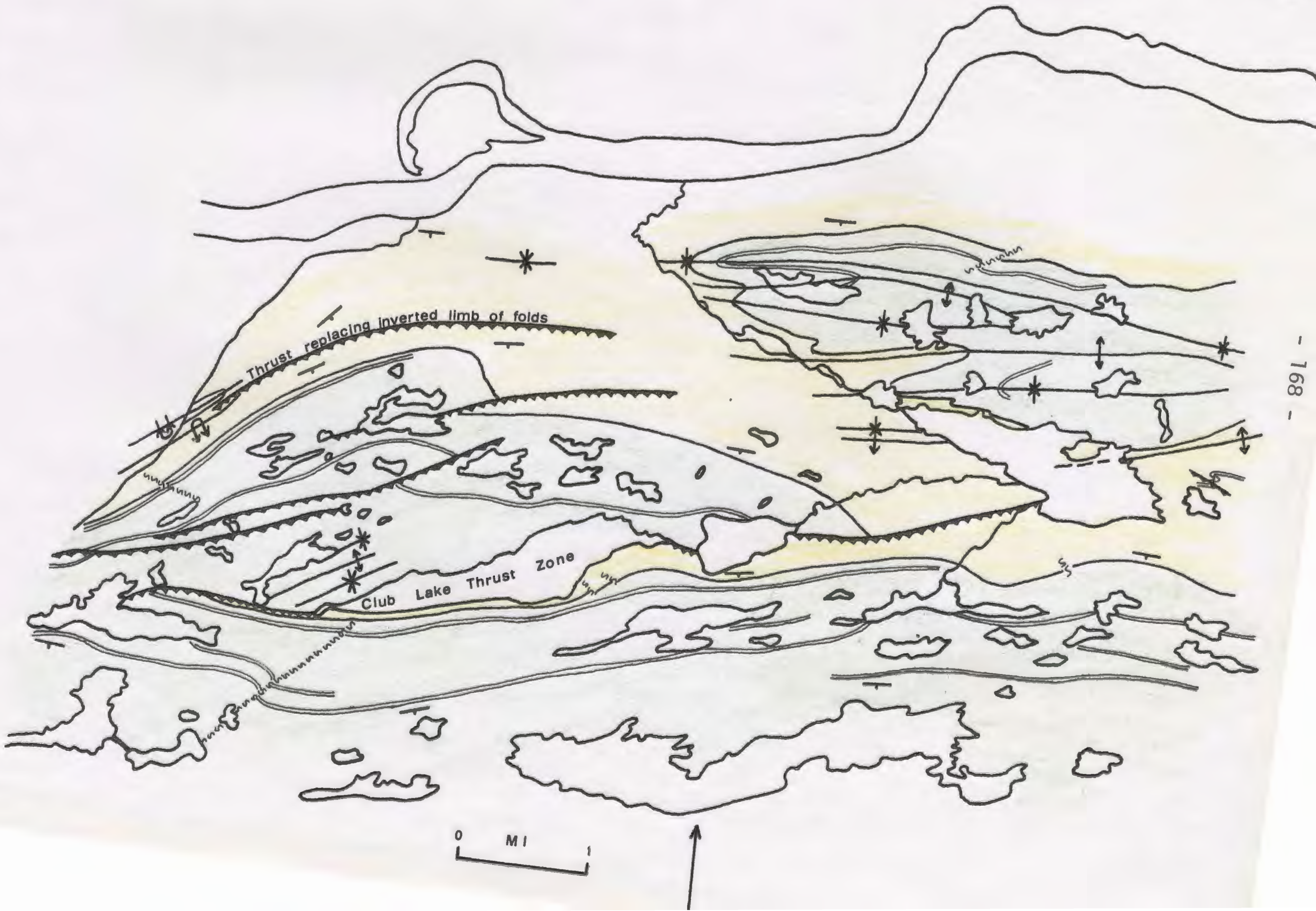
Two major folds occur within the eastern part of the area around Arkose Lake. A major anticline closes in the vicinity of Arkose Lake and a complimentary syncline occurs to the north of it. The folding involves both the Arkose Lake and Majoque Lake Formations and the Majoque Lake Basalts and sediments are folded over the anticline to form the core of the syncline. The Arkose Lake Formation forms the core of the anticline.

The anticline is a broad, asymmetrical structure (see section C - C_1) whose axis strikes east-west along the Arkose Lake Valley. Its southern limb which is long in both a strike and dip direction dips gently to the south. Moderate dips of about 28^o occur in the highest stratigraphic levels of the Arkose Lake Formation and in the Majoque Lake Formation. Dips steepen, however, up to 65^o within the Arkose Lake Formation as the axis of the fold is approached. The northern limb of the anticline dips at approximately 45^{o}N. although dips up to 73^{o}N. and as low as 15^{o}N. have been recorded. This variation depends upon the outcrop in relation to its position in the fold and its proximity to minor folds which are abundant in the northern part of the Arkose Lake valley.

Although the fold closes in the vicinity of Arkose Lake, no obvious major fold axis or fold closure could be mapped. The axial region of the anticline is a series of minor folds whose axes strike about an east-west direction and are arranged en-echelon along the northern shore of Arkose Lake. The folds are generally asymmetric with axial planes dipping steeply southwards. Other folds are recumbent with their inverted limbs dipping at 12 - 16° to the south. All the folds face northwards. The fold axes plunge to both the east and west even along the length of one fold. The angle of plunge varies between 4° and 26°. The major anticline however plunges west in the east of the area and the plunge is the reverse in the west. This is indicated by the plunges of the larger minor folds and by the plunge of the syncline to the north. The syncline to the north is a broad, open structure which has the form of a shallow elongated basin. The basin closes to the west due to an easterly plunge and appears to close to the east although mapping did not extend as far east as the possible closure. The dips of the basalts within the syncline are usually moderate and they range from 10° to 47°.

The main axis of the syncline strikes east-west and occurs just to the north of Kingfisher Lake. Related folds which warp the basin die out within the syncline. The boundary between the Arkose Lake and Majoque Lake Formations serves as a useful indicator of the form of the syncline. Along the southern limb of the syncline, the boundary is folded around the minor folds. In some cases, the minor folds such as the syncline at the north-west end of Arkose Lake and the anticline which occurs in the vicinity of Margaret Lake may strongly modify the boundary pattern (fig. XXXIII). The boundary pattern along the northern limb is gently warped and also displaced by a number of faults.

Fig. XXXIII. Major structural features of the Arkose Lake Area. (Symbols as used on detailed map.)



A penetrative regional cleavage related to the folding can be seen within the eastern part of the area and also to the west where thrust faulting occurs. It is an axial planar cleavage which varies in its orientation relative to bedding with its position within the folds.

The development of the cleavage varies throughout the area depending upon the rock lithology. Slaty - cleavage is best developed in fine-grained silts and in the laterite horizons of the area. Within the cross-bedded sandstones and grits of the Arkose Lake Formation however, the cleavage is often localised at the base of each cross-bedded unit. It appears that each trough cross-bedded unit acted as a separate entity and slip occurred along the base of each trough. As a result, cleavage is developed parallel to the trough base so that dip and strike of the cleavage corresponds to the curvature of the trough base. Together with the development of cleavage, sediment grains are flattened and smeared out.

In the Majoque Lake Basalts, the cleavage is best developed in the vesicular tops of flows but frequently only a closely spaced, finely marked lineation can be distinguished on the outcrop surface. In more massive basalt, a 1/2 cm. spaced fracture cleavage is developed.

2. Thrust Faults

Thrust faults occur in the area south-west of the Arkose Lake Valley. They are important structures as they repeat the succession in a number of instances (Fig. XXXIII & section B - B_1). They cause the repetition of:

a) The Arkose Lake/ Majoque Lake Formation stratigraphic boundary.

b) The stratigraphy within the Majoque Lake Formation.

The thrust faults strike approximately east-west to east-north-east to west-south-west. The dip of the thrust planes is variable between 17° and 44° S. Slickensiding which is often very coarse, indicates a direction of movement of the blocks above the fault planes to the north to northwest. Drag-folding accompanies the thrusting and the folds may occur above or below the thrust zone. The folds which are often recumbent, have southward dipping axial planes and face northwards. The sense of movement given by the drag-folds is the same as that of the slickensides.

The largest thrust zone in the area is the Club Lake Thrust Zone which strikes along the valley of Club Lake. The zone carries above it a repetition of the upper member of the Arkose Lake Formation and the lower part of the Majoque Lake Formation. The thrust zone separates areas of different strikes. This is seen best at the western end of the Club Lake (Grid. Ref. 042 022) where northsouth trends to the north of the thrust zone opposes the general eastwest trend to the south. The stratigraphy overlying the thrust zone is cut out westward against the thrust zone. The formation boundary is cut out approximately a kilometer west of Club Lake (Grid. Ref. 034 022) and Band A of the Majoque Lake Formation 600 metres further west. This suggests that the thrust zone dips to the southeast and is cutting obliquely upwards through the stratigraphy.

The main thrust plane within the zone occurs below the waters of Club Lake. However, smaller faults can be seen within the Arkose Lake sediments above the lake (Grid. Ref. 053 023) (Pl. LVI). Here a thrust plane strikes at 092 and dips at 17° S. The thrust plane is completely

Pl. LVI. Smooth, thrust plane cutting Upper Member sandstones of the Arkose Lake Formation, Club Lake. The sandstones occur just beneath the first basalt of the Majoque Lake Formation.

Pl. LVII. Low angle thrust fault cutting across a cliff of columnar jointed basalt. The columns have been deformed during the deformation and underlie a fault zone of sheared basalt.

smooth with no slickensiding but the surface truncates and transgresses the bedding and is underlain by bedding which is slightly buckled.

High angle thrusts thought to be related to the Club Lake Thrust Zone occur at south-east end of Club Lake (Grid Ref. 078 027 and 079 028). The faults strike 075° and 090° and probably peel off the main thrust zone. Their sense of movement is not known.

Drag folds occur at a number of localities along the Club Lake Thrust Zone. Recumbent folds occur at the eastern end of Club Lake (Grid Ref. 089 034) and above the centre of Club Lake (Grid Ref. 063 025). They have inverted limbs that dip between 3^o and 50^o south and axial planes that strike 074 to 088 and dip south at between 47^o and 52^o. Their axes plunge 4^o or 5^o east or west.

Asymmetrical folds occur to the west of Club Lake (Grid Ref. 041 021). These folds plunge to the west at 2 - 5^o and the axial planes strike about 045 to 065 and dip between 71^o and 75^o north.

All the drag folds described above occur in the sediments overlying the thrust zone but drag folds also occur in the basalts underlying the thrust zone to the north-west of Club Lake. The folds which strike north-east - south-west are fairly large, open structures. They are thought to be associated with the general, north-south movement of the thrust slices. The folds plunge south-west and die out along their axial trace and against the thrust zone. This open pattern of folding is characteristic of the deformation of the volcanics within the area. The lateral extent of the Club Lake Thrust Zone is not known. It is probable, however, that it extends at least as far east as Arkose Lake and possibly west beyond the western margin of the map area.

Within the rocks which underlie the Club Lake Thrust Zone, several smaller thrust zones occur. They occur predominantly in the basalts of the Majoque Lake Formation but are seen to offset a sediment band which is thought to be equivalent to Band C of the stratigraphy to the south of the Club Lake Thrust Zone (see page 74). These faults vary in length and their direction is not constant although their general trend is east-north-east. In the basalts they are marked by zones of intense fracturing and shearing. Epidote and quartz veining is abundant in the thrust zones whilst the basalt is chloritised and fractured surfaces are coated with chlorite. Slickensiding is often present and the direction of movement varies from north to north-west.

The contact between sediment Band C and the overlying basalt, in the thrust area, has been a surface of movement (Grid Ref. 029 029). At the contact, a thrust plane has developed and is associated with a recumbent syncline which occurs in the sediment below the fault. The inverted limb of the fold is directly in contact with the thrust plane and the southward dipping, overlying basalt. The axial plane of the fold dips at 64° to the south-east. No other drag folds were recorded in the thrust area, although two small folds do occur beneath sediment Band C (Grid Ref. 035 035 and 035 036). It is not known if they are related to faulting.

Within the area of thrust faulting, the strike of the rocks swings from east-west in the east to north-east-south-west in the west. This south-western swing is oblique to the usual trends found in the area and there is an increase in intensity of deformation of the rocks at the western margin of the area where the intersecting strikes are most prominent and several thrust faults are in close proximity. The increase is reflected in:

1. A flattening of grit grains and pebbles in sediment Band C and of the amygdales in the basalts of the western most exposures along Band C (Grid Ref. 016 022).
2. Development of a coarse foliation within the sediment bands and a strong penetrative cleavage within the basalts.
3. The presence of a major recumbent anticline which faces northward (see sections A to A_1) (Grid Ref. 026 038 to 035 046).

The anticline occurs within the Arkose Lake Formation but has a complementary syncline to the north in which a wedge of basalt which is probably equivalent to basal Majoque Lake Formation volcanics occur. The southern limb of the anticline dips south-east at 47^o and the inverted limb can be overturned as much as 34^{o}S but vertical dips also occur. Minor drag folds plunging south-east were recorded in a narrow band on the inverted limb (Grid Ref. 028 040) just south of the core of the syncline. The northern limb of the syncline dips south at 60^o - 76^o but to the north, in the outcrops near the Canairiktok River, the dips decrease to 42^{o}S. The recumbent fold was distinguished using cleavage bedding relationships and tops of cross-bedding. However, the basalt wedge disappears rapidly north-east along the trend of the fold as does the inverted limb(Grid Ref. 035 046) of the folds, and the beds here are consistently right way up and dipping southwards. This suggests that a major thrust fault may replace the inverted limb of the fold as the structure passes eastward. The fault probably continues eastward through a deep valley which occurs a kilometer south of the Canairiktok River (Grid Ref. 055 056). This is supported by intersecting strike patterns (Grid Ref. 043 052). The fault cannot be followed beyond the valley because of lack of outcrop but it is possible that it may link up with the Arkose Lake Anticline just to the west of Arkose Lake.

There is abundant evidence throughout the Arkose Lake area that many more thrust zones occur particularly within the basalts. The thrusts already discussed within the Majoque Lake Formation occur along the bases of basalt ridges. Throughout the area, small basalt ridges usually from half to one kilometer in length occur. They are isolated from one another by valleys which strike obliquely to the trend of the ridges and ridges are slightly offset from one another along strike. The basalt at the base of the cliffs beneath the ridges is heavily fractured and minor amounts of movement have occurred upon the many small fractures. Sometimes, clean, low angle thrusts can be seen cutting the basalt in the cliffs and tilting primary volcanic structures such as column stacks (pl. LVII) (Grid Ref. 124 024).

The ends of the ridges are usually terminated by high angle faulting which may displace the ridge across strike. Such high angle faults may be wrench or reverse and they appear to terminate thrust zones. For example, a small wrench fault cutting Band C at the western boundary of the area (Grid Ref. 014 014) terminates a thrust zone of fracturing and shearing in the basalts which underlies the band to the east of the wrench fault. Such terminating faults also occur within the basalts overlying sediment Band E

(Grid Ref. 118 023) where the basalt is similarly fractured.

Hale (1968) describes similar fault and ridge associations in the south of the Seal Lake Basin. He suggested that different rates of movement along a single thrust plane causes the separating of the large thrust slices into small blocks separated by high angle tear faults. The small blocks are represented by the isolated basalt ridges. In the Arkose Lake area, the field relationships suggest that the wrench faults change into reverse faults. One such fault occurs within the thrust region in the western area and cuts both basalt and sediment (Grid Ref. 029 029). The fault plane which strikes south-east, dips steeply at 64^{o} SW and has slickensiding which indicates that the western block has moved up obliquely to the north across the fault plane. The fault is associated with a thrust which occurs along the upper contact of sediment Band C with the overlying basalt (see previous page 173).

3. Other Faults

A number of faults, other than the thrust faults, displace the succession by minor amounts. The faults are divisible into several groups:

a) A series of faults striking north-east to south-west which are high angle normal faults with the downthrow to the north-west. In one case, a hinge fault occurs with displacement increasing southward away from the origin which is located at the south-west end of Club Lake.

b) A series of normal and reverse faults which strike north-west to south-east. The normal faults downthrow to the north-east.

c) A series of north-south faults which are normal, reverse, wrench or thrust types. This group includes numerous small normal, reverse and wrench faults which displace the bedding up to 10 - 20 cm. A thrust fault having a large displacement occurs three-quarters of a kilometer to the east of Arkose Lake. A basalt sill (see page 55) within sediments of the Arkose Lake Formation is thrust south-east and is associated with asymmetric drag folds which indicate a similar movement direction. The displacement involves 15 - 30 metres of overthrusting.

B. Minor Structures

1. Kink Bands and En-echelon Tension Gashes

Where the cleavage is well developed in the basalts and occasionally in the sediment bands of the Majoque Lake Formation, later deformation has resulted in the kinking of the cleavage. The kinking may be bounded by planes as in true kink bands but very often the kink is represented by a series of en-echelon tension gashes. Both are treated as kink bands in the following description.

The kink bands (Pl. LIII) are 1 - 2 cm. wide and can extend up to 70 cm. in length before pinching out. They occur singly, in parallel series or in conjugate sets. The conjugate sets may be fully developed with interference of one kink band by its conjugate partner. Often, however, the meeting of the pair is not completed and one kink band which is usually shorter in length will end at the kink boundary of the other without affecting the intra-kink folia of that band.

The kink bands are commonly not bound by distinct kink planes and

Pl. LVIII. Kink bands outlined by epidote in massive basalt.

usually only one kink plane is developed and even this may be intermittent. The intra kink folia in contact with the kink plane may be dragged into a parallel orientation by shear movement along the plane. Small chevron folds may occur where two or more kink planes of opposite senses of movement lie parallel to one another.

The intra-kink folia are usually planar, parallel structures spaced 1/2 to 1 cm. apart. The folia rotate to give both normal and reverse kink bands (Dewey, 1965) with both sinistral and dextral senses of movement. Occasionally the folia become sigmoidally bent and dilation within the kink band produces both straight and sigmoidal tension fractures which are infilled by epidote. The epidote is ubiquitous within the kink band zones.

In the western part of the area, sinistral kink bands of a conjugate pair strike between 020° and 042° and are cut by dextral kinks striking 140° to 170°. Many single or parallel series of kink bands parallel these strikes but many kink bands with orientations close to the dextral group show sinistral movement. The obtuse angle between the conjugate pairs is between 120° - 128° and the main cleavage bisects this angle. This relationship indicates that the kink bands formed in response to compressive stress orientated nearly parallel to the strike of the existing cleavage. Several kink bands occur in single outcrops and each band has a different orientation. Several sets of kink bands occur in single outcrops and each kink band has a different orientation.

In the east of the area, kink bands exist in parallel sets of which there are two distinct sets. Kink bands having a sinistral sense of movement strike at 175^{o} - 212^{o} whilst dextral kink bands strike 116^{o} - 122^{o}. These sets form chevron and box folds at one locality within the northern syncline (Grid Ref. 126 056). In the box fold, both sets of kinks are developed but do not intercept. They would intersect with an angle of 90^{o} and the cleavage bisects this angle.

The formation of kink bands throughout the area is in response to east-west compression which parallels or nearly parallels the cleavage. The presence of several sets of kink bands with different orientations at one outcrop indicate that several generations of kink bands formed with progressive deformation. It is likely that a kink band formed in response to the east-west compression and rotated until it reached its locking position where frictional resistance prevented further deformation and shortening (Ramsay, 1965). When one set has frozen in the locked position, a new set begins to form with a slightly different orientation to those formed previously (Dewey, 1969, Ramsay, 1965). Progressive deformation such as this also appears to deform the intra-kink folia. Shearing along one bounding kink plane produces a shear plane which bends the folia in the vicinity of the plane. The comparative rarity of conjugate sets of kink bands suggests that the cleavage except locally was not parallel to the maximum stress axis of the deformation (Paterson and Weiss, 1966, Donath, 1968) but was inclined at angles of 10^{o} - 25^{o} to the maximum stress axes.

No kink bands developed in the Arkose Lake Formation sediments because of the poor development of the cleavage within the sediments although numerous randomly orientated, quartz-filled fractures, do occur.

C. Conclusions

The rocks of the Arkose Lake area were deformed in one major period of deformation. This resulted in the development of major east-west trending folds and thrust faults. These trends occur throughout the Seal Lake Basin (Mann, 1959). The deformation is related to the Grenville Orogeny and the Arkose Lake area lies at the northern limit of Grenvillian deformation (see also Wynne-Edwards, 1971).

Within the Arkose Lake area, it is likely that the deformation first led to the development of major folds and an associated cleavage in response to north-south compression. Folds are developed in the east of the area, and the style of folding is directly related to the lithologies they affect. The basalts of the Majoque Lake Formation since they were relatively massive and competent acted as an envelope overlying and restraining the Arkose Lake sediments during the deformation. As a result, the basalt envelope deformed into broad fold structures. Beneath this envelope, however, the Arkose Lake sediments were compelled to accommodate themselves in a confined space and consequently crumpled into many minor folds, the crumpling being greatest in the area of the major fold axis. Within the folds, there is abundant evidence of bedding plane slip and the type of folding may be classified as flexural slip (Donath and Parker, 1964).

As the deformation progressed, thrust slices developed with the movement of the thrust blocks northward. It is probable that the major folds became recumbent with further deformation and that the inverted limbs eventually were sheared out with the development of thrust planes. This process occurred in the Arkose Lake sediments in the west of the area, and may have formed the Club Lake thrust. The thrusting process was probably aided by the restraining influence of the basalts which overlie the sediments of the Arkose Lake Formation.

Many of the larger thrusts contained in the basalts of the western area may represent higher level expressions of thrusts which originate within the Arkose Lake sediments. However, many of the smaller thrusts are probably local features which formed by brittle fracture of the basalts as the strain passed beyond the limit of plastic deformation.

There appears to be some correlation between the style of deformation and the shape of the Anorthosite Massif to the north. The change in structural trends within the Arkose Lake area correspond closely to changes in trend of the southern boundary of the anorthosite. This suggests that the anorthosite acted as a resistant massif against which the sediments and volcanics of the area were compressed during the main period of deformation. Likewise, the style of deformation, i.e. folding, faulting, and intensity of deformation, can also be related to the massif's shape. In the east where the southern boundary of the anorthosite swings northwards, open folds occur. In the west where the boundary projects southwards, increased compression of the rocks has produced considerable shortening by thrust faulting and is associated with an increased intensity of deformation.

The presence of kink bands which deform the earlier, regional cleavage, suggests that late in the area's structural history, the maximum stress directions changed from north-south to east-west, causing shortening of the rocks by the formation of kink bands. Later release of stress within the rocks caused dilation of the kink zones and may also have formed some of the north-east and north-west trending normal faults. The kink bands also indicate that the Arkose Lake area and probably the whole Seal Lake Basin, were high structural elements of the continental crust and that there was very little overburden during their development (Dewey, 1965).

The relationship of the faults to the general picture of deformation is not very clear. Some are obviously related to the major, north-south compression and associated with the thrust movements. Others formed following the major period of deformation.

CHAPTER VI

ENVIRONMENTAL CONCLUSIONS

A. The Arkose Lake Formation

1. Depositional Environment

The sediments of the Arkose Lake Formation show characteristics typical of sequences of fluviatile sediments such as described by Butler (1959), Friend (1961), Selley (1965), Allen (1965c), Read and Johnston (1967), Williams (1969). Red, poorly sorted, cross-bedded sandstones usually are deposited under terrestrial conditions in several different fluvial regimes each of which have distinctive characteristics. Such regimes are low sinuosity braided rivers, low sinuosity straight rivers and high sinuosity meander rivers (Allen, 1965a), Leopold and Wolman, 1957). Braided rivers can exist on alluvial fans and alluvial plains whereas straight and meander rivers are usually restricted to alluvial plains.

The deposits of the Arkose Lake Formation are typified by poorly sorted, coarse sandstones and grits in the lower member. Very few argillaceous beds or detrital evidence of their previous existence occurs within the sandstones which display almost ubiquitous trough cross-bedding. This suggests that there was little overbank sedimentation and that the river system migrated continually across its flood plain. The river system was heavily loaded with coarse sediment which was probably rapidly dumped on entering the depositional environment. This is supported by the coarseness, sorting and composition of the sediment which is subarkosic and rich in polycrystalline quartz which is indicative of immaturity and close proximity of the source area (Blatt and Christie, 1963; Cleary and Connelly, 1971).

Palaeocurrent data for the Lower Member indicates derivation of the sediments from the north or northwest. This is supported by the coarsening of the sediments to the west and north. The paleocurrents are relatively restricted in their distribution, which would be expected in a low sinuosity stream (Allen, 1965a, Read and Johnston, 1967). However, the coarseness of the sediment, its poor sorting, and the lack of argillaceous beds suggest a braided stream regime rather than a 'straight' river.

The upper member of the formation is fine-grained with more argillaceous beds and also abundant clasts derived from red siltstone layers. Trough cross-bedding is the dominant sedimentary structure. However, only a few current directions were measured though these suggest that the palaeoslope and source area had not changed from that of the lower member. This is also supported by northward coarsening of the sediment. The finer grain size suggests a retreat of the source area and the presence of more argillaceous beds and locally derived siltstone clasts suggests that there was appreciable overbank sedimentation during the deposition of the upper member. The red siltstone clasts however, show that the river was systematically reworking its earlier deposits. This may be indicative of a river system with higher sinuosity, i.e. meander or the distal part of a braided river system with the siltstones deposited in channel cutoffs and in part on a limited flood plain. Slow subsidence and relatively low sediment supply would have aided reworking (Beerbower, 1964; Read and Johnston, 1967) and this might be expected to occur on the distal portion of an alluvial fan drained by a braided river system.

2. Source Area and Source Rock

From the paleocurrent data and lithological coarsening as the sediments are traced to the north and northwest, it is thought that the source of the detrital material lay to the north of the Arkose Lake Region. The detritus within the sediments is typical of that derived from a metamorphic and granitic terrane. Such a source would be provided by the granite gneiss of the basement rocks to the northwest of the area. It is likely that during Seal Lake times, these rocks covered the area of the anorthosite massif which is now exposed directly north of the Arkose Lake area. The source lithologies were thus predominantly granite-gneiss, granite and probably other quartz rich, metamorphic rocks, some cherty ironstones which are known to occur in the Michikamau area (A.F. King, personal communication and one grain of which was found in thin section; and possibly some of the marginal granitic rocks of the anorthosite complex such as mangerite and red hornblende granite.

This source area was proximal to the basin during the deposition of the lower member but must have later retreated resulting in the finer deposits of the upper member.

3. Palaeogeographical Setting of the Arkose Lake Formation

From the sediments of the Arkose Lake Formation there was suggestion of deposition in a subsiding basin which lay to the south of an upland source area. The poorly sorted, coarse and immature sandstones of the lower member indicate rapid deposition by sediment-laden rivers. Subsidence probably exceeded deposition so that the earlier deposits were quickly covered. This type of setting is known to occur when rapid, sediment charged rivers emerge from a mountain belt and the river flow is quickly checked by the decrease in the angle of gradient at the point of emergence from the mountains. As a result alluvial fans occur which form thick wedge shaped deposits marginal to mountain fronts.

Alluvial fans can be formed of different deposits depending upon a number of factors which include climate, palaeoslope, availability of sediment, lithology of source rock, proximity to apex of a fan (Davis, 1938; Blissenbach, 1954; Hooke, 1967 & 1968). Upon alluvial fans, mudflows or debris flows (Blissenbach, 1954; Hooke, 1967 & 1968), stream flood deposits and stream deposits (Davis, 1938, Blissenbach, 1954) are formed. Mudflows are usually found near the apex of a fan whilst stream flood and stream deposits near the foot of a fan. It is evident from the description of the Arkose Lake Formation sediments that there are no mudflow deposits and that all deposition is by stream or river deposition. This suggests that they are distal from the apex of the alluvial fan or that conditions were more favourable for stream deposits. Blissenbach (1954) suggests that stream deposits alone will occur if the annual rainfall exceeds 20" - 25", since this prevents the streams becoming super charged with sediment and thus viscous enough to form mudflows. Similar conditions are likely to occur if sediment supply is low. Stream deposition in the lower slopes of a fan is also aided by entrenchment at the apex of the fan of the stream or river as it leaves the mountains. In this way, apical fan deposition is by-passed and the stream deposition occurs downslope on the fan. This can also occur if the gradient upon the fan is relatively steep so that no appreciable change in the slope occurs between mountain stream and fan. This would occur if subsidence of the fan exceeded deposition on it as previously suggested. Only on a few occasions was conglomeratic material found within the sandstones and grits and this occurs in the northwest of the area. This together with the palaeocurrent data suggests that the fan apex was to be found to the northwest of the Arkose Lake area during deposition of the lower member.

The deposits of the upper member show that the source area had retreated northwards probably as the mountain source was worn back (cf. Williams, 1969). The member may be the distal portion of an alluvial fan with braided streams working over their own deposits or it may be a braided stream or high sinuosity streams flowing in an alluvial plain which existed to the south of a retreating alluvial fan. From the palaeocurrent data, there is no apparent change of palaeoslope or source so that whether the deposit is distal alluvial fan or alluvial plain braided or meander river, it is still controlled by an upland area which existed to the north of the basin and by a constant palaeoslope. Either model is probably similar to Model A (fig. 35) of Allen (1965a).

Today, alluvial fans occur in arid, semi-arid and humid regions. Each climatic regime has however, common controls necessary for fan formation. These are high mountains with steep gradient rivers draining on to a low-gradient plain and seasonal fluctuation of precipitation which produce seasonal, heavy river and sediment discharge. In arid and semi-arid regions, stream flood is restricted to the wet season of short duration which may occur twice a year. In more humid areas, however, runoff reaches a seasonal maximum often in spring with melting of the winter's snow and ice as occurs in the Alpine and Himalaya Mountains.

During the deposition of the Arkose Lake Formation, it is probable that the climate was semi-arid (which is confirmed by evidence in the Majoque Lake Formation) although rainfall may have been quite high (Blissenbach, 1954). Quartz and feldspar sand grains are often corroded and partly replaced by clay minerals suggesting that in situ weathering may have occurred after deposition. In truly arid or semi-arid, alluvial fans, however, water is quick to drain through the sediment because of its porosity so that such corrosion and breakdown may not be so widespread. However, there is often deep weathering of granitic terranes in semi-arid areas (Davis, 1938) and deep erosion of the weathered profile to unweathered granite could result in a mixture of altered and fresh feldspar and corroded and fresh quartz grains (Folk, 1961). The amount of corroded quartz decreasing with distance from the source (Connelly, 1971).

B. The Majoque Lake Formation

1. Character of Succession

The Majoque Lake Formation succession may be summarised as follows:

a. The volcanic flows are extensive, thick columnar, aa and pahoehoe types typical of subaerial volcanism. Occasionally, localised pillow lavas and pillow breccias occur which indicate that parts of flows were entering rivers or ponded water bodies. The volcanics probably originated to the north of the area.

b. Relatively thin horizons of interbedded, massive-bedded conglomerates and planar, cross-bedded sandstones and grits form sheet-like bodies within the volcanics. They may slowly thin out laterally or end abruptly against basaltic rocks as does Band E.

c. The sediment was derived from outside the basin of deposition and is similar in composition to that of the Arkose Lake Formation. This suggests that the source area was a granitic-gneiss - granite terrane. However, pebble clast types in Band A, area III, indicate that there was an acid-volcanic source early in Majoque Lake Formation times. Little basaltic volcanic or weathered volcanic material of local origin occurs in the sediment suggesting that little erosion of the volcanics occurred prior to or during deposition of the sediments.

d. The sediment composition and the apparent direction of inclination of the cross-beds suggest that the material was deposited from north to south, building out over the volcanics. This cannot be statistically supported since there is no information regarding increase in grain-size and band and and bed thickness (cf. Blissenbach, 1954; Bluck, 1964 and 1967) northwards or significantly along strike since it is concluded that the present outcrops represent a section nearly parallel to depositional strike of the sediments. Only in Band C (area III) is there increase of thickness and pebble size (fig. VIII) as the band strikes westward. This, however, probably represents either the area of most active river activity or the central axial region of a fan-like deposit (cf. isopleth diagrams of Bluck, 1965, fig. 6, p. 230).

e. Very thin, localised deposits of sandstone and grit intercalated with laterite, eg. sediment Band I, were formed by small streams following depressions in the volcanic topography.

f. The sedimentary structures and grain-size associations suggest a braided stream environment.

g. Some driekanter pebbles which occur in the bands indicate that arid or semi-arid conditions existed in either source of depositional area or both and that windblown sand must have existed.

h. Localised in area I, the usual sandstone, grit and conglomerate facies is replaced by a fine-grained quartzitic facies which is flat bedded and may represent a beach deposit or a water-lain, windblown sand. It is impossible to determine whether it was deposited in fresh or marine waters.

i. Lateritic profiles exist beneath each sediment band. The laterites are the result of deep weathering of the lava flows prior to the influx of sediment. This indicates a long period of exposure to subaerial conditions suggesting intermittent volcanism and sedimentation. The tops of the laterite deposits are reworked and are also mixed with fine, extrabasinal detrital sediment. Occasionally deep erosion and redeposition of the laterite occurred prior to the deposition of a sediment band.

Petrographically the laterites are apparently typical of weathering in a climate which is neither excessively dry or wet.

2. Discussion

The coarse, conglomeratic nature of the thin sediment bands of the Majoque Lake Formation contrasts markedly with that of the upper member of the Arkose Lake Formation. The deposits represent minor sedimentary depositional events at a time of thick and extensive plateau basalt type volcanism. In this association, the sediments appear to be relatively rare in the geological record perhaps only comparable with the interbedded conglomerates in the plateau volcanic group of the British Tertiary Province (Richey, 1948; Stewart, 1965) and the sediments of the Murky Formation of the Et - then Group of the East Arm Fold Belt, North-West Territories (Hoffman, 1969).

Since the volcanic rocks display features that are typically continental it is appropriate, since there is no evidence to the contrary, to conclude that the sediments are of fluviatile origin. The deposition of the sediments appears to have occurred during non-eruptive periods which were of long duration since lateritic weathering of the basalts preceded the deposition of each sediment band. This also suggests that the influx of sediment into the depositional area was sporadic. This may have been due to a number of reasons.

a. The volcanic rocks formed high areas over which no water flowed and it was only following subsidence that water regimes were re-established.

b. The extrusion of the volcanics in the north dammed the valley exits of the rivers draining south into the depositional area.

c. There was a climatic control over sedimentation, the bands being the result of severe flash floods.

d. The sediments were deposited following periodic relative downwarp of the basinal area and uplift of the source area. Uplift of the source area preceded rapid erosion and sedimentation was possibly terminated by the next volcanic episode possibly coupled with a reduction of the highland source area.

e. There was no interruption of sedimentation during the volcanism but the depositing rivers were diverted by contemporaneous volcanic flows.

It seems most probable that sedimentation occurred with extended interruption by volcanism. Although the presence of pillow lavas indicates the presence of local water bodies in the volcanic terrane, it is probable that river drainage into the area was prevented or limited by the damming effect of flows to the north. During the periods of volcanism, long periods of weathering produced lateritic profiles upon a very extensive, undulose though basically planar volcanic surface possibly comparable to a 'pediment'. Subsidence of the basin during the period of weathering lowered the volcanic 'pediment' and extrabasinal water began to flow into the basin producing small scale reworking of the tops of the lateritic profiles and carrying in fine extrabasinal sand. Occasional extensive redeposition of the laterite, eg. southeast of Club Lake beneath Band A, probably represents river entrenchment into the lateritic 'pediment'. Uplift of the source area to the north caused rejuvenation of the upland rivers and the coarse debris of the sediment bands was carried into the depositional environment along these river courses probably by flash floods. The sediment in part appears to have been deposited as a sheet deposit. The depositing rivers were not erosional since only rarely has the lateritic profile been removed and very little basalt or laterite debris occurs in the sediment. Therefore, it is certain that no erosional topography in the basin controlled deposition although the original lava flow topography may have contributed in part to the thickness variations of the bands.

Contemporaneous volcanic flows or topographically high flow margins or fronts may have controlled the lateral extent of some of the bands and would account for the sudden, western termination of Band E. Deposition of each sediment band was terminated by renewed volcanism.

The sediments were laid down during periods of severe flood by a braided stream system which can occur upon alluvial fans or outwash plains. However, there is little statistical evidence to suggest that the deposits were formed upon alluvial fans and neither do they resemble descriptions of ancient and modern alluvial fan sediments since they lack mudflows although the tectonic setting may be the same. However, the type of sediments, sedimentary structures and sheet-like form of the deposits is typical of outwash deposits such as described by Doeglas (1962), Williams and Rust (1969), and McDonald and Banerjee (1971). The Majoque Lake Formation deposits however, differ from these outwash and other similar deposits, eg. the sandur plains of Iceland (Krigstrom, 1962) as they are laid down upon a volcanic 'pediment' and not in depressions eroded into the volcanic terrane. Since the Majoque Lake Formation deposits were associated with a semi-arid climate they will differ somewhat from the outwash deposits which are of glacio-fluvial origin.

C. Tectonic and Geographic Setting During the Deposition of the Arkose Lake and Majoque Lake Formations

The deposits of the Arkose Lake and Majoque Lake Formation were laid down in a subsiding basin which lay to the south of a granitic, upland area. Decrease of grain size in the upper part of the Arkose Lake Formation indicates that the upland area which was the source of the sediment receded as it was worn down. With the onset of volcanism however, there was renewed uplift of the source area producing coarse conglomeratic material which was deposited periodically in the depositional basin. Infrequency of the sediment bands suggests that the earth movement may also have been periodic. Such movements were probably associated with faulting which would have occurred at the northern margin of the Seal Lake Basin possibly in the vicinity of the present Canairiktok River. Since there is some supporting directional evidence, and thick continental basalts occur in tensional environments, it is also probable that the basalts were extruded through fissure eruptions associated with the graben faulting. Periodic movements upon the faults were probably an isostatic response to the weight of thick, dense, basaltic flows which were laid down in the basin (cf. Bott, 1964).

Climatically, the deposits were laid down in a semi-arid climate although the deep lateritic weathering of the basalts and the form of sedimentary deposits of the Arkose Lake Formation, suggest that seasonal rainfall was relatively high.

Sedimentation during Arkose Lake Formation times occurred upon large alluvial fans which probably coalesced to form the extensive deposits of the northern part of the Seal Lake Basin and as such is comparable to the model proposed by Williams (1969) for the Precambrian Torridonian of Scotland. The alluvial fans were deposited at the foot of a fault scarp which with time receded along with the fan.

The sediments of the Majoque Lake Formation however, represent outwash deposits whose distribution in time and space was contolled by volcanic eruptions and terrane and periodic subsidence. Each sediment band is however, a discrete deposit restricted to the depositional extent of a single upland river and probably rarely the product of coalescing gravel deposits. Figure XXXIV is a reconstruction of the possible environment during deposition of the Majoque Lake Formation.

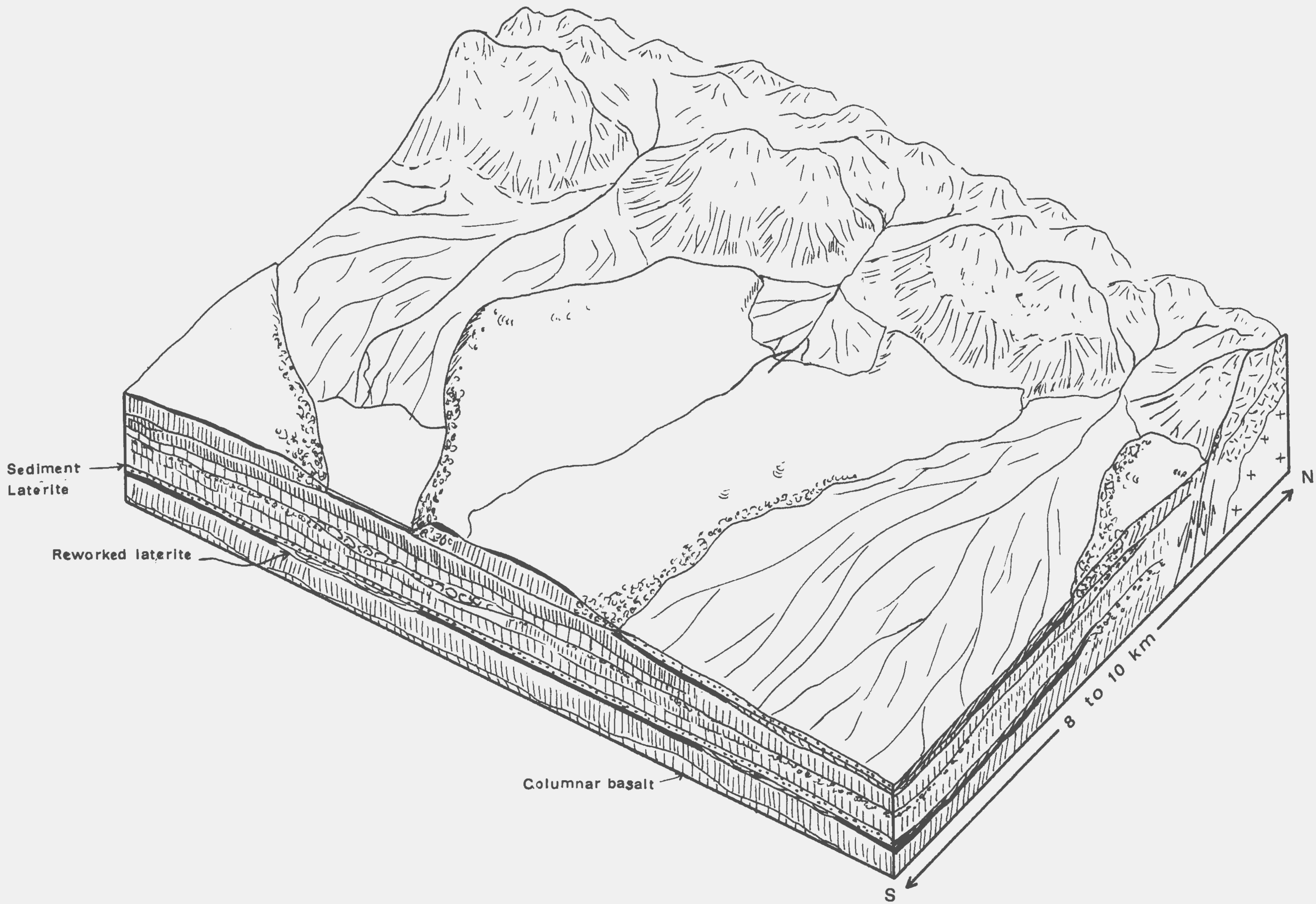


Fig. XXXIV. Hypothetical Model of depositional environment at time of deposition of Majoque Lake Formation.

Application of the Structure of the Arkose Lake Formation to the Overall Seal Lake Basin and Its Implications Regarding the Stratigraphy of the Basin.

Structurally the most significant feature of the Arkose Lake area is the presence of large, south dipping thrust faults which involve large, northerly displacements. Similar thrust faults have been described by Hale (1968) and Baragar (1969) suggests their presence as a major factor in the reduction in thickness of the Wuchusk Lake Formation from that quoted previously by Brummer and Mann (1961). Since the degree of deformation increases southwards (Brummer and Mann, 1961), it is reasonable to assume that further thrust faults exist to the south. The valley of the Naskaupi River may be topographic expression of such a feature.

Such large thrust faults would be also expected to thrust sediments and volcanics which were originally located further south to a more northerly location and higher structural position. As a result, rocks which are equivalent in age may overlie one another. If thrust faulting is not recognised however, a conformable sequence and a possible misrepresented stratigraphy would result. In previous works, Baragar (1969), Hale (1968) and Kidd (1969), have already suggested correlation of the Wuchusk Lake and Salmon Lake Formations with the Whisky Lake and Adeline Island Formations (see figure V) and examination of the lithologies reported within the Wuchusk Lake Formation and Salmon Lake Formation in the light of the environmental conclusions presently suggested (page 192), may indicate further correlations especially between the Majoque Lake Formation and the Wuchusk Lake Formation. The reputed characteristic feature of the Wuchusk Lake Formation is the presence of diabase sills of much younger age than the sediments and volcanics of the Seal Lake Basin. This is detrimental to the interpretation of the stratigraphic relationships of the sediments of one formation to those of another. Disregarding the presence of the diabases (some of which may, with further study, prove to be lava flows) it is noted that the Wuchusk Lake Formation is composed of much finer sediments than the Majoque Lake Formation. Within the environmental models proposed previously, it is probable that there would be fine-grained, red shales, black shales, and some shallow water carbonates deposited further south in the basin. Such fine-grained clastics occur in places which are commonly associated with alluvial fans, in semi-arid areas (Melton, 1965; Bluck, 1967 and Davis, 1938) or shallow water, marine deposits. Kidd (1968) indicates that shallow marine conditions existed in the south during the deposition of the Salmon Lake Formation. With deformation and maximum compression from the south, the more distal or central basinal facies may be thrust northwards over coarser, near-source sediments which are of similar age. Thus, not until more extensive and detailed mapping of the northern limb of Seal Lake Basin has been undertaken can the present stratigraphy of the basin be accepted.

BIBLIOGRAPHY

Allen, J.R.L., 1961, Sandstone-Plugged Pipes in the Lower Old Red Sandstone of Shropshire, England. J. Sediment. Petrol., V. 31, pp. 325 - 335.

___________ , 1963, The Classification of Cross-Stratification Units With Notes on Their Origin. Sedimentology, V. 2, pp. 93 - 114.

___________ , 1965a, Sedimentation to the Lee of Small Underwater Sand Waves: An Experimental Study. J. Geol., No. 73, pp. 95 - 116.

___________ , 1965b, Upper Old Red Sandstone Palaeography (Farlovian) in South Wales and The Welsh Borderlands. J. Sediment. Petrol., V. 35, pp. 167 - 195.

___________ , 1965c, A Review of the Origin and Characteristics of Recent Alluvial Sediments. Sedimentology, V. 5, pp. 89 - 191.

___________ , 1966, On Bedforms and Palaeocurrents. Sedimentology, V. 6, pp. 153 - 190.

Bagnold, R.A., 1954, Experiments on a Gravity-Free Dispersion of Large Solid Spheres in a Newtonian Fluid Under Shear. Roy. Soc. London, Proc., Ser. A, V. 225, pp. 49 - 63.

Baragar, W.R.A., 1969, Volcanic Studies in the Seal Lake Area, Labrador, Geol. Surv. Canada, Paper 69-1, pt. A. pp. 142 - 146.

Beal, M.A. and Shepard, F.R., 1956, A Use of Roundness to Determine Depositional Environments. J. Sediment, Petrol., V. 26, pp. 49 - 60.

Beerbower, J.R., 1964, Cyclothems and Cyclic Depositional Mechanism in Alluvial Plain Sedimentation. Kansas Geol. Surv. Bull., V. 169, pp. 35 - 42.

Blatt, H. and Christie, J.M., 1963, Undulatory Extinction in Quartz of Igneous and Metamorphic Rocks and Its Significance in Provenance Studies in Sedimentary Rocks.J.Sediment.Petrol., V. 33, pp. 559 - 579.

Blissenbach, E., 1954, Geology of Alluvial Fans in Semi-Arid Regions. Bull. Geol. Soc. America, V. 65, No. 2, pp. 175 - 189.

Bluck, B.J., 1964, Sedimentation of an Alluvial Fan in Southern Nevada. J. Sediment. Petrol., V. 34, pp. 395 - 400.

___________, 1965, The Sedimentology History of Some Triassic Conglomerates in the Vale of Glamorgan, South Wales, Sedimentalogy, V. 4, pp. 225-245.

___________, 1967, Deposition of Some Upper Old Red Sandstone Conglomerates in the Clyde Area: A Study in the Significance of Bedding. Scottish J. Geol., V. 3, pt. 2, pp. 139 - 167.

Bott, M.M.P., 1964, Gravity Measurements on the Northeastern Part of the Irish Sea. Quart. J. Geol. Soc. London, V. 120, pp. 369 - 396.

Brückner, W.D., 1957, Laterite and Bauxite Profiles of West Africa as an Index of Rhythmic Climatic Variations in the Tropical Belt. Eclogae Geologiscae Helvetiae, V. 50, No. 2, pp. 239 - 254.

Brummer, J.J., 1957, Report on Operations in Frobisher's Seal Lake Concession, Central Labrador, Newfoundland. Kennco Exploration (Canada) Ltd.

____________ and Mann, E.L., 1961, Geology of the Seal Lake Area, Labrador, Bull. Geol. Soc. Am., V. 72, pp. 1361 - 1382.

Brush, M., Jr., 1965, Experimental Work on Primary Sedimentary Structures, in Middleton, G.V., Ed., Primary Sedimentary Structures and Their Hydrodynamic Interpretation, Soc. Econ. Palaeontologists and Mineral-ogists, Spec. Pub., 12, pp. 17 - 24.

Butler, H., 1959, Das Old Red - Gebiet am Muskoksefjord; Attempt at a Correlation of the Series of Various Devonian Areas in Central East Greenland. Medd. Grøn., Bd. 160, No. 5, pp. 1 - 188.

Carlisle, D., 1963, Pillow Breccias and Their Aquagene Tuffs, Quadra Island, British Columbia. J. Geol., V. 71, No. 1, pp. 48 - 71.

Cleary, N.J. and Connelly, J.R., 1971, Distribution and Genesis of Quartz in a Piedmont - Coastal Plain Environment: Bull. Geol. Soc. Am., V. 82, pp. 2755 - 2766.

Connelly, J.R., 1965, The Occurrence of Polycrystallinity and Undulatory Extinction in Quartz in Sandstones.J.Sediment. Petrol., V. 35, No. 1, pp. 116 - 135.

Craig, D.C. and Longhman, F.C., 1964, Chemical and Mineralogical Transformations Accompanying the Weathering of Basic Volcanic Rocks From New South Wales, Australia. J. Soil Res., V. 2, pp. 218 - 234.

Crook, K.A.W., 1968, Weathering and Roundness of Quartz Sand Grains. Sedimentology, V. 11, pp. 171 - 182.

Cummings, G.L., Wilson, J.T., Farguhar, R.M. and Russel, R.D., 1955, Some Dates and Subdivisions of the Canadian Shield in Derry, D.R., Symposium on Precambrian Correlation and Dating. Geol. Assoc. Canada Proc., V. 7, pt. 2, pp. 27 - 49.

Daly, R.A., 1914, Igneous Rocks and Their Origin. McGraw - Hill Pub. Co., New York, 563 p.

Davis, W.M., 1938, Sheet Floods and Stream Floods. Bull. Geol. Soc. Am., V. 8, pp. 1337 - 1416

Deer, W.A., Howie , R.A. and Zussman, J., 1967, An Introduction to the Rock Forming Minerals. Longmans, Green and Co. Ltd., London.

DeGrace, J., 1969, Geology of the Pocketknife Area, Labrador. Report: British Newfoundland Exploration Ltd.

Dewey, J.F., 1965, Nature and Origin of Kink Bands. Tectonophysics, V. 1, No. 6, pp. 459 - 494.

___________, 1969, The Origin and Development of Kink Bands in a Foliated Body. Geol. J., V. 6, pt. 2, pp. 193 - 216. In Baer, A.J.,and Norris, D.K., Eds., Research in Tectonics. Geol. Surv. Canada., Paper 68-52. pp. 255 - 288.

Dinely, D.L., 1960, The Old Red Sandstone of Eastern Ekmanfjorden, Vest-spitzbergen: Geol. Mag., V. 97, pp. 18 - 32.

Doeglas, D.J., 1962, The Structure of Sedimentary Deposits of Braided Rivers. Sedimentology, V. 1, pp. 167 - 190.

Donath, F.A., 1968, Experimental Study of Kink Band Development in Martinsburg Slate in Baer, A.J., and Norris, D.K., eds. Research in Tectonics. Geol. Surv. Can., Paper 68 - 52.

Dott, R.M. and Howard, J.K., 1962, Convolute Lamination in Non-graded Sequences. J. Geol., V. 70, pp. 114 - 12.

Drake, L.D., 1970, Rock Texture: An Important Factor for Clast Shape Studies. J. Sediment. Petrol., V. 40, pp. 1356 - 1361.

Einarsson, T., 1949, The Eruption of Helka 1947 - 48, IV, 3. The Flowing Lava. Studies of its Main Physical and Chemical Properties. Soc. Scientiarum Islandica, Reykjavik, 70 p.

Emslie, R.F., 1969, Crystallisation of Differentiation of the Michikamau Intrusion, in Isachen, Y.W., Ed., Origin of Anorthosite and Related Rocks. Mem. 18, N. York State Museum and Science Service, pp. 163 - 173.

Evans, E.L., 1952, Native Copper Discoveries in the Seal Lake Area, Labrador. Geol. Assoc. Canada Proc., V. 5, pp. 111 - 116.

Fahnstock, R.K. and Haushild, W.L., 1962, Flume Studies of the Transport of Pebbles and Cobbles on a Sand Bed. Bull. Geol. Soc. Am., V. 73, pp. 1431 - 1436.

Fahrig, W.F., 1959, Snegamook Lake, Coast of Labrador, Newfoundland. Geol. Surv. Can., Map 1079A.

Frazier, D.E. and Osanik, A., 1961, Point Bar Deposits. Old River Lochsite Louisiana. Trans. Gulf Coast Assoc.,Geol. Soc., V. 11, pp. 121 - 137.

Friedman, G.M., 1961, Distinction Between Dune, Beach and River Sands From Their Textural Characteristics. J. Sediment. Petrol., V. 31, pp. 514-529.

_____________, 1967, Dynamic Processes and Statistical Parameters Compared For Size Frequency Distribution of Beach and River Sands. J. Sediment. Petrol., V. 37, pp. 329 - 354.

Friend, P.F., 1961, The Devonian Stratigraphy of North and Central Vestspitz-bergen. Proc. Yorkshire Geol. Soc., V. 33, pp. 77 - 118.

____________, 1965, Fluviatile Sedimentary Structures in the Wood Bay Series (Devonian) of Spitzbergen. Sedimentology, V. 5, pp. 39 - 68.

Folk, R.L., 1961, Petrology of Sedimentary Rocks Hemphills, Austin, Texas.

__________ and Ward, W.C., 1957, Brazos River Bar: A Study in the Significance of Grain Size Parameters. J. Sediment. Petrol., V. 27, pp. 3 - 26.

Gandhi, S.S., Grasty, R.L. and Grieve, R.A.F., 1969, The Geology and Geo-chronology of the Makkovik Bay Area, Labrador. Can. J. Earth Sci., V. 6, No. 5, pp. 1019 - 1035.

Hale, W.E., 1968, Summary of Report on Seal Lake Area, Central Labrador. Report: British Newfoundland Exploration Ltd.

Happ, S.C., Rittenhouse, G, and Dobson, G.C., 1940, Some Aspects of Accelerated Stream and Valley Sedimentation. U.S. Dept. Agr., Tech. Bull., V. 695, 134 p.

Harms, J.C., McKenzie, D.B. and McCubbin, D.G., 1963, Stratification in Modern Sands of the Red River, Louisiana. J. Geol., V. 71, pp. 566 - 580.

__________ and Fahnstock, R.K., 1965, Stratification, Bed Forms and Flow Phenomena (With an Example From the Rio Grande), in Middleton. G.V., Ed., Primary Sedimentary Structures and Their Hydrodynamic Interpretation. Soc. Econ. Palaeontologists and Mineralogists, Spec. Pub., 12, pp. 84 - 115.

Harrossowitz, H., 1930, Boden der Tropischen Regionen, in Edwin Black, ed., Handbuch der Bodenlehre, V. 3, pp. 362 - 436. J. Springer, Berlin.

Heath, S.A. and Fairbairn, H.W., 1969, Sr^{87}/Sr^{86} Ratios in Anorthosites and Some Associated Rocks, in Isachen, Y.W., Ed., Origin of Anorthosite and Related Rocks. Mem. 18, N. York State Museum and Science Service pp. 99 - 110.

Hoffman, P., 1969, Proterozoic Palaeocurrents and Depositional History of the East Arm Fold Belt, Great Slave Lake, Northwest Terrorities. Can. J. Earth Sci., V. 6, pp. 441 - 462.

Hook, R.L., 1967, Processes on Arid Region Alluvial Fans. J. Geol., V. 75, pp. 438 - 460.

__________, 1968, Steady-State Relationships on Arid-Region Alluvial Fans in Closed Basins. Am. J. Sci., V. 266, pp. 609 - 629.

Jopling, A.V., 1963, Hydraulic Studies on the Origin of Bedding. Sedimentology, V. 2, pp. 115 - 121.

_____________, 1965, Labratory Studies of the Distribution of Grain-Sizes in Cross-Bedded Deposits, in Middleton, G.V., Ed., Primary Sedimentary Structures and Their Hydrodynamic Interpretation, Soc. Econ. Palaeontologists and Mineralogists, Spec. Pub., 12, pp. 53 - 65.

Kidd, W.S.F., 1968, The Geology of Southwest Seal Lake and North Adeline Lake in the Seal Lake Area, Labrador. Report: British Newfoundland Exploration Limited.

Knight, I., 1970, Geology of Arkose Lake Area, Labrador. Unpublished Report: British Newfoundland Exploration Limited.

Krigström, A., 1962, Geomorphological Studies of Sandur Plains and Their Braided Rivers in Iceland. Geograf. Ann., V. 44, pp. 328 - 346.

Krumbein, W.C., 1941, Measurement and Geological Significance of Shape and Roundness of Sedimentary Particles. J. Sediment. Petrol., V. 11, pp. 64 - 72.

Kuenen, P.H., 1948, Slumping in the Carboniferous Rocks of Pembrokeshire. Quart. J. Geol. Soc. London, V. 104, pp. 365 - 379.

Kuno, H., 1960, High-Alumina Basalts. J. Petrol., V. 1, pt. 1, pp. 121 - 145.

________, 1967, Differentiation of Basalt Magmas, in Hess,H.H. and Poldervaart, A., Ed., Basalts: The Poldervaart Treatise on Rocks of Basaltic Composition. J. Wiley and Sons. V. 2, pp. 623 - 688.

La Croix, A., 1913, Les Laterites de La Guinee, et Les Produits D'Alteration Qui Leur Sont Associes. Nouvelle Archives de Musee d'Historie Naturelle. 5th Serie, No. 5, Paris, pp. 255 - 352.

Leopold, L.B. and Wolman, G.M., 1957, River Channel Patterns: Braided, Meandering and Straight. U.S. Geol. Surv. Prof. Pap. 282-B, pp. 39 -85.

Loughnan, F.C., and Golding, H.G., 1957, The Mineralogy of the Commercial Dyke Clays in the Sydney District. J. Roy. Soc. New South Wales. V. 91, pp. 85 - 91.

Macdonald, G.A., 1967, Forms and Structures of Extrusive Basaltic Rocks, in Hess, H.H. and Poldervaart A., Eds., Basalts: The Poldervaart Treatise on Rocks of Basaltic Composition. J. Wiley & Sons, London. V. 1, pp. 1 - 61.

______________ and Katsura, T., 1964, Chemical Composition of Hawaiian Lavas. J. Petrol. V. 5, pp. 82 - 133.

McDonald, B.C. and Banerjee, A., 1971, Sediments and Bed Forms on a Braided Outwash Plain. Can. J. Earth Sci., V. 8, No. 10, pp. 1282 - 1301.

McKee, E.D., and Weir, G.W., 1953, Terminology for Stratification and Cross-Stratification in Sedimentary Rocks. Bull. Geol. Soc. Am., V. 64, pp. 381 - 390.

_______________, Reynolds, M.A. and Baker, C.M., 1962, Experiments on Intra-formational Unconsolidated Sediment. U.S. Geol. Surv. Prof. Pap. 450-D, pp. 155 - 160.

Mann, E.L., 1959, The Geology of the Seal Lake Area, Central Labrador, Ph.D. Thesis, McGill University, unpublished.

Manson, V., 1967, Geochemistry of Basaltic Rocks; Major Elements, in Hess, H.H. and Poldervaart, A., Eds., Basalts: The Poldervaart Treatise on Rocks of Basaltic Composition. J. Wiley and Sons, London, V. 1, pp. 215 - 269.

Mason, C.C. and Folk, R.L., 1958, Differentiation of Beach, Dune and Aeolian Flat Environments by Size Analysis, Mustang Island, Texas. J. Sediment. Petrol. V. 28, No. 2, pp. 211 - 226.

Mattox, R.B., 1955, Eolian Shape-Sorting. J. Sediment.Petrol., V. 25, pp. 111 - 114.

Melton, M.A., 1965, The Geomorphic and Palaeoclimatic Significance of Alluvial Deposits in Southern Arizona. J. Geol., V. 73, No. 1, pp. 1 - 38.

Morse, S.A., 1969, Layered Intrusions and Anorthosite Genesis, in Isachen. Y. W. Ed., Origin of Anorthosite and Related Rocks. Mem. 18, N. York State Museum and Science Service, pp. 175 - 187.

Noe-Nygaard, A. and Rasmussen, J., 1968, Petrology of a 3,000 Metre Sequence of Basaltic Lavas in the Faeroe Islands. Lithos, V. 1, No. 3, pp. 286 - 304.

Paterson, M.S. and Weiss, L.E., 1966, Experimental Deformation and Folding in Phyllite. Bull. Geol. Soc. Am., V. 77, pp. 343 - 374.

Pettijohn, F.J., 1957, Sedimentary Rocks. 2nd edition. Harper and Row.

Poldervaart, A., 1962, Aspects of Basalt Petrology. Geol. Soc. India Jour., V. 3, pp. 1 - 14.

_______________, 1964, Chemical Definition of Alkali Basalts and Tholeiites. Bull. Geol. Soc. Am., V. 75, No. 3, pp. 229 - 232.

Powers, M.C., 1953, A New Roundness Scale For Sedimentary Particles. J. Sediment. Petrol., V. 23, pp. 117 - 119.

Ramsay, J.G., 1967, Folding and Fracturing of Rocks. McGraw-Hill, New York.

Read, W.A. and Johnson, S.R.H., 1967, The Sedimentology of Sandstone Formations Within the Upper Old Red Sandstones and Lowest Calciferous Sandstone Measures West of Stirling, Scotland. Scottish J. Geol., V. 3, pt. 2, pp. 242 - 267.

Reiche, P., 1962, A Survey of Weathering Processes and Products. Univ. of New Mexico, Publ. in Geol., No. 3, Albuquerque, Univ. of New Mexico Press.

Richey, J.E., 1948, British Regional Geology, Scotland. The Tertiary Volcanic Districts, 1st Edition.

Roscoe, S.M., East Kasheshibaw, Newfoundland; Geol. Survey Can., unpublished map.

Russell, R.D., 1939, Effects of Transportation on Sedimentary Particles: in Recent Marine Sediments, Trask, P.D., Ed., Am. Assoc. Petroleum Geologists. Tulsa, pp. 32 - 47.

___________ and Taylor, R.E., 1937, Roundness and Shape of Mississippi River Sands. J. Geol., V. 45, pp. 225 - 267.

Sames , C.W., 1966, Morphometric Data of Some Recent Pebble Associations and Their Application to Ancient Deposits. J. Sediment. Petrol., V. 36, No. 1, pp. 126 - 142.

Selley, R.C., 1965, Diagnostic Characters of Fluviatile Sediments of the Torridian Formation (Precambrian) of Northwest Scotland. J. Sediment. Petrol. V. 35, pp. 366 - 380.

Shepard, F.P. and Young,R., 1961, Distinguishing Between Beach and Dune Sands. J. Sediment. Petrol. V. 31, No. 2, pp. 196 - 214.

Sherman, G.D., 1949, Factors Influencing the Development of Lateritic and Laterite Soils in the Hawaiian Islands, Pac. Sci., V. 3, pp. 307 - 314.

_____________, 1952a, The Titanium Content of Hawaiian Soils and Its Significance. Proc. Am. Soil Soc., V. 16, pp. 15 - 18.

_____________, 1952b, The Genesis and Morphology of the Alumina-Rich Laterite Clays. Clay and Laterite Genesis, Am. Inst. Min. Met., pp. 154 - 161.

Sigvaldason, S.E., 1968, Structures and Products of Subaquatic Volcanoes in Iceland. Contr. Mineral. and Petrol., V. 18, pp. 1 - 16.

Simons, D.B., Richardson, E.V. and Norden, C.F., 1965, Sedimentary Structures Generated by Flow in Alluvial Channels, in Middleton, G.V., Ed., Primary Sedimentary Structures and Their Hydrodynamic Interpretation. Soc. Econ. Palaeontologists and Mineralogists. Spec. Pub., 12, pp. 34 - 52.

Smith, N.D., 1970, The Braided Stream Depositional Environment: Comparison of the Platte River with Some Silurian Clastic Rocks, North Central Appalachians. Bull. Geol. Soc. Am., V. 81, pp. 2993 - 3014.

Smith, R.E., 1967, Segregation Vesicles in Basaltic Lava. Am. J. Sci., V. 265, pp. 696 - 713.

Spriggs, M.J., 1969, Follow Up Over Site of Baragar's Radioactive Arkosic Conglomerates. Unpublished Report: British Newfoundland Exploration Limited.

Stewart, F.H., 1965, Tertiary Igneous Activity. In Craig, G.Y. Ed., The Geology of Scotland, Oliver and Boyd, pp. 420 - 465.

Steward, J.H., 1961, Origin of Cross-Strata in Fluvial Sandstone Layers in the Chinle Formation (Upper Triassic) on the Colorado Plateau. U. S. Geol. Surv., Prof. Pap. 424-B, pp. 127 - 129.

Stockwell, C.H., 1965, Tectonic Map of the Canadian Shield. Can. Dept. Mines, Tech. Surv., Geol. Surv. Can., Map 4 - 1965.

Wanless, R.K., Stevens, R.D., Lachance, G.R. and Rimsaite, R.Y.H., 1965, Age Determinations and Geological Studies. Pt. 1, Isotopic Ages. Report 5. Geol. Surv. Can., Paper 64 - 17, pt. 1, 122 p.

______________________________, 1966, Age Determinations and Geological Studies, K - Ar Isotopic Age, Report 6. Geol. Surv. Can., Paper 65 - 17, 96 p.

Washington, H.S. 1922, Deccan Traps and Other Plateau Basalts. Bull. Geol. Soc. Am., V. 33, pp. 765 - 804.

Waters, A.C., 1960, Determining Direction of Flow in Basalts. Am. J. Sci., (Bradley Volume) V. 258 - A, pp. 350 - 366.

__________, 1961, Stratigraphic and Lithological Variation in the Columbia River Basalt. Am. J. Sci., V. 259, pp. 583 - 611.

Wentworth, C.K., 1922, A Scale of Grade and Class Terms for Clastic Sediments. J. Geol., V. 30, pp. 377 - 392.

West, W.D., 1958, The Petrography and Petrogenesis of Forty-eight Flows of Deccan Trap Borings in Western India. Nat. Inst. Sci. India Trans., V. 4, pp. 1 - 56.

Wheeler, E.P. II, 1960, Anorthosite-Adamellite Complex of Nain, Labrador. Bull. Geol. Soc. Am., V. 71, pp. 1755 - 1762.

____________, 1969, Minor Intrusions Associated with the Nain Anorthosite, in Isachen, Y.W., Ed., Origin of Anorthosite and Related Rocks. Mem. 18., N. York State Museum and Science Service, pp. 189 - 206

Williams, G.E., 1966, Planar Cross-Stratification Formed by Lateral Migration of Shallow Streams. J. Sediment. Petrol., V. 36, pp. 742 - 746.

________________, 1969, Characteristics and Origin of a Precambrian Pediment. J. Geol., V. 77, pp. 183 - 207.

________________, 1971, Flood Deposits of the Sand-Bed Ephemeral Streams of Central Australia. Sedimentology, V. 17, pp. 1 - 40.

Williams, H. and Stevens, R.K., 1969, Geology of Belle Isle; Northern Extremity of the Deformed Appalachian Miogeosynclinal Belt. Can. J. Earth Sci., V. 6, No. 5, pp. 1145 - 1157.

Williams, P.F. and Rust, B.R., 1969. The Sedimentology of a Braided River. J. Sediment. Petrol., V. 39, pp. 649 - 679.

Wynne-Edwards, H.R., 1971, Stratigraphic Relationships In and Around the Grenville Province. Abst., Geol. Soc. Am., V. 3, No. 7.

Yoder, H.S. and Tilley, C.E., 1962, Origin of Basalt Magmas: An Experimental Study of Natural and Synthetic Rock Systems. J. Petrol., V. 3, pt. 3, pp. 342 - 532.

Zingg, M., 1935, Beitrag Zur Schotteranalyse, Schweiz. Mineralog. Petrog. Mitt., Bd. 15, pp. 39 - 140.

APPENDIX

TABLE II

Pebble Counts - Conglomerates in Sediment Bands of the Majoque Lake Formation

Count #	White Qtz.	Purple Qtz.	Red Qtz.	Grey Qtz.	Opalescent Qtz.	K.F.	Sand-stone	Gran-ite	Jas-per	Basalt & Laterite	Epidote	Gneiss	Anortho-site
Band C (area III)													
1a.	58.8	3.85	-	-	-	35.0	-	-	-	0.7	0.7	-	0.7
1b.	80.0	1.6	-	-	-	18.3	-	-	-	-	-	-	-
2.	24.0	19.63	1.45	-	-	53.1	-	-	-	0.36	1.45	-	-
3a.	31.1	8.86	-	-	-	60.0	-	-	-	-	-	-	-
3b.	30.86	20.98	3.7	-	-	40.7	-	-	-	3.7	-	-	-
3c.	26.38	34.89	1.7	-	-	35.74	-	-	-	-	1.27	-	-
3d.	56.71	16.91	-	-	-	20.89	-	-	-	-	5.47	-	-
3e.	41.6	12.8	-	-	-	37.6	-	-	-	-	8.0	-	-
4a.	43.5	17.0	-	2.0	-	33.5	-	-	0.5	-	3.5	-	-
4b.	36.43	15.54	-	-	-	42.63	-	-	-	-	5.42	-	-
5.	41.48	10.37	4.44	4.44	-	29.62	-	-	-	-	9.62	-	-
6.	51.0	21.0	-	-	-	22.0	1.0	1.0	2.0	-	2.0	-	-
7.	33.54	25.94	-	-	-	36.82	-	0.83	1.25	-	1.67	-	-
8.	39.44	14.1	-	-	-	42.26	0.93	1.87	-	0.93	0.04	-	-
9a.	36.63	4.95	-	1.23	-	55.94	-	0.74	-	-	0.49	-	-
9b.	44.66	16.19	4.28	0.95	-	28.57	-	1.42	-	-	1.90	-	-
9c.	51.93	18.23	2.76	1.1	-	24.3	-	-	-	-	1.65	-	-
10a.	46.37	24.63	5.79	-	-	17.39	-	-	-	-	5.79	-	-
10b.	54.42	-	8.16	2,04	-	31.97	-	-	0.68	-	2.72	-	-
11.	62.92	3.39	12.36	3.37	-	17.97	-	-	-	-	-	-	-
12a.	59.2	8.64	4.9	4.9	-	22.22	-	-	-	-	-	-	-
12b.	57.54	-	7.32	-	1.04	30.34	-	2.09	-	-	2.09	-	-

TABLE II (cont.)

Count #	White Qtz.	Purple Qtz.	Red Qtz.	Grey Qtz	Opalescent Qtz.	K.F.	Sand-stone	Gran-ite	Jas-per	Basalt & Laterite	Epidote	Gneiss	Anortho-site
13.	63.58	-	9.75	2.05	-	20.51	-	1.02	0.51	-	1.02	0.51	-
14a.	73.12	4.06	-	1.62	1.62	17.07	-	-	2.43	-	-	-	-
14b.	81.17	1.17	3.52	2.35	3.52	8.23	-	-	-	-	-	-	-
14c.	42.4	3.76	1.88	-	2.82	47.11	-	-	1.88	-	-	-	-
14d.	70.32	2.19	12.1	-	-	15.38	-	-	-	-	-	-	-
14e.	47.45	21.18	4.23	1.69	1.69	22.88	-	-	0.84	-	-	-	-
14f.	56.17	16.85	4.49	2.25	17.97	2.25	-	-	-	-	-	-	-
14g.	45.37	1.85	17.59	3.70	1.85	28.70	-	-	-	-	0.92	-	-
Band C (area II)													
15.	41.48	-	2.88	3.21	-	51.85	-	-	-	-	-	-	-
16.	70.7	-	6.06	4.04	-	17.17	-	1.01	1.01	-	-	-	-
17a.	85.71	6.66	2.85	2.85	-	-	-	-	0.95	-	-	-	0.95
17b.	66.45	0.63	2.55	2.55	-	26.83	-	0.63	0.32	-	-	-	-
Band E (area III)													
18.	38.36	23.35	-	-	-	27.9	-	1.66	2.32	-	6.97	-	-
19.	52.45	30.6	-	-	-	15.30	-	-	0.54	0.54	0.54	-	-
20.	48.45	15.46	1.03	2.06	1.03	30.92	-	-	-	-	1.03	-	-

TABLE II (cont.)

Band A (area III)	White Qtz.	Purple Qtz.	Red Qtz.	K.F.	Rhyo- lite	Rhyol. Porph.	Feldsp. Porphyr.	Sand- stone	Jasper	Laterite & Basalt	Epidote
21a.	66.15	4.61	-	16.92	3.07	-	-	-	-	4.61	4.61
21b.	45.91	1.63	-	42.63	-	1.63	-	1.63	1.63	4.90	-
21c.	60.34	10.34	1.72	15.51	0.86	2.58	1.72	0.86	0.86	0.86	0.86

Average of Pebble Counts

Band #	White Qtz.	Purple Qtz.	Red Qtz.	Grey Qtz.	Opalescent Qtz.	K.F.	Sand- stone	Gran- ite	Jas- per	Basalt & Laterite	Epidote	Gneiss
C (area III)	44.71	12.14	3.38	1.08	0.58	35.18	0.01	0.03	0.36	0.21	1.88	0.01
C (area II)	64.04	1.31	3.34	2.76	-	27.80	-	0.03	0.01	-	-	-
E (area III)	48.35	25.0	0.27	0.54	0.27	22.52	-	-.27	0.82	0.27	2.19	-

Band #	White Qtz.	Purple Qtz.	Red. Qtz.	K.F.	Rhyo- lite	Rhyol. Porph.	Feldsp. Porphyr.	Sand- stone	Jasper	Laterite & Basalt	Epidote
A (area III)	58.26	6.61	0.1	22.72	0.16	0.12	0.08	0.08	0.08	0.28	0.33

TABLE II (cont.)

Total Average for all Bands

White Qtz.	Purple Qtz	Red Qtz.	Grey Qtz.	Opalescent Qtz.	K.F.	Rhyo-lite	Rhyol Porph.	Feldsp. Porphyr.	Sand-stone	Granite	Jasper	Basalt & Laterite
46.82	11.65	3.15	1.16	0.5	33.69	0.05	0.04	0.02	0.10	0.29	0.37	0.27

Epidote	Anorthosite	Gneiss
1.27	0.04	0.01

1. Grid. Ref. 160 028
2. Grid. Ref. 143 032
3. Grid. Ref. 145 032
4. Grid. Ref. 106 025
5. Grid. Ref. 132 028
6. Grid. Ref. 063 016
7. Grid. Ref. 072 017
8. Grid. Ref. 083 020
9. Grid. Ref. 034 015
10. Grid. Ref. 058 014
11. Grid. Ref. 014 014
12. Grid. Ref. 018 016
13. Grid. Ref. 027 016
14. Grid. Ref. 088 022
15. Grid. Ref. 021 023
16. Grid. Ref. 060 037
17. Grid. Ref. 040 035
18. Grid. Ref. 142 025
19. Grid. Ref. 118 024
20. Grid. Ref. 152 025
21. Grid. Ref. 116 036

Fig. XXXV - Location map of specimen localities referred to in text (see Tables III, V, VI, VII, VIII & IX).

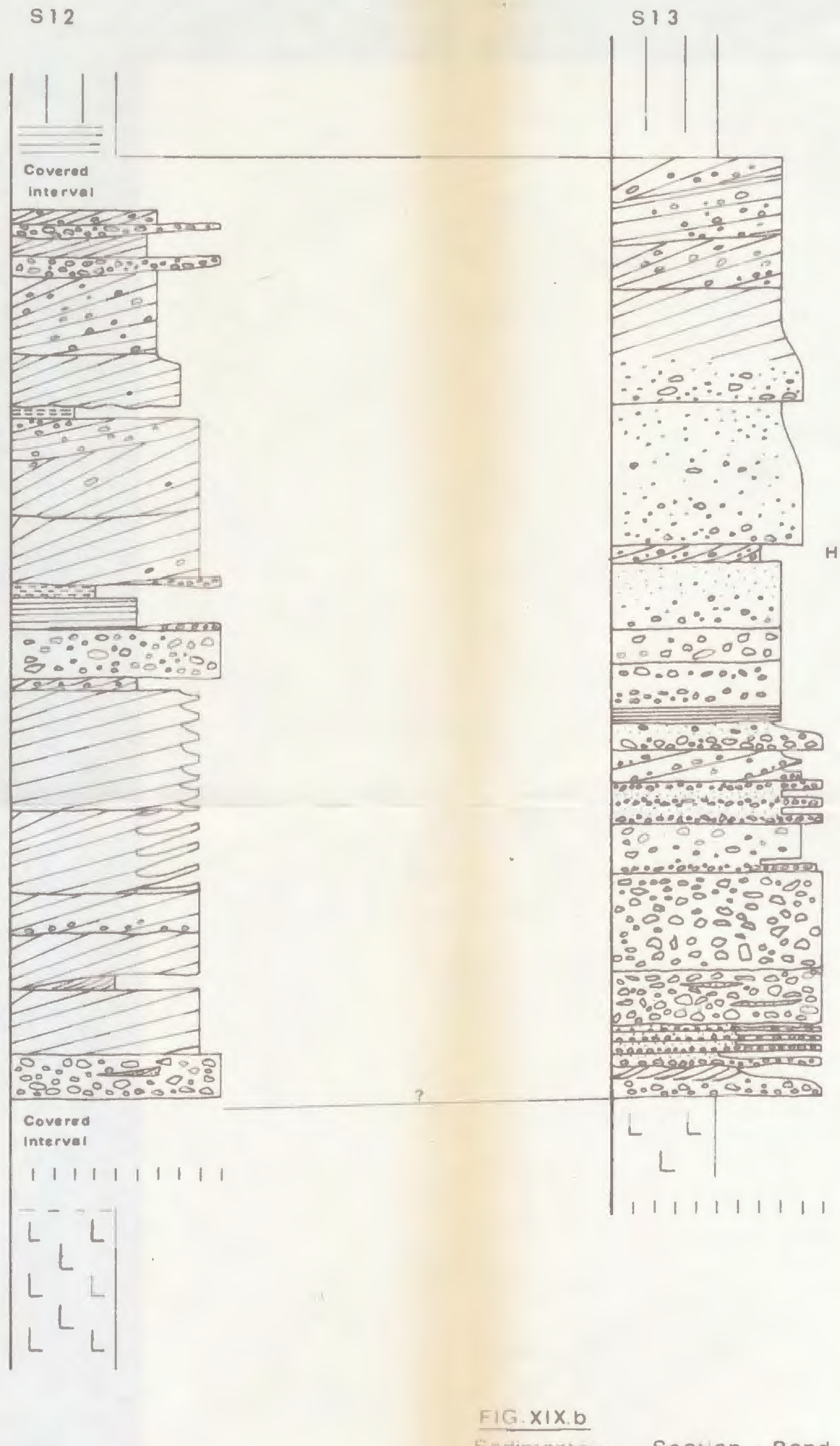
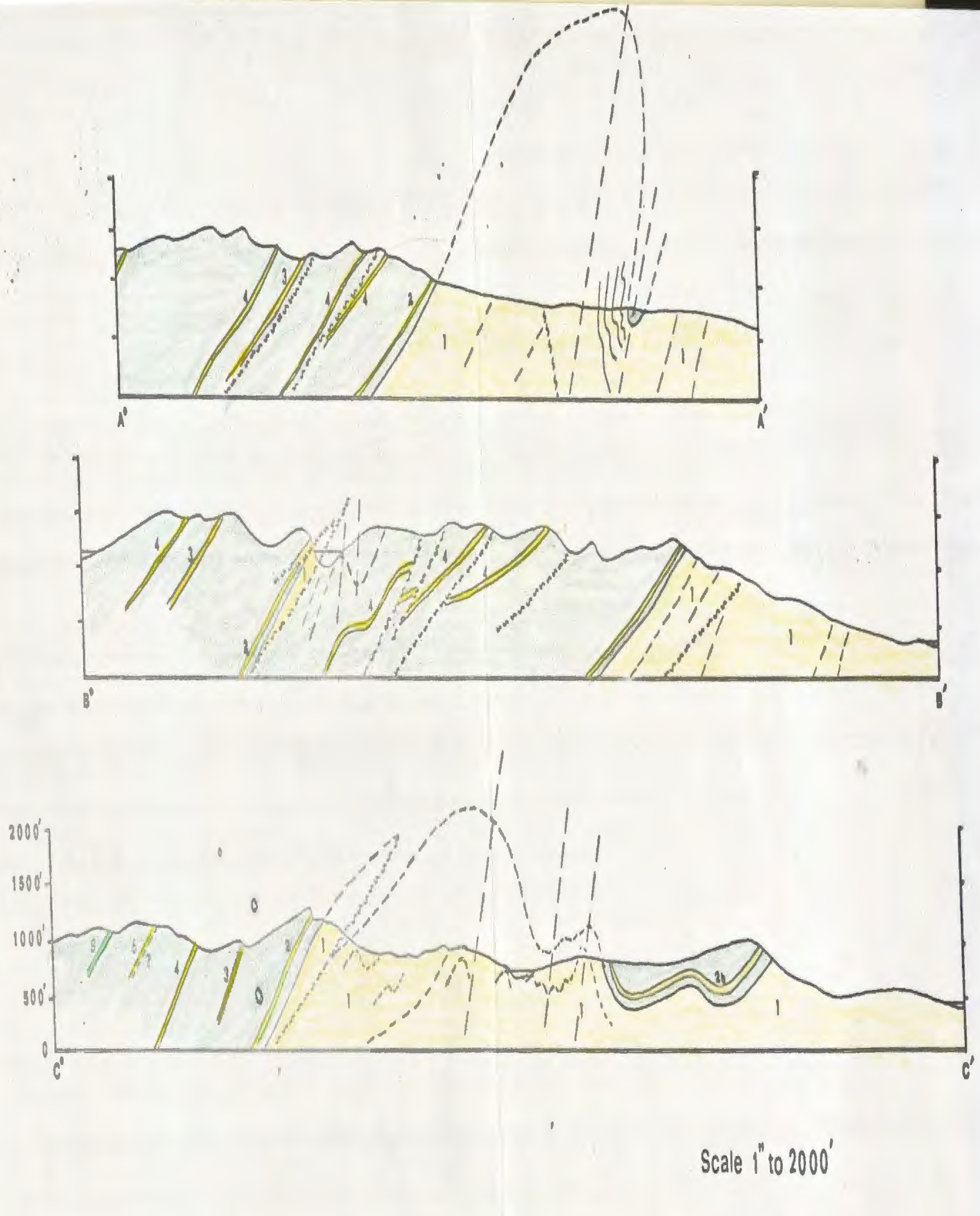


FIG. XIX.b

Sedimentary Section - Band C (Area II)

Scale & symbols

as in fig.xixa



Structural Profiles · Arkose Lake Area (For legend see map)