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PAPER 72-10

PROTEROZOIC FLOOD BASALTS OF EASTERN LAKE SUPERIOR: THE KEWEENAWAN VOLCANIC ROCKS OF THE MAMAINSE POINT AREA, ONTARIO

R.N. Annells

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(Report, 2 plates, 4 figures and 1 table)

R.N. Annells

DEPARTMENT OF ENERGY, MINES AND RESOURCES

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CONTENTS

Illustrations

Appendices

ABSTRACT

A 14,300-19,960-foot (4,290-5,988 m) sequence of Middle Keweenawan flood basalt lava flows interbedded with coarse conglomerates and injected by rhyolite and felsite bodies outcrops on the east shore of Lake Superior near Mamainse Point. Olivine-phyric basalts occur near the base of the section, which has been divided informally into Lower and Upper Divisions, the junction being set at the base of the 1,400-foot (420 m) "Great Conglomerate" about halfway up the succession. Conglomerates are abundant in the Upper Division and make up 24 per cent of the total thickness of the entire section, a much greater proportion than has been found in other Middle Keweenawan sequences in Lake Superior. A thinner lava sequence at Alona Bay (4,300 feet: 1,290 m) shows less lithological variation than the Mamainse Point section and contains no acid rocks. The Mamainse Point and Alona Bay sequences together with similar but thinner flood basalt sequences at Cape Gargantua and Michipicoten Island comprise the Mamainse Point Formation which has a maximum thickness of 21,000 feet (6,800 m).

Both the Alona Bay and Mamainse Point lava sequences rest unconformably on an irregular surface eroded in Superior Province Archean rocks and both were tilted and eroded prior to burial by sandy sediments probably correlative with the Upper Keweenawan Freda Formation.

No flows of intermediate composition were found in the Alona Bay or Mamainse Point sequences, and these volcanic rocks show pronounced chemical bimodalism. The basalts are tholeiitic and rich in copper relative to tholeiites elsewhere in time and space; a marked "high" in their copper and silver contents occurs at the base of the Upper Division. Copper sulphides and native copper occur in fissure-filling veins at this level and the main economic copper deposits of the area are located in this zone.

The geological description of the area is followed by short descriptions of 10 instructive outcrops along Highway 17 (Trans-Canada Highway).

RÉSUMÉ

Sur la rive orientale du lac Supérieur, près de la pointe Mamainse, se trouve un affleurement épais de 14,300 à 19,960 pieds (4,290 à 5,988 m) constitué par une séquence de laves faite de basalte des plateaux datant du milieu du Keweenawien (début du Précambrien), interstratifié de conglomérats grossiers. Des basaltes phyritiques à olivine se retrouvent près de la base de la section qui a été divisée pour les besoins en divisions inférieure et supérieure; la jonction a été établie à la base du "grand conglomérat" épais de 1,400 pieds (420 m), situé environ à mi-hauteur de la séquence. Les conglomérats sont abondants dans la division supérieure et atteignent 24 p. 100 de l'épaisseur totale de la section, soit une proportion plus forte que celle trouvée dans les autres séquences du milieu de Keweenawien situées dans la région du lac Supérieur. Une séquence de laves plus mince trouvée à la baie Alona (4,300 pieds; 1,290 m) présente moins de variation lithologique que la section de la pointe Mamainse et ne contient pas de roches acides. Les séquences de la pointe Mamainse et de la baie Alona mises ensemble et jointes

aux séquences de basalte des plateaux analogues mais plus minces, situées au cap Gargantua et à l'île Michipicoten, constituent la formation de Mamainse Point dont l'épaisseur maximum atteint 21,000 pieds (6,800 m).

Les séquences de laves de la baie Alona et de la pointe Mamainse reposent toutes deux en discordance sur une surface irrégulière érodée, dans des roches archéennes de la province du lac Supérieur; toutes deux ont subi un basculement et une érosion avant d'être enterrées par les sédiments sableux probablement liés à la formation de Freda du milieu du Keweenawien.

On n'a pas trouvé de laves de composition intermédiaire dans les séquences de la baie Alona ou de la pointe Mamainse et ces roches volcaniques présentent un caractère chimique bimodal prononcé. Les basaltes sont tholéitiques et riches en cuivre comparativement aux tholéites trouvées en d'autres temps et lieux; leurs teneurs en coivre et en argent est plus élevée à la base de la division supérieure. Les veines qui colmatent les fissures contiennent des sulfures de cuivre et du cuivre natif à ce niveau et les principaux gisements de cuivre exploitables de la région se situent dans cette zone.

Après la description géologique de la région viennent de brèves descriptions relatives à 10 affleurements particulièrement intéressants situés le long de la route 17 (route Trans-canadienne).

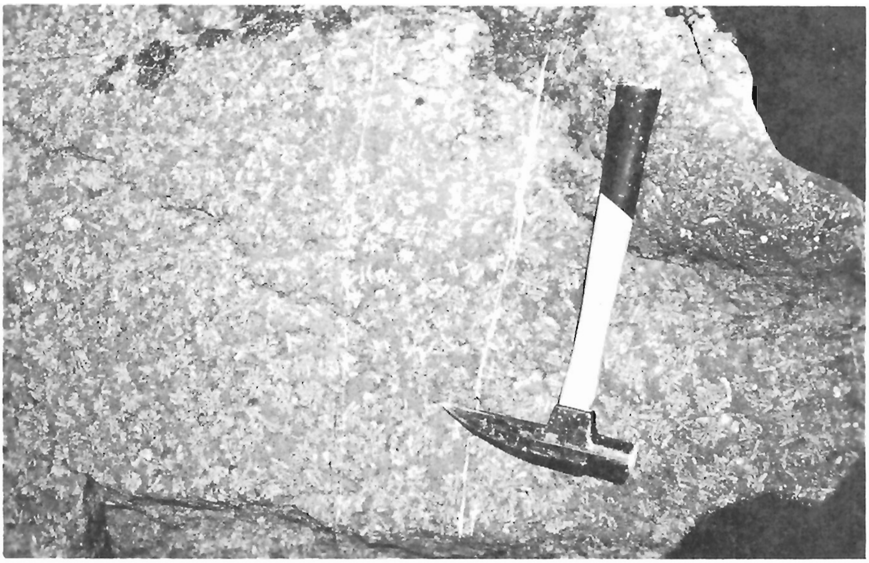

Plate 1. Glomerophyric "Daisy Stone" basalt bearing spherulitic clusters of plagioclase laths; outcrop on shore near base of the Lower Division lavas, Mica Bay. The hammer handle is 12 inches (30 cm) long. G. S. C. photo 201785-B

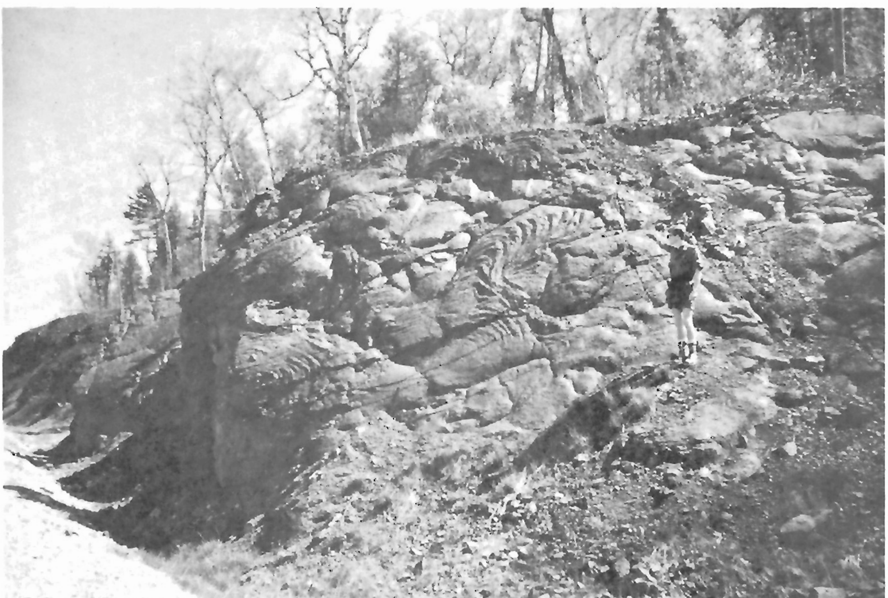

Plate 2. Ropy pahoehoe flow top exposed in the Highway 17 road-cut through Lower Division olivine tholeiite lava flows dipping west-southwest towards Lake Superior. G. S. C. photo 201785-A

PROTEROZOIC FLOOD BASALTS OF EASTERN LAKE SUPERIOR: THE KEWEENAWAN VOLCANIC ROCKS OF THE MAMAINSE POINT AREA, ONTARIO

INTRODUCTION

The Mamainse Point area first attracted practical men because of the occurrence of native copper in its basaltic rocks. Long before the arrival in Canada of the French explorers Jacques Cartier and Samuel de Champlain, the presence of this copper was known to the Indians of Lake Superior who dug large pieces of the soft metal from shallow pits, some of which have been found in the bush just east of Hibbard Bay (Fig. 2). Pits of similar type to these were also worked by the Indians farther westwards on Isle Royale and have been dated as 3,800 ± 500 years old (Drier, 1961). The Indians worked the metal into knives and cooking vessels which they traded for tobacco with the Indians of eastern Canada; in 1610, Champlain himself was presented with a foot-long piece of this native copper by an Algonquin chief on the St. Lawrence just east of the present site of Montreal (Hornick, 1969).

White men made a number of attempts to mine the native copper in the eighteenth century, but these endeavours were not very successful. Shafts were put down at several locations in the Mamainse Point area in the mid-nineteenth century when it was realized that the bedrock was similar in lithology to the rocks being successfully exploited for copper on the Keweenaw Peninsula of Michigan; these are the Mamainse Mine and the Copper Creek and Silver Creek Shafts.

Sir William Logan, the first director of the Geological Survey of Canada, noted in 1863 that the Mamainse copper was present in dark extrusive trap flows resting unconformably on the Archean gneisses, granites and metavolcanics, then known as the Laurentian Series; he assigned these younger traps to his Upper Copper-bearing Series of Lake Superior. The Mamainse volcanics were studied for the Survey in more detail by Macfarlane (1866) who found them to be intruded in places by red-coloured acid bodies which he interpreted as sandstones; these intruded parts of the succession he described as showing "evidences of great disturbances, and of a conflict between some of the igneous beds and a sandstone, which here appears in highly contorted and sometimes vertical strata" (op. cit., p. 134). Bell made geological traverses of the Mamainse Point area in 1876-77, and Moore (1926) mapped the east shore of Lake Superior between Batchawana Bay and Montreal River. The area immediately surrounding the Mamainse Point copper locations was mapped at a scale of 1 inch to 1,000 feet by Thomson (1953), and Giblin (1969a-d) extended detailed mapping of the volcanic rocks over the entire Mamainse Point Keweenawan outcrop; Nuffield (1955) mapped the lavas and dykes at Alona Bay. The writer made detailed stratigraphic sections of the shore section between Mica Bay and Pancake Point, the shore at Alona Bay, and of some inshore sections (Annells, 1971) and made petrographic and

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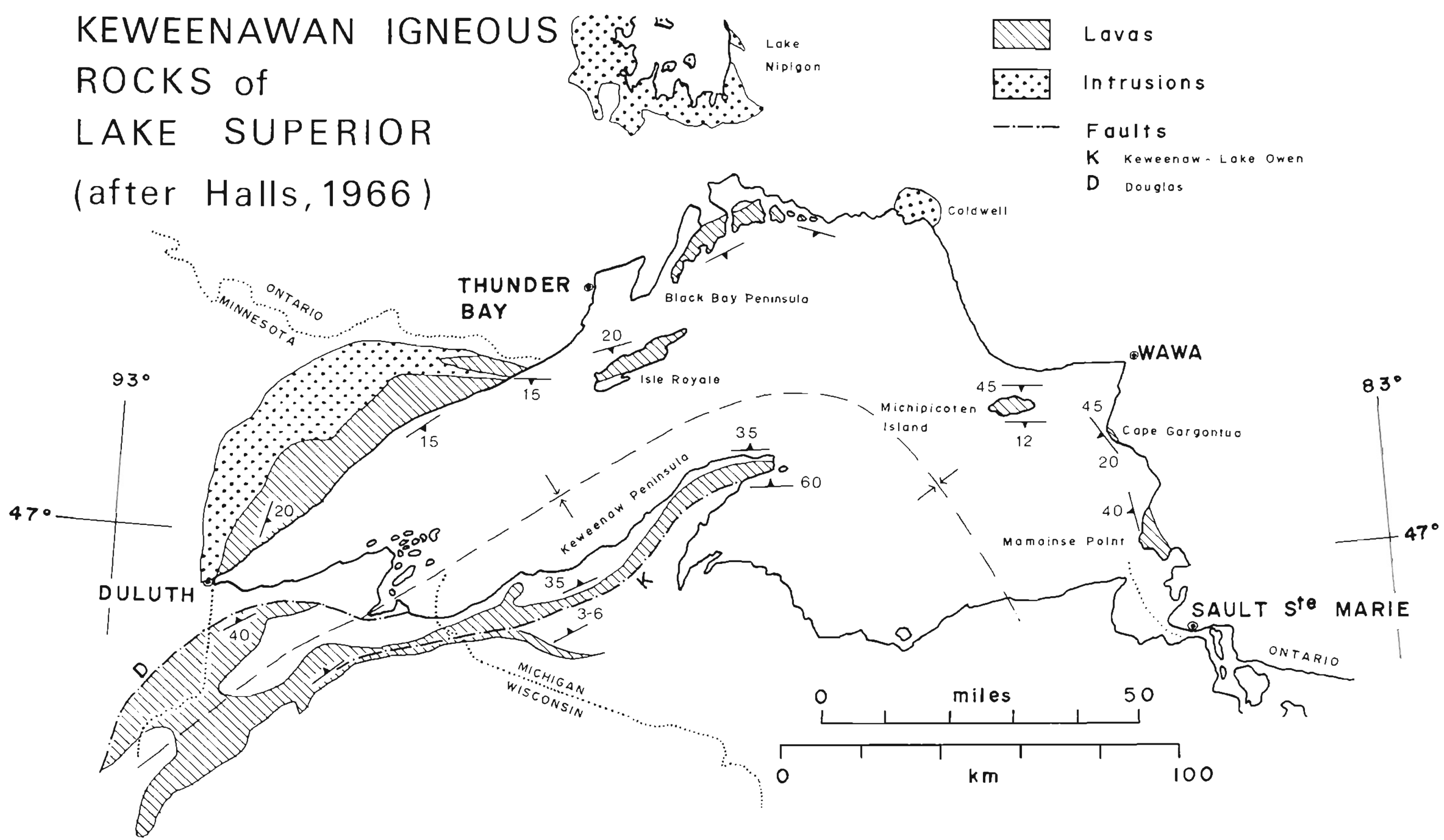

Figure 1. Keweenawan igneous rocks of the Lake Superior region, showing the location of the excursion area in the Lake Superior trough structure (after Halls, 1966).

chemical studies of these rocks. This report draws heavily on the work of Thomson (1953), Giblin (1969a-d) and the writer's own work in the area.

REGIONAL SETTING

The Mamainse Point and Alona Bay volcanics are placed in the Keweenawan Group because of their long-known broad stratigraphic correlation with the Portage Lake volcanics of the Proterozoic type-sections of the Michigan Keweenaw Peninsula; the lithologic similarity of the Mamainse Point volcanic rocks to these rocks was established by Irving (1883, p. 348). The term "Keweenawan Group" is equivalent to, and supersedes, that of "Upper Copper-bearing Series" set up by Logan (1863); rocks of this group yield K-Ar ages in the range 900-1, 100 m.y. (McGlynn, 1970, p. 109). Other outcrops of Keweenawan volcanics occur along the Ontario side of Lake Superior at Gros Cap, Harmony Bay, Chippewa Falls, Cape Gargantua, Michipicoten Island, St. Ignace Island and the Black Bay Peninsula near Thunder Bay (see Fig. 1).

The Keweenawan flows of Mamainse Point and Alona Bay lie at the eastern end of the Lake Superior trough structure and rest unconformably on Archean granitic rocks, metasediments and metavolcanics of the Superior Province (>2.5 b.y.); this trough structure has a maximum length of about 300 miles in Lake Superior and trends in an east-northeast direction (see Fig. 1). Recent magnetic and gravity surveys and shallow seismic refraction work have shown that the Keweenawan basalts of Lake Superior lie along the eastern part of the pronounced Midcontinent Gravity High which marks the axis of a broad rift-ridge system of Precambrian to mid-Paleozoic age extending from Canada to Texas (Smith et al., 1966; Craddock and Mooney, 1970; Ocola and Meyer, 1970). The 1963 Lake Superior seismic experiment showed that both the thickest and nearly the thinnest crust observed on the North American continent occur in the Lake Superior region; high velocity crust (6.67 km/sec) was found under the lake beneath 4-6 km of Keweenawan sediments and volcanics and the depth to the M discontinuity was found to vary from 20 km just west of the lake to 55 km or more in the eastern part of the lake (Smith et al., 1966). The same authors suggested (p. 1170) that "Lake Superior may... be a tensional feature in which the crust is made up of basic material somehow abstracted from adjacent areas or the mantle beneath. It does seem that the mantle has some special connection to the crust in Lake Superior"; they attribute the thickness of the Lake Superior crust to simple isostatic adjustment to a section of high-density crustal rocks.

GENERAL GEOLOGY

In the two areas which form the subject of this report (Fig. 2) the basalts strike north to northwest and dip westwards towards Lake Superior at 15-45 degrees with an outcrop width of about 6 miles across strike. This outcrop forms a tract of ground ribbed by flow cuestas rising to elevations of about 900 feet (270 m) above the lake, and backed to the east by a land surface which rises to 1,600 feet (480 m) above sea level in the peneplaned Superior Province basement rocks; the lower ground near the lake is blanketed by thick glaciolacustrine gravel terraces.

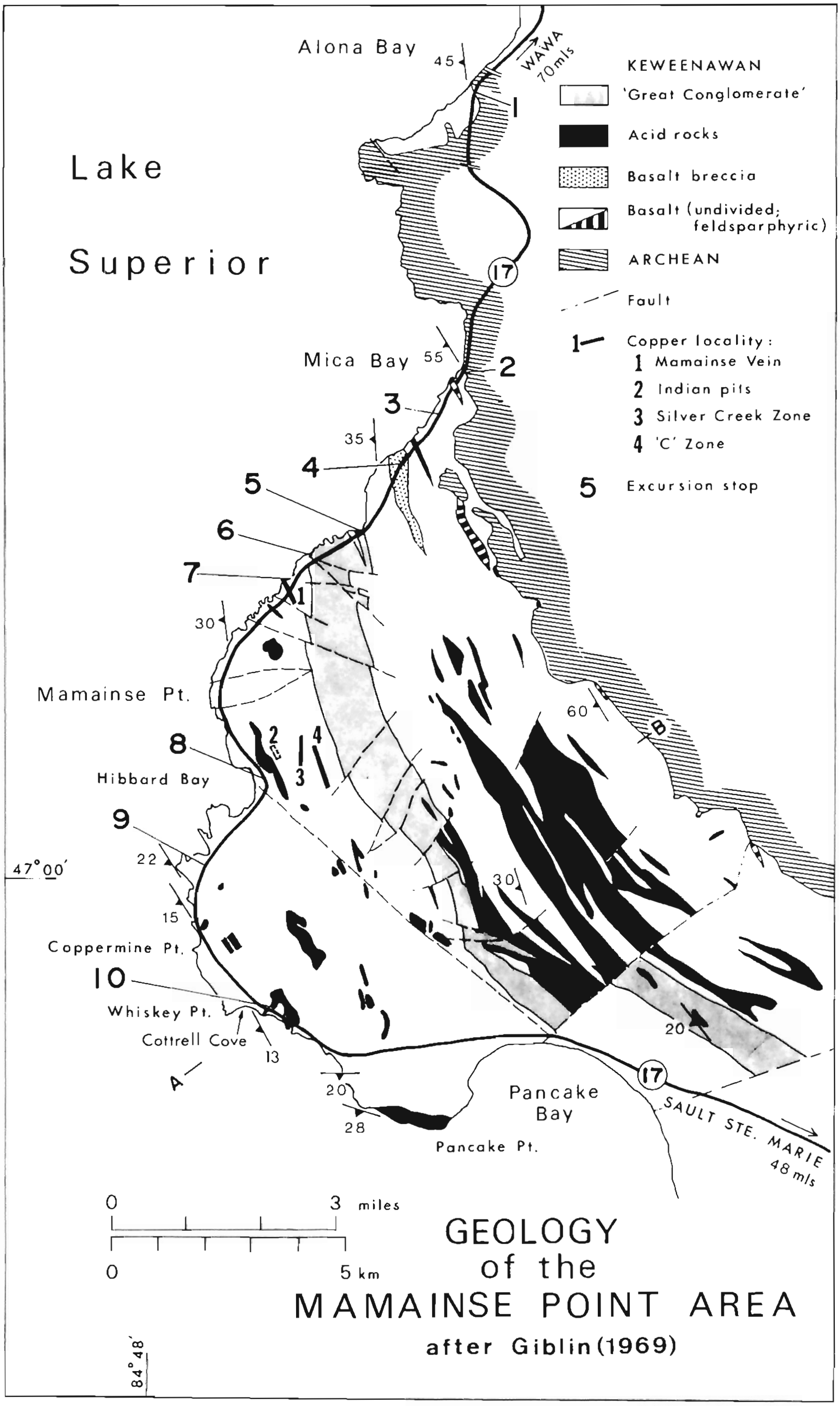

Figure 2. General geology of the Mamainse Point excursion area, showing excursion stops (after Giblin, 1969 a-d).

The lava flows are predominantly basaltic types and no intermediate types have been found; the flows are interlayered with polymictic conglomerate and rare volcaniclastic horizons and are intruded by small acid bodies. Thin basic dykes of Middle or Upper Keweenawan age cut the flows, together with a few small quartz gabbro intrusions.

No large basic intrusive complexes comparable in size to the Keweenawan Duluth Complex of Minnesota are exposed in the Mamainse Point area.

The Mamainse Point and Alona Bay flows are unconformably overlain by conglomerates, arkosic sandstones and shales of Upper Keweenawan or Lower Cambrian age which are well exposed in the northern parts of both outcrop areas; at these points the younger sediments dip to the north-northeast (Giblin, 1969a).

AGE DETERMINATIONS AND PALEOMAGNETISM

A number of K-Ar age determinations have been carried out on whole rocks from the east shore of Lake Superior in the Geochronology laboratory of the Geological Survey of Canada and the range of values obtained is 800-1,055 m.y. (Wanless et al., 1967, 1968). Van Schmus (pers. comm., 1971) carried out a number of Rb-Sr analyses on Keweenawan basic and acid rocks from Mamainse Point and assigned an overall age of 1,070 ± 50 m.y. to them, allowing the possibility that "some, if not all, of them may be as old as 1,100 ± 30 m.y."; his values fall in the same range as the ages reported for other Middle Keweenawan igneous rocks of the Lake Superior region (McGlynn, 1970, p. 109).

DuBois (1962) made the first paleomagnetic study of the Keweenawan volcanic rocks and he suggested that the Mamainse flows could be correlated with the Middle Keweenawan Michigan Portage Lake lavas as both units have similar normal polarity; he showed the Alona Bay flows to have reverse polarity almost coincident with that of the Lower Keweenawan Logan Sills of the Thunder Bay region and on this basis assigned to them a Lower Keweenawan age of about 1,200 m.y.

More recent detailed work in this field by Palmer (1970) showed the Mamainse Point area flows to be mainly of normal polarity but revealed the presence of two thin sequences of reversely magnetized basalt flows in the lower third of the succession; the top of each of these two reversed zones occurs immediately beneath distinctive clastic horizons and Palmer suggested that the two clastic bodies were once coextensive and have since been separated by a strike fault. With this interpretation, he suggested that the original magnetic sequence from the base to the top of the exposed lavas was reverse, normal, instead of the present reverse, normal, reverse, normal. New paleomagnetic studies of the Mamainse Point lavas are in progress.

STRUCTURE

The structure of the Mamainse Point and Alona Bay lavas is simple, but is somewhat complicated in the former outcrop area by the intrusion of acid material at different structural levels within the sequence.

The Alona Bay flows strike north and dip westwards towards Lake Superior at a fairly constant angle of 45-49 degrees. The flows at the east end of the outcrop area can be seen resting unconformably on the Archean basement along Highway 17 (see Appendix I, Stop 1); the contact is irregular and sinuous in plan, indicating that the Keweenawan lavas flowed out on to an irregular land surface (Nuffield, 1955). The Alona Bay outcrop consists of 4,300 feet (1,290 m) of basalt flows and is terminated abruptly to the west by a northwest-trending fault in the Archean which is occupied by a Keweenawan diabase dyke.

The Mamainse Point outcrop area has the form of an arc convex towards Lake Superior, the strike of the flows swinging from north-northwest in the northern part to west-northwest in the southern part; the westward dip of the flows decreases from east to west with increasing height in the lava sequence. Thus the basal flows dip at 55 degrees in Mica Bay, falling to 30 degrees at Mamainse Point itself, and finally to a minimum of 15-20 degrees in the uppermost flows near the Coppermine Point lightstation (see Fig. 2). Near Pancake Point the highest flows dip at 28 degrees; between this point and Whiskey Point the dips and strikes of the lavas are highly variable and irregular due to intrusion of acid bodies into the pile. Some of the flows in this part of the shoreline have been overturned by these disturbances. The gross structure here appears to be a small dome about two miles (3.2 km) across, with a highly eroded and shattered core zone.

Much of this disturbance is probably due to the injection of a considerable number of small acid bodies showing a variety of plug, dyke and sheet forms (see Appendix I, Stop 10). These small acid bodies, which commonly have auto-brecciated margins sometimes seen in contact with agglomeratic material, have been interpreted as small eroded rhyolitic domes by Giblin (1969b); some of them are very similar in structure to small rhyolite plugs associated with Tertiary intrusive-extrusive complexes examined in Iceland by the writer. Acid material also occurs in the Mamainse Point area as thick broadly concordant lensoid bodies interleaved with the basalt flows; these bodies are concentrated at low to median stratigraphic levels in the central part of the Keweenawan outcrop and it is difficult to determine whether they are intrusive or extrusive as their margins are often obscured by thick overburden. The presence of a thin, clearly extrusive acid tuff at a similar stratigraphic level near Mica Bay confirms that some extrusion of acid material took place (see Appendix I, Stop 4); the occurrence of acid clasts in the Upper Division conglomerates also shows that acid bodies were present at the surface (Giblin, 1969a).

Basic intrusions are rare in the Mamainse Point succession and only about fifteen basic dykes were found in the 13 miles (21 km) of shoreline between Mica Bay and Pancake Point. Many of these dykes are steeply inclined, and as individual dykes show widely differing degrees of alteration they are taken to have been intruded more or less consecutively throughout the building of the lava pile (see Appendix I, Stop 3). No direct physical connections between dykes and flows were found, but it seems likely that the dykes fed flows at the surface in the same manner as that described from the Tertiary of Iceland by Walker (1960) and the Columbia River Plateau by Gibson (1969). The Mamainse Point dykes are very thin, being usually less than 10 feet (3 m) thick and most strike in easterly or northerly directions.

The thickness of the Mamainse Point succession has been estimated as 14,300 feet (4,290 m) along the shoreline from the basal flows at Mica Bay to the uppermost flows on which the Coppermine Point lightstation stands. The thickest part of the Mamainse Point section is that lying along the line AB on Figure 2; the thickness here was estimated using the dips given by

Giblin (1969b, c) and gave a value of 19,960 feet (5,988 m). This value does not account for possible repetitions of the sequence by faulting and should be regarded only as a maximum value; this high thickness may also be due to dilation of the basalt pile by acid intrusions.

The basalt flows and associated acid bodies are cut by a large number of small normal faults, most of which trend in northeast or northwest directions oblique to the strike of the lavas. Few of these faults appear to cause any great vertical displacement of the flows; absolute determinations of such displacements are however rendered difficult by the frequent scarcity of good distinguishing features between the lava outcrops on opposite sides of fault planes. Giblin (1969c) has postulated the existence of two orthogonal major faults in the area (see Fig. 2); one of these has northeast trend transverse to the flows and the other has northwest trend parallel to the strike of the flows.

Numerous small fractures of variable trend and zero vertical displacement cut the basalt flows at all levels of the Alona Bay and Mamainse Point sections; these cracks are up to 12 inches (30 cm) wide and are commonly infilled by red-brown silt or sand material similar to that which forms the matrix of the conglomerates interbedded with the flows (see Appendix I, Stop 7). These "clastic dykes" are felt to indicate the occurrence of minor earth movements contemporaneous with the accumulation of the lava pile; similar clastic dykes have been found in the Keweenawan lavas of Cape Gargantua (Ayres, 1969) and Michipicoten Island (Annells, in prep.), and in the Huronian near Espanola and Elliot Lake, Ontario (Collins, 1925; Eisbacher, 1970).

GENERAL FIELD CHARACTERISTICS OF THE ROCKS

The Mamainse Point and Alona Bay Keweenawan volcanic rocks are very similar in appearance and chemistry to lavas from flood basalt provinces elsewhere in space and time. They show a marked chemical bimodalism (see Fig. 4) of the type first noticed by Bunsen (1851) in Iceland, and consist of basalt and rhyolite types; this bimodalism is considered to be real, as no intermediate rocks were found in the area.

The lavas appear to have been extruded subaerially on to flat-lying ground which was susceptible to intermittent subsidence and flooding as is indicated by the presence of intercalated sedimentary horizons; the red colour of these sediments suggests that the flows were erupted in a fairly arid environment (Schwarzbach, 1963) of piedmont-valley flat type (Van Houten, 1961). There is little evidence of submarine extrusion in the Mamainse Point and Alona Bay flows but a fragmental body consisting entirely of poorly sorted and angular fragments of Keweenawan basalt which occurs near the base of the sequence in Mica Bay (see Appendix I, Stop 4 and Fig. 3) appears to have formed under water and passes up into a thin top zone of finely comminuted hyaloclastitic material. This body may have formed when basalt was erupted into a localized body of still water such as a lake. No clear examples of pillow basalts were found in the excursion area. The basal parts of some flows have been converted to breccias of highly vesicular fragments often mixed with some silty material where the flows rest on conglomerate horizons; this feature is probably due to the rapid and explosive volatilization of small pools of water lying on the conglomerate when it was crossed by the advancing flow. Structures of this kind are common in the modern volcanic fields of

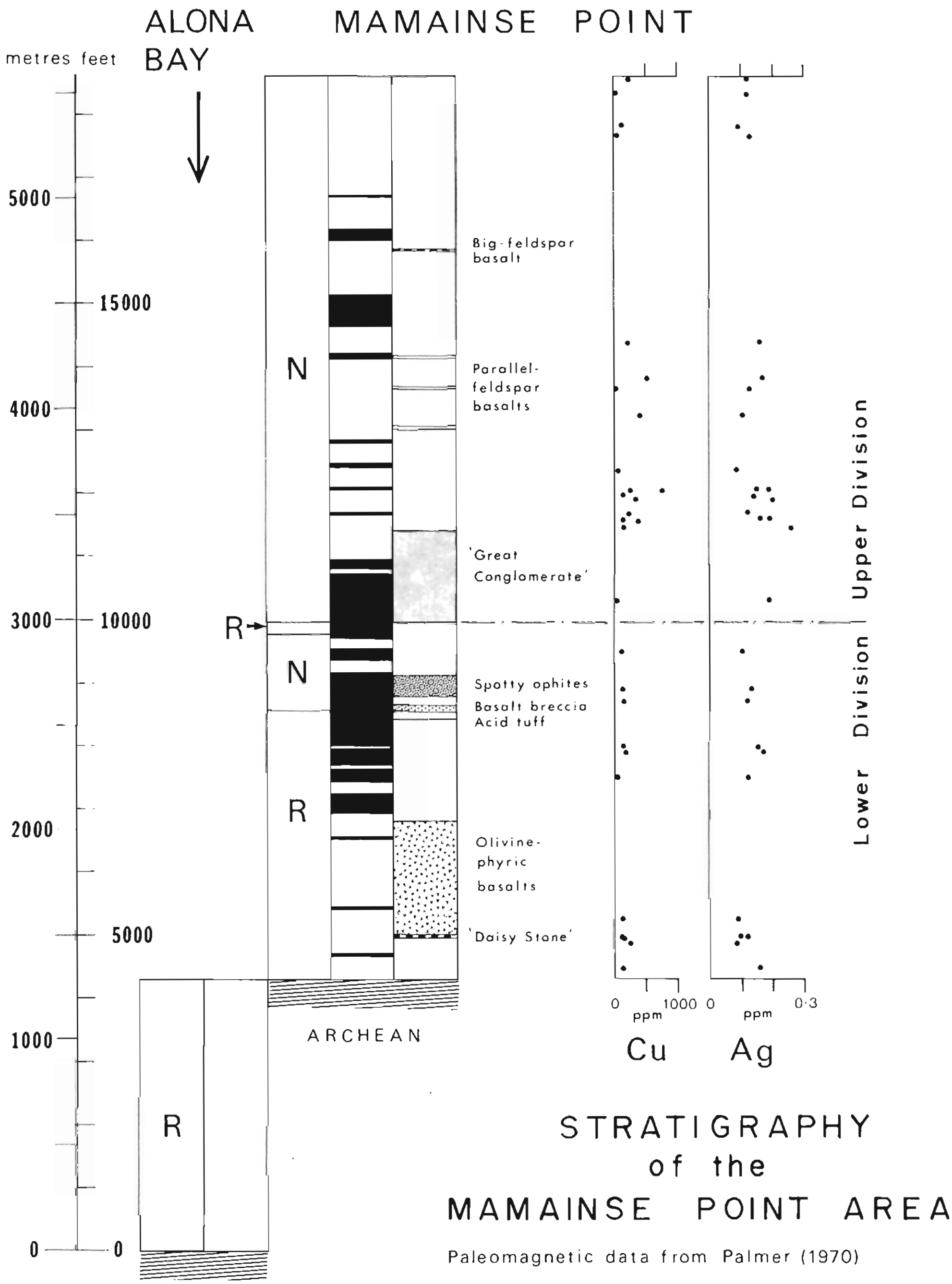

Figure 3. General Keweenawan stratigraphy of the Mamainse Point and Alona Bay sections. Left part of each column shows magnetic polarity of flows (N - normal; R - reverse), (after Palmer, 1970), right part shows lithology (legend as for Fig. 2). Centre of Mamainse Point column shows levels at which acid material (black) occurs.

Iceland where explosions caused by such volatilization of surface water may be violent enough for flows to be perforated by "pseudocraters" surrounded by scoria cones (Thorarinsson, 1953).

Few of the flows are of great thickness and most of them occur in groups up to several hundred feet thick of lithologically similar flows. Flows with strikingly distinctive appearance are rare, so that the lateral extent of individual lavas is difficult to estimate. One remarkable 70-foot (21 m) flow 650 feet (195 m) above the base of the Mamainse Point section (Fig. 3) is crowded with large plagioclase laths concentrated in spherulitic clusters up to 2 inches (5 cm) in diameter (Giblin, 1969a; Pl. 1, this paper); this flow is known as the "Daisy Stone" to local residents (see Appendix I, Stop 2). A flow of exactly similar lithology and thickness also occurs near the base of the thin Cape Gargantua sequence 40 miles (64 km) north of Mica Bay (Ayres, 1969), and both occurrences are associated with a group of olivine-tholeiite flows rich in pseudomorphs after large olivine phenocrysts which may make up to 35 per cent by volume of parts of the Mica Bay flows (see Appendix I, Stop 3) (Annells, 1971). The striking similarity of the flows in the lower levels of the Mamainse Point and Cape Gargantua sequences suggests simultaneous eruption of the same mafic magma supply over a wide area. These are of similar extent to that of the Greenstone Flow of the Michigan Keweenaw Peninsula which has been traced over a strike distance of 55 miles (88 km) (White, 1960). This gives a good idea of the large horizontal extent of the Keweenawan basaltic lava field and shows that such flows are quite comparable in size to flows of classical flood basalt provinces.

Sediments are rare in the Alona Bay section but are abundant in the Mamainse Point sequence, where they make up 24 per cent of the 14,300-foot (4,290 m) shore section (see Appendix I, Stops 5, 7, 9). These are massive polymictic conglomerates commonly forming horizons over 100 feet (30 m) thick, one very thick body near the middle of the section reaching a thickness of 1,800 feet (540 m) (see Appendix I, Stop 5; also Fig. 3). No conglomerates were found in the Alona Bay section. The conglomerates bear well rounded clasts up to 4 feet (1.2 m) in length of Archean rocks such as greenstone, quartzite, granite and gneiss derived from the ancient highlands bordering the Keweenawan trough, together with clasts of Keweenawan basalt and rhyolite; these sediments are fanglomerates deposited by short-lived streams flowing towards the centre of the trough and do not appear to have caused much erosion of the flows on which they now rest. The conglomerates have a red-brown sand to silt matrix which is sometimes concentrated in thin well-stratified layers that often show crossbedding possibly, but not necessarily, indicative of the temporary development of deltaic depositional environments. Most of the conglomerates occur in the upper half of the Mamainse Point succession, where their great abundance evidences frequent subsidence of the lava pile.

Basic Volcanics

Over 300 basalt flows were counted in the shore section at Mamainse Point. These show great variation in thickness, and most are in the range 5-30 feet (1.5-9.0 m) (Giblin, 1969b); flows of 100 feet (30 m) are however fairly common. Many of the coarser grained flows consist of several thin "flow units" of identical lithology, some of which may be as thin as

6 inches (15 cm) (see Appendix I, Stop 2). These thin units have lower zones bearing vesicles and upper vesicular zones topped by ropy pahoehoe surfaces; they are taken to represent separate but closely successive pulses of the same erupted material and are exactly similar in form to the thin flow units described from basalt flows by Nicholls (1936). Most of the basalt lavas were very fluid as is indicated by the many well-preserved wrinkled and ropy pahoehoe tops to be seen in the sections along the shoreline and Highway 17 (see Appendix I, Stops 1, 2, 3, and Pl. 2). A few flows of rather finer grain were found to have clinkery scoriaceous tops often bearing red-brown dusty material; most of these finer flows have better-developed prismatic jointing than the coarser flows. Basal pipe vesicle zones are common in both fine and coarse grained flows and the vesicles may be bent over in the direction of movement of flows. Some of the thin coarse-grained flows have small tumuli or pressure ridges (schollendomes) up to about 15 feet (4.5 m) wide; these are seen in section in wave-cut platforms as highly vesicular plates of solidified crust outlining small V-sectioned humps in flow tops.

Pahoehoe structures and flow units are not common in the fine-grained, less olivine-rich flows but these flows show prismatic jointing and clinkery scoriaceous tops and many of them contain large vesicles up to 2 feet (60 cm) across scattered throughout. Such features reflect the higher viscosity and more silicic nature of the olivine-poor flows. The tops of both fine and coarse grained flow types commonly bear stratiform infillings of red silty material.

The basalt flows show little variation in lithology or chemistry but several textural variants exist and this assists stratigraphic mapping of the lavas. The flows are olivine tholeiite types and can be broadly divided into coarse grained and fine grained types, the former being the richer in olivine.

The coarse grained basalts make up 81 per cent of the total thickness of basalt flows at Mamainse Point and 89 per cent at Alona Bay; they can be subdivided into ophitic and diabasic types, the textures of these rocks being dependent on the relative sizes of the plagioclase and pyroxene crystals in them. In the ophitic types (see Appendix I, Stop 8) small feldspar laths (up to 1 mm) and granular olivines are enclosed in poikilophitic intergrowth by large spheroidal augite grains commonly up to 5 mm across and sometimes as large as 2 cm. Small olivine grains occur in the zones between contiguous augite crystals and are seen in association with interstitial opaque grains moulded on to the first three minerals. These ophitic rocks, or "ophites", have a characteristic lustrous mottled appearance on smoothed surfaces. In the diabasic types, the augite and plagioclase crystals are of the same order of size (2-4 mm) and form a largely intergranular, gabbroic-textured fabric in which the pyroxenes are partly moulded on to the plagioclases. Both types of coarse grained basalt flows may contain thin streaks or schlieren of coarse basaltic pegmatite with plagioclase and pyroxene crystals up to 3 cm long.

The fine grained types make up 19 per cent of the total thickness of basalt flows at Mamainse Point and 11 per cent at Alona Bay; they have the uniform intersertal texture typical of many other tholeiitic basalts but the fine grained mesostasis material is neither fresh nor abundant. Feldspars in these rocks are up to 1 mm in length. By analogy with the glassy interstitial material common in Mesozoic and Cenozoic tholeiites this mesostasis material probably represents originally glassy material. The altered material is sometimes concentrated into thin streaks parallel to the base of some of the Mamainse Point and Alona Bay olivine-poor tholeiites (see Appendix I, Stop 5) in the same manner as has been described for the Keweenawan olivine-free tholeiite flows of Michipicoten Island (Annells, in prep.).

All of these Mamainse Point and Alona Bay basalt flow types may bear phenocrysts of plagioclase and olivine, but these are rarely present in the spectacular concentrations seen in the "Daisy Stone" flow and its associated olivine-rich flows, some of which can be assigned picrite-basalt compositions using the chemical classification system of Irvine and Baragar (1971); these olivine-rich flows were followed along strike for about 5 miles (8 km). One flow high in the Mamainse Point shore section just west of Hibbard Bay bears a 4-foot zone rich in large euhedral plagioclase tablets up to 10 cm in length; outcrops are too poor however to trace this feldsparphyric material far inland.

Acid Volcanics

Giblin (1969c) reported great variation in texture between the different acid bodies of the Mamainse Point area and the three main types found are quartz porphyry, felsite and flow-banded rhyolite; these rocks are surprisingly abundant and appear to be too salic to be straight-forward differentiates of a basaltic magma. The rocks are orange, pink, purplish red or pale grey in colour and all except the quartz porphyries are poor in phenocrysts. The compositions of the acid volcanics fall in the quartz latite range and they are thus similar in composition to the Keweenawan acid volcanics of the Minnesota North Shore Group described by Green (1971). The acid rocks are fine grained, with a tough, compact, flinty or rough, granular texture and many of the small intrusive bodies show well-developed flow lamination at their margins which causes development of a platy fracture (see Appendix I, Stop 10); the interior parts of these intrusions have an irregular blocky or splintery joint pattern. Some of the small acid intrusions exposed on the shore near Cottrell Cove have auto-brecciated margins and interiors of flow-laminated rhyolite, the laminae of which are often contorted.

The thickest, stratiform acid bodies are of pale grey to pink, fine-grained, compact rhyolite with some flow banding and scattered feldspar phenocrysts; rocks of this type are well exposed in the shore section at Pancake Point and in the bush road running east of Pancake River. The Pancake Point rock shows spectacular flow lamination which is often seen to be complexly overfolded and contorted.

The quartz porphyries commonly occur as small plugs or thin intrusive sheets and are crowded with phenocrysts (up to 8 mm) of paramorphed β - quartz and altered euhedral feldspars; smaller phenocrysts of opaques and rare pseudomorphs after ferromagnesian minerals also occur in this type. A good example of a thin quartz porphyry sheet concordant with the basalt flows outcrops in the Highway 17 road-cut near the base of the Mamainse Point section.

Evidence of the simultaneous mobility of basic and acid material is seen in a composite inclined sheet cutting basalt lava flows near the middle of the Mamainse Point sequence (Fig. 2); this intrusive sheet dips northwest at 45-50 degrees (see Appendix I, Stop 6). The sheet has a 2-foot (60 cm) basal selvage of fine-grained, olivine-free, tholeiitic basalt chilled against the host basalt flows and an upper 50-foot (15 m) part of grey-white to pink compact flinty rhyolite with scattered feldspar microphenocrysts. The upper contact of this sheet is either submerged in the lake or obscured by beach debris. Small rounded inclusions of the basal selvage basalt have been incorporated into the rhyolite near the basic-acid interface and these are seen in thin section to be in the state of loose mush clusters, indicating that the rhyolite material was injected before complete consolidation of the basic lining to the fissure now occupied by the intrusion. Little mechanical mixing between the rhyolite and basalt was seen and the rhyolite has developed flow lamination parallel to the interface, implying that the two melts remained immiscible. Chemical analyses of the basalt selvage and upper rhyolite of this intrusion follow:

Chemical analyses of material from a composite intrusive sheet in the Mamainse Point Keweenawan succession (analyses recalculated water-free to 100 per cent)

	Basalt of lower selvage	Rhyolite of main part
SiO_2	51.14	78.70
TiO_2	2.53	0.09
Al_2O_3	14.86	12.57
Fe_2O_3	5.27	0.84
FeO	7.86	0.10
MnO	0.29	0.05
MgO	7.32	0.52
CaO	6.89	1.57
Na_2O	3.44	0.42
K_2O	0.11	5.13
P_2O_5	0.29	0.01
Total =	100.00	100.00

(Analyses carried out by Analytical Chemistry Section, Geological Survey of Canada, using X-ray fluoresence and rapid chemical methods)

STRATIGRAPHY

Mamainse Point Formation

The name "Mamainse Point Formation" is proposed for the thick succession of flood basalt lavas with conglomerate and sandstone intercalations which forms the lowest part of the Keweenawan volcanic pile at the eastern end of Lake Superior. The type section forms the shore between Mica Bay and Pancake Point in Kincaid Township and the Mamainse Point area (see Fig. 2, and Giblin 1969a, b), and the formation is named for the promontory near the top of the type section. The base of the formation outcrops at Alona Bay and its probable upward continuation occurs along the shore between Mica Bay and Pancake Point, and at Cape Gargantua. At each of these three type areas the basal flows rest on a surface eroded in Archean Superior Province rocks. The topmost flows of the formation outcrop in a fourth type area along the north shore of Michipicoten Island, where they form the

Quebec Mine Member (Annells, in press) and the whole formation has a thickness of about 21,000 feet (6,800 m). The four type areas would lie in an arcuate band which strikes about east-west at Michipicoten Island and swings round to a north-south strike at Alona Bay and Mamainse Point.

Although the four type areas are widely scattered, the low stratigraphic level and striking lithologic similarity of the lavas in each area suggest strongly that the flows are part of the same widespread flood basalt episode; they are thus interpreted as a rock-stratigraphic unit.

Stratigraphic subdivision of the Mamainse Point and Alona Bay sections is difficult as the flows show rapid alternation of the fine grained and coarse grained types, and suitably distinctive and laterally persistent marker horizons are rare. The succession is also complicated by faults and acid bodies in the Mamainse Point succession. These acid bodies have been omitted from the compiled lava section of Figure 3 as it is uncertain whether they are intrusions or extrusions; the presence of acid material in any volume at a given stratigraphic level is however indicated in Figure 3 in a separate column which represents a generalized profile along the line AB in Figure 2. This column shows the bulk of the acid material to be concentrated in the lower half of the Mamainse Point section.

The Alona Bay section may be at a lower stratigraphic level than the Mamainse Point section, as its flows have reversed magnetic polarity which DuBois (1962) showed to be almost coincident with that of the Lower Keweenawan Logan sills. No "Daisy Stone" horizon was found at Alona Bay and the flows are mainly thin pahoehoe types (see Appendix I, Stop 1) with occasional thin red sandy intercalations and clastic dykes.

The Mamainse Point sequence can be divided informally into two parts (Fig. 3) each of which consists mostly of coarser grained basalt flows with subordinate finer grained flows; the Lower Division bears no conglomerates except for a thin basal unit in Mica Bay, and the Upper Division begins with the thickest conglomerate unit in the entire section. The Lower Division comprises the lower reverse-normal-reverse part of the paleomagnetic sequence of Palmer (1970), whereas the Upper Division coincides with his uppermost normal zone.

Lower Division (5,700 feet; 1,710 m)

Near the base of this division is a 1,550-foot (465 m) group of basalt flows rich in large olivine phenocrysts; at the base of this group is the distinctive "Daisy Stone" feldsparphyric flow (Pl. 1). A thin acid tuff interbedded with thin pahoehoe flows occurs halfway between this olivine-rich group and the top of the Lower Division (see Appendix I, Stop 4); this would have been deposited at about the middle of the phase of acid activity indicated in the central column of Figure 2. This tuff is closely followed by a distinctive group of ophitic basalt flows with remarkably regular spherical pyroxene-plagioclase intergrowths up to 5 mm in diameter and of very uniform distribution which weather out as pale grey spots.

Upper Division (8,600 feet; 2,580 m)

This division begins with the 1,400-foot (420-m)-thick "Great Conglomerate" which bears abundant clasts of Archean rocks; some thin basalt flows are intercalated with this conglomerate (see Appendix I, Stop 5).

The conglomerate marks a period in which considerable subsidence occurred; this subsidence may have been caused by local collapse of the lava pile after the "drawing-off" from depth of large volumes of acid magma in the vicinity of a central volcanic structure.

Distinctive flows are rare in this upper part of the succession. Three fine grained intersertal basalt flows each 30-60 feet (9-18 m) thick occurring over a vertical range of 120 feet (36 m) are crowded with elongated feldspar microphenocrysts up to 3 mm in length which are conspicuously oriented parallel with the basalt contact. Faulting occurs in the succession at this point and it is possible that some repetition of this parallel-feldspar material has taken place. Between these flows and the top of the sequence is the big-feldspar basalt flow already referred to which bears a zone of large tabular plagioclase phenocrysts up to 10 cm in length.

METAMORPHISM AND MINERALIZATION OF THE KEWEENAWAN VOLCANIC ROCKS

The rocks of the Mamainse Point and Alona Bay section have undergone low-grade hydrothermal and depth of burial metamorphism which has affected all the primary minerals to varying degrees in most of the basalt flows and has precipitated secondary minerals in vesicles and along small fractures and fragmental flow tops. Some of this alteration appears to have been deuteric.

Studies of the secondary minerals are still in progress, so that it is not yet known whether a clear depth zonation of secondary minerals comparable to that described by Walker (1960) from the Tertiary flood basalt pile of Iceland exists in the Keweenawan of the excursion area. No rocks in the area were found to have empty vesicles.

Olivine appears to have been the first primary mineral to have been affected by the metamorphism as it is invariably pseudomorphed by saponite and hematite even in basalts bearing fresh plagioclase and augite; no fresh olivines were found in the Mamainse Point or Alona Bay basalt flows. The plagioclases are often partly or wholly zeolitized and sometimes show saussuritization to patches of albite and epidote. The augites in many rocks are partly altered to a near-colourless clinoamphibole and greenish chloritic material and the calcium-poor pyroxenes commonly show some alteration to carbonate; the considerable degree of alteration of pyroxene found in the basalts is surprising, as pyroxenes are usually very resistant to deuteric alteration (Wilshire, 1959). Opaque minerals in the flows are commonly oxidized to hematite, and titanium-rich types show many stages of alteration to leucoxene and sphene.

Quartz is a common secondary mineral in cavities within the acid rocks and the alkali feldspar crystals in some of the rhyolites are kaolinized, as in a small intrusion exposed about one-quarter mile (396 m) northwards along the old Highway 17 from Coppermine Point.

The vesicles of the basalt flows bear amygdales of a wide variety of secondary minerals comparable to those found in other occurrences of Keweenawan basalts (Stoiber and Davidson, 1959; Green, 1971). In the most common type, the vesicle is lined by a thin veneer of dark green chlorite followed by a thin zone of colourless to grey chalcedony which may show some agate banding; the main part of the cavity is filled by colourless quartz and zeolites with some yellow epidote and colourless prehnite and the core is occupied by colourless calcite. These amygdale minerals also occur in narrow fracture-filling veins and some of the calcites were found to be pink and fluorescent (Sabina, 1963); common zeolites in the basalts are stilbite, heulandite and laumontite (Sabina, op. cit.).

Epidote is common throughout the entire section, but appears to be particularly abundant in the Lower Division flows, where it often forms a coating on joint planes. Rare small crystals of specular hematite occur in some of the quartz-carbonate veins near the base of the Lower Division (see Appendix I, Stop 2), and agate appears to be best developed in the finer grained Upper Division basalt flows occurring between the thick basal conglomerate and the parallel-feldspar flows (see Fig. 3). Thin vertical veins of blood-red jasper cut some of the coarser grained flows at this level of the Upper Division; the quartz-carbonate veins and amygdales of these flows and their associated basaltic pegmatite veins also bear fan-shaped radial aggregates of bright turquoise-blue pumpellyite which occurs in association with lustrous bornite or native copper. Specks of native copper are common in vesicles and flow tops of the Upper Division basalts; a 147-pound (66.7 kg) piece of almost pure native copper was found in Upper Division rocks at mile 55 from Sault Ste Marie during the construction of Highway 17 in 1936 (Thomson, 1953). The northwest-trending Mamainse Vein, site of the old Mamainse Mine, cuts these copper-bearing Upper Division basalt flows near mile 62 on Highway 17; this vein bears a little native copper in cross fractures in the vein material, together with some finely disseminated chalcocite (see Appendix I, Stop 7).

Chalcocite and chalcopyrite with some bornite occur in fissure-filling veins of north-northeasterly trend in the "C" zone east of Hibbard Bay, and these deposits are presently being worked by Sheridan Geophysics (North Canadian Enterprises) (Giblin, 1969c); one of these veins was found to bear euhedral fluorite crystals up to 5 mm in diameter. A small intrusion of Keweenawan quartz porphyry which cuts Archean metavolcanics about 8 miles (13 km) east of Mamainse Point bears disseminated chalcopyrite, pyrite and rare chalcocite and is cut by narrow quartz veins carrying molybdenite, pyrite and chalcopyrite (Giblin, 1969c).

KEWEENAWAN GEOLOGICAL HISTORY OF THE LAKE SUPERIOR REGION

The Keweenawan flows of the Lake Superior basin (see Fig. 1) occur within the Southern Structural Province of the Canadian Shield (Stockwell, 1970, p. 47) and in places rest unconformably on the Archean rocks of the Superior Structural Province; this unconformity spans a gap of about 1.5 b.y. in the geological record.

During the Archean, the Superior Province volcanic and sedimentary rocks formed in a number of easterly-trending geosynclines; these rocks were folded, faulted, and metamorphosed by granite intrusions with a mean age of 2.5 b.y. during the Kenoran orogeny (McGlynn, 1970, p. 54). A period of erosion followed this orogeny and in the early Proterozoic an east-west trending geosyncline of Aphebian age developed to overlap at least the western half of the present site of Lake Superior. Siliceous sediments and iron-formations of the Animikie Group (1.6-2.1 b.y., Halls, 1966) were deposited in this geosyncline, and the succession thins northwestwards from

Minnesota into northern Ontario; there is no record of it on the eastern shore of Lake Superior.

The Penokean orogeny (1.7-1.9 b.y.) caused folding and mild metamorphism of the Minnesota Animikie sediments, while those in Ontario were only gently deformed (McGlynn, 1970, p. 108-109).

The earliest Lower Keweenawan rocks known in the Lake Superior region are the Sibley Formation of northern Ontario, the Puckwunge Formation of Minnesota and the Bessemer Formation of Michigan and Wisconsin; these formations rest unconformably on Animikie rocks. Well-sorted quartz sandstones predominate in all of these three thin units, and the Sibley Formation contains some horizons of carbonate, shale, marl, and a distinctive brick-red earthy material which was interpreted as a tuffaceous rock by Tanton (1931); the Puckwunge and Bessemer Formations have been interpreted as shallow-water sediments derived from pre-Keweenawan rocks and deposited during the transgression of a sea into the Lake Superior region (Mattis, 1971).

DuBois (1962) suggested that the earliest igneous event of the Lower Keweenawan was the intrusion of concordant Logan diabase sills (1.4 b.y.) into the Sibley sediments of the Thunder Bay – Nipigon region on the north side of Lake Superior; he interpreted a swarm of east-west diabase dykes cutting Archean and Animikie rocks of northern Michigan as being of similar age to these sills (op. cit., 1962, p. 65). The presence of inclined sheets of Logan diabase in the Sibley and Animikie rocks of the Thunder Bay – Nipigon area indicates some regional warping during this stage (McGlynn, 1970, p. 118) which probably marks the birth of the Lake Superior basin structure. Basalt flows were extruded onto eroded Archean rocks at Alona Bay during this part of the Lower Keweenawan (DuBois, 1962) and flows of basic, intermediate and acid compositions were erupted at this time in western Michigan (White et al., 1971) and in Minnesota (Green, 1971). The Michigan Lower Keweenawan flows are succeeded by unconformable Middle Keweenawan Portage Lake series basalt flows, indicating that sagging of the dense lava pile had already begun. Quiet non-explosive basaltic volcanism predominated during the Middle Keweenawan and thick floods of fluid olivine tholeiite spread over a wide, largely flat and arid region; successions representing this phase of activity occur at Mamainse Point, Cape Gargantua, Thunder Bay (the Osler Formation), in Minnesota (North Shore Group) and the Keweenaw Peninsula of Michigan (Portage Lake lava series). Detailed work by White et al. (1971, p. 71) has shown that the Middle Keweenawan lavas of westernmost Michigan "accumulated in separate tectonic basins rather than in a single large one". White (1966) has estimated that the volume of lava in individual flows is about one hundred times greater than that in flows from modern Hawaiian shield volcanoes.

The flows appear to have spread outwards towards the trough margins from a fissure-rift system whose main vents were "certainly bordering and possibly underlying the present area of the lake" (Van Hise and Leith, 1911, p. 411). Progressive sagging of the growing lava pile caused it to thicken towards the centre of the basin, and allowed the formation of local basins which became filled with conglomerate and sandstone deposited by streams flowing from the rim of the Lake Superior trough to its centre (Halls, 1966). Acid eruptions occurred at intervals throughout the entire span of Middle Keweenawan basalt effusion; some of this acid material was erupted as flows or tuffs interfingering with the basic flows, while part congealed as plugs and sills of fine-grained rhyolite and felsite. The local abundance of this acid material and the relative scarcity of rocks of intermediate composition may indicate that it formed by remelting of pre-existing sialic crustal rocks.

Intermediate flows were extruded at some levels of the Keweenawan lava pile as at Isle Royale (Huber, 1971), and some of these lavas can be related to localized eruptive centres characterized by abundant acid intrusions and coarse volcaniclastic rocks; associations of this type occur in Middle Keweenawan sequences at Michipicoten Island (Annells, in prep.) and near the Porcupine Mountains of Michigan (White et al., 1971). It seems unlikely that such centres were concentrated at any given stratigraphic level as there appears to be no overall cyclic pattern to the Keweenawan volcanism; it seems more likely that rocks of intermediate and acid compositions were erupted at irregular intervals by the "accidental" development of local eruptive centres of the type found interdigitated with flood basalts in the Tertiary lava pile of Iceland (Walker, 1964).

Van Hise and Leith (1911) estimated from geological evidence that a total thickness of 60,000 feet (18,000 m) of lava flows accumulated in the Lake Superior basin during the Keweenawan volcanism; more recent seismic work has suggested a possible maximum of 50,000 feet (15,000 m) of flows (W.S. White, in Smith et al., 1966).

Sill-like gabbro complexes of age 1.1 b.y. (Goldich et al., 1961) were intruded into the middle Keweenawan volcanic rocks at Duluth (Minnesota) and Mellen (Wisconsin); the Coldwell syenite complex on the Ontario shore of Lake Superior is of broadly similar age (Chaudhuri et al., 1971) and intrudes the older Superior Province rocks. Phinney (1970) has suggested that the Duluth complex represents crystalline material left in the magma chambers from which the Minnesota North Shore Group Keweenawan flows proceeded.

Downwarping of the Lake Superior basin continued during Upper Keweenawan time, when there was a sharp decline in extrusive activity, the youngest flows being the Upper Keweenawan Lake Shore Traps of the Keweenaw Peninsula (Halls, 1966). Other younger flows may exist on the lake floor and it is possible that the uppermost andesitic flows of Michipicoten Island are of Upper Keweenawan age (Annells, in prep.). The Lake Shore Traps interfinger with the thick Copper Harbour conglomerate, the last coarse clastic body to be deposited in Keweenawan time. The basin was next gradually flooded by shallow water and deposition of arkosic sandstones ensued over much of its area between the end of Middle Keweenawan time and Upper Cambrian time; the Freda Formation is the youngest Upper Keweenawan unit and consists of alternating layers of arkosic sandstone and silty shale (Hamblin, 1961). The Mamainse Point and Alona Bay lava flows were tilted and eroded before deposition of the Freda, the base of which is a thin pebble conglomerate bearing fragments of Keweenawan basalt similar to the flows on which it rests with considerable angular unconformity.

The red Jacobsville-Bayfield sandstone formation succeeds the Freda Formation; the relations between these two sedimentary formations are uncertain as their contacts are poorly exposed and it is not known whether they were originally continuous or separated by an unconformity. Recent seismic refraction work suggests that these two sandstone formations underlie most of Lake Superior (Halls and West, 1971a); their combined thickness reaches a maximum of 23,000 feet (6,900 m) in central Wisconsin (Halls, 1966).

The Jacobsville sandstone is cut by easterly trending faults of late Keweenawan age that lie along the north sides of Isle Royale and Michipicoten Island. Their north sides are downthrown 1-2 km and the Isle Royale fault, at least, is of reverse type (Halls and West, 1971a, b). Middle Keweenawan flows have been thrust southwards over the Jacobsville

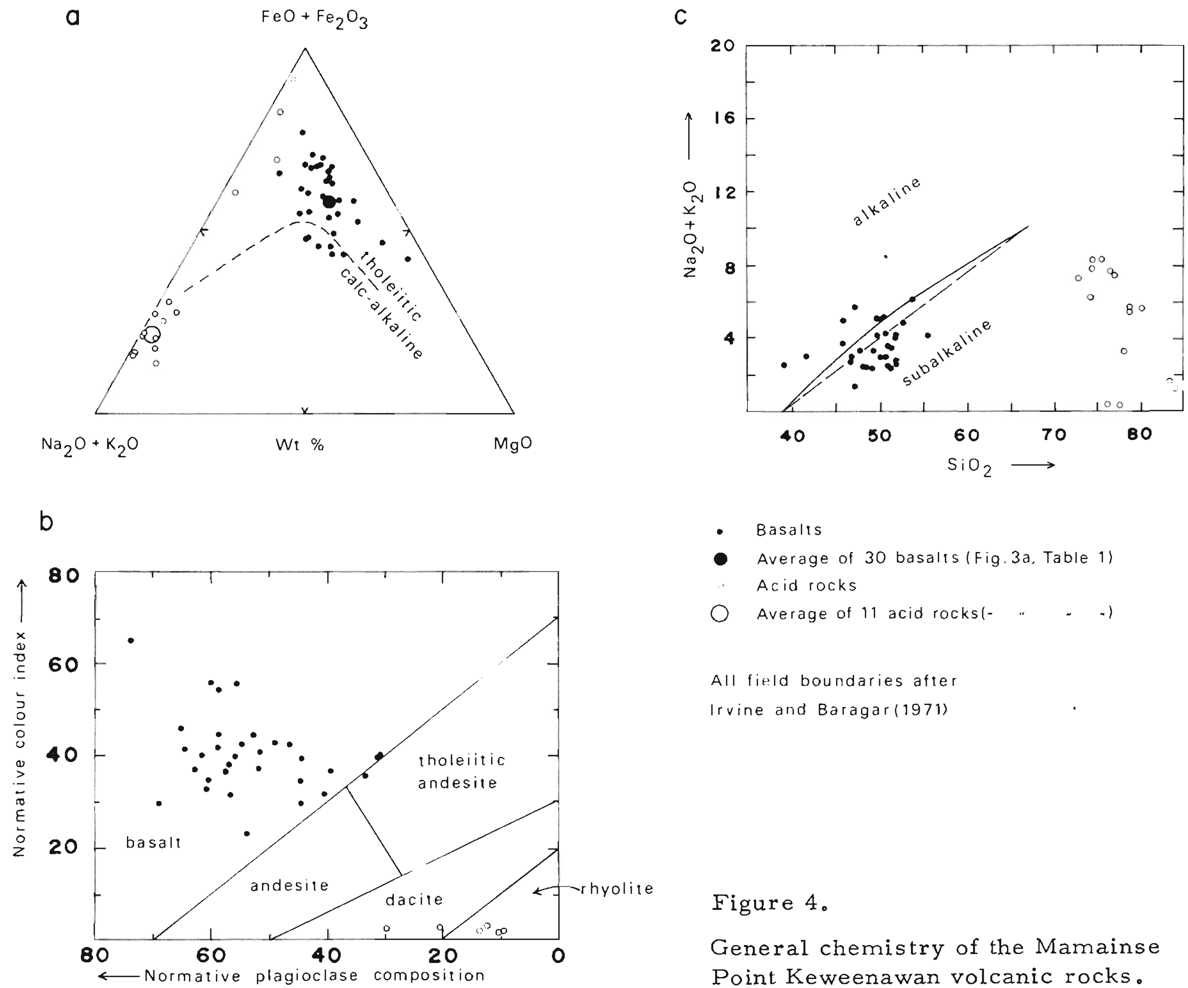

Figure 4.

General chemistry of the Mamainse Point Keweenawan volcanic rocks.

sandstone along the northeast-trending Keweenaw reverse fault in Michigan; this fault dips northwards at 20-70 degrees (White, 1966, p. 37) and the southern boundary of the Keweenawan volcanic field lay some distance south of it.

CHEMISTRY OF THE MAMAINSE POINT AREA VOLCANIC ROCKS

Major Elements

The results of 47 new analyses[1] of these rocks are plotted in Figure 4. A simple MFA plot of all Mamainse Point rocks (Fig. 4a) shows their marked chemical bimodalism. The basalts plot mostly in the tholeiite field, showing a broad trend of high iron-enrichment developing from the Lower Division olivine-phyric flows which plot nearest to the M apex; most of the acid rocks plot near to the A apex, but those plotting near the F apex are altered types fairly rich in iron which have lost alkalis due to leaching during hydrothermal alteration.

Figure 4b is a plot of normative colour index[2] against normative plagioclase composition of the type devised by Irvine and Baragar (1971). The flows plot within a basalt field similar to that of the Mid-Atlantic Ridge and Thingmuli (Iceland) tholeiites. Only the fresher acid rocks are plotted on this diagram, and these fall within the dacite-rhyolite fields.

In the total alkalis/silica plot of Figure 4c most of the basalts cluster in a low-alkali field similar to that given by tholeiites from the Mid-Atlantic Ridge, Iceland, Columbia River, Yellowknife and Noranda (Irvine and Baragar, op. cit.); the low alkali content of the altered acid rocks is particularly noticeable in this diagram.

The mean alumina content of the Mamainse Point area basalts lies in the range 14-17 per cent weight; Irvine and Baragar (op. cit.) suggest that the alumina content of tholeiites lies in the range 12-16 per cent and that of high-alumina calc-alkaline types in the range 16-20 per cent. The balance of chemical evidence shows the Mamainse Point Keweenawan basalts to be tholeiites tending towards high-alumina compositions. Average analyses of the Mamainse Point area basalts and acid rocks are given in Table 1 and are plotted on the MFA diagram (Fig. 4a) as large circles; analyses of comparable volcanic rock types from other areas are also given in this table.

Minor Elements

The concentrations of copper and silver[3] in basalts at different levels of the Mamainse Point section are plotted in Figure 3, and average values and

[1] Rapid analyses carried out by Analytical Chemistry Section, Geological Survey of Canada, using X-ray fluorescence and rapid chemical methods.

[2] Normative colour index = Ol + Opx + Cpx + Mt + Il + Hm; Normative plagioclase composition = 100 An/(An + Ab); Norms used are cation norms, otherwise known as "molecular norms" or "Barth-Niggli katanorms".

[3] Spectrochemical analyses by Analytical Chemistry Section, Geological Survey of Canada. Values accurate to within ±15 per cent (copper) and ± 30 per cent (silver).

Table 1

AVERAGE CHEMICAL COMPOSITIONS OF MAMAINSE POINT AREA AND OTHER VOLCANIC ROCKS

(All analyses recalculated to 100 per cent water- and CO_2-free)

	No. of analyses	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5
Average Mamainse Point basalt[1]	30	49.11	2.31	14.84	7.35	6.36	0.23	6.40	9.54	2.67	0.92	0.27
Average Greenstone flow basalt[2] (Keweenawan, Michigan)		49.00	1.58	17.39	3.19	8.18	0.18	6.88	10.21	2.70	0.50	0.19
Average Kearsarge flow basalt[2] (Keweenawan, Michigan)		50.12	1.52	16.86	4.88	6.30	0.16	6.64	9.99	2.77	0.57	0.19
Average Coppermine River basalt[3] (Proterozoic, Northwest Territories)	163	50.84	2.27	13.63	5.53	7.99	0.21	6.88	7.90	2.98	1.54	0.23
Average Yakima flow basalt[4] (Tertiary, Columbia River Plateau)		54.55	2.03	14.10	2.64	9.33	0.20	4.16	8.02	3.04	1.52	0.41
Average late Yakima and Ellensburg[4] basalt (Columbia River Plateau)	4	50.5	3.23	13.63	1.92	12.62	0.25	4.44	8.38	2.93	1.40	0.70
Average Picture Gorge basalt[4] (Columbia River Plateau)	16	50.14	1.63	15.86	3.56	7.94	0.20	6.61	10.50	2.75	0.51	0.30
Average Deccan Trap[5] (Cretaceous-Eocene, India)	10	50.56	2.78	12.79	3.23	11.28	0.22	5.40	10.29	2.55	0.59	0.31
Average Thingmuli basalt[6] (Tertiary, Iceland)	10	49.64	2.90	13.35	4.73	9.78	0.25	5.57	9.89	2.90	0.50	0.49
Average continental tholeiite*	946	51.95	1.21	16.44	2.82	7.97	0.17	5.95	9.88	2.52	0.87	0.21
Mamainse Point acid rocks[1]	11	76.37	0.14	13.12	1.37	0.51	0.04	0.25	1.50	1.31	5.38	0.01
Icelandic acid rocks[7]	52	73.5	0.31	13.3	1.44	1.81	0.08	0.33	1.64	4.46	3.03	0.11
Calc-alkaline rhyolite and[8] rhyolite-obsidian	22	74.2	0.22	13.6	1.26	0.76	0.03	0.32	1.14	3.02	5.40	0.07

[1] New analyses. Average for acid rocks calculated from 11 freshest samples.

[2] Broderick, 1935, p. 513. Each analysis represents a composite sample of an entire flow.

[3] Baragar, 1969, Table V, p. 33.

[4] Waters, 1961, p. 592-594. Figure for Yakima flow is average of 3 analyses of composite samples representing 60 flows.

[5] Sukheswala and Poldervaart, 1958, p. 1487.

[6] Average calculated from analyses 1-10, Carmichael, 1964, Table 9, p. 454.

[7] Average of 52 analyses of Icelandic acid rocks, Walker, 1966, p. 398.

[8] Average of 22 analyses of calc-alkaline rhyolite and rhyolite-obsidian, Nockolds, 1954, p. 1012.

* Average of 946 analyses of continental tholeiites, Manson, 1968.

ranges for basalts, acid rocks and basic dykes are shown in Table 2. The average copper content of the basalts is 200 ppm and that of silver 0.13 ppm; these concentrations rise to maximum values of 760 ppm and 0.26 ppm in the lowest 3,800 feet (1,140 m) of the Upper Division flows (see Appendix I, Stop 7). As already mentioned, the basalts in this zone bear numerous veins and amygdales containing copper minerals, and the main economic copper deposits of the area have been found at this level. The increase in copper and silver concentrations towards the top of the Mamainse Point section is a similar distribution pattern to that found in the Coppermine River basalts by Baragar (1969). The Coppermine River flows however are poorer in copper and silver than the Mamainse Point rocks, the respective values for average Coppermine basalt being 126 ppm and 0.109 ppm (Baragar, op. cit., Table IIIb, p. 31). The average copper content of the Mamainse Point flows is high compared to the average of 127 ppm (range 8-300 ppm) obtained for 107 tholeiites by Prinz (1967, p. 278).

The Mamainse Point area acid rocks contain less copper (average 77 ppm) and more silver (average 0.16 ppm) than the basalts; the highest copper values were found in a rhyolite dyke cutting Lower Division basalts (860 ppm copper and 0.41 ppm silver) and the highest silver values were found in the rhyolite on Pancake Point (14 ppm copper and 0.48 ppm silver).

The highest copper values reported in the analyzed rocks occur in two diabase dykes. One dyke filling a fault plane in Archean rocks at the west end of the Alona Bay outcrop area has 960 ppm copper and 0.20 ppm silver; another cutting Upper Division basalts near Cottrell Cove has 1,200 ppm copper and 0.13 ppm silver.

Table 2

CONCENTRATIONS OF COPPER AND SILVER IN
MAMAINSE POINT AREA, KEWEENAWAN VOLCANIC ROCKS
(all values in ppm)

Rock Type and Number of Samples	Copper		Silver	
	Average Value	Range	Average Value	Range
Basalt flows (30)	200	11-760	0.13	0.083-0.26
Acid rocks (15)	77	11-860	0.16	0.090-0.48
Diabase dykes (2)	1080	960-1200	0.16	0.13-0.20

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APPENDIX I

PROTEROZOIC FLOOD BASALTS OF EASTERN LAKE SUPERIOR: EXCURSION STOPS

The following stops have been selected to give a general view of the geology and structure of the Alona Bay and Mamainse Point volcanics in a short time. The exposures to be examined lie in or near the excellent Highway 17 road-cuts along a distance of 20.4 miles and are numbered on Figure 2; distances along this highway are given in miles and kilometres south of Wawa (junction Highway 17/Highway 101) or north of Sault Ste. Marie (junction Highway 17B (south)/Highway 17 (north)). Descriptions of route between stops are for southward travel.

The best small scale volcanic structures (pahoehoe flow tops, pipe vesicles, etc.) are fragile and in short supply, and participants are requested not to remove or break them, as such features will be of great use to future excursions for students and other visitors.

Miles from Wawa	Miles from Sault Ste. Marie	
		Between Montreal River and Alona Bay, the highway passes over Archean rocks of the Superior Province (> 2.5 b.y.), which comprise pale pink and grey granites, granite gneisses and darker migmatites, all of which are cut by dark northwest-trending Keweenawan basic dykes.
70.6	70.1	Stop 1: Alona Bay basalt flows. The highway descends to near lake level at a scenic lookout car park at Alona Bay and crosses the Archean/Keweenawan unconformity just under a mile south of this lookout. The unconformity itself is not exposed on the road at this point, but the lowest Alona Bay flows are exposed on the east side of Highway 17 where this meets a now disused section of the old highway. The basalts are fractured thin flow units of coarse olivine tholeiite and dip westwards at about 49 degrees; some have ropy pahoehoe tops and all are rich in secondary minerals. The base of the Keweenawan is exposed 2,840 feet (852 m) southwards of this outcrop as a small patch of vesicular dark basalt resting against grey Archean gneiss 50 feet (15 m) east of the pavement. Notice the undulating nature of this contact, indicating the irregular land surface on to which the oldest Keweenawan flows were extruded. The strike of the contact swings from a broadly north-northeast direction at this locality to run westwards towards the shore of Lake Superior. Leaving Stop 1, the highway climbs out of the depression occupied by the Keweenawan flows and passes through often steep sided road-cuts in pink Archean granitic rocks cut by dark grey-black Keweenawan basic dykes. After about three miles the road descends into Mica Bay and runs along shore beneath steep cliffs cut in Archean rocks.

74.8 65.9 Stop 2: Basal flows of the Mamainse Point section. The basal unconformity is poorly exposed at this locality, but the basalt flows occupy the lower ground lakeward of the steep 300-400-foot (90-120 m) bluffs carved into the Archean subsurface. The lavas in the road-cut dip west-southwest at about 48 degrees and are thin flow units of medium coarse ophitic olivine tholeiite with basal pipe vesicles, upper vesicular zones and reddish ropy pahoehoe tops. Some of these flow units are as thin as 6 inches (15 cm) and end in small pahoehoe toes which can be seen to step across or to be pinched out by other toes. The flows are rather fractured at this level and calcite, quartz, epidote, zeolites and rare specular hematite occur in veins and vesicles within them.

On the beach west of this thin flow outcrop, well laminated siltstones and sandstones rest unconformably on the Lower Division basalts and dip at 15-30 degrees to the northwest; these shallow-water marine deposits have been assigned an Upper Keweenawan or Lower Cambrian age by Giblin (1969a) and have been correlated with similar sediments of the Upper Keweenawan Freda formation of Michigan by Hamblin (1961).

About 1,000 feet (300 m) south along the highway from the thin basalt flows is an outcrop of the glomerophyric "Daisy Stone" flow which yields good samples rich in calcic plagioclase laths grouped into spherulitic clusters up to 2 inches (5 cm) across (Pl. 1). In the shore section this flow has an 18-foot (5.4 m) zone near its base which is free of spherulitic feldspar clusters and rich in pseudomorphs after small olivine phenocrysts.

75.5 65.2 Stop 3: Lower Division olivine tholeiite flows and olivine-phyric basalt. This stop shows a well-preserved ropy pahoehoe top on a 22-foot (6.6 cm) olivine tholeiite flow (shown in Pl. 2) at the south end of the road-cut on the east side of the highway. The top of the olivine-phyric basalt group outcrops a few flows beneath this pahoehoe flow and these flows can be seen to bear abundant small lustrous red saponitic pseudomorphs after small olivine phenocrysts. A northwest-trending diabase dyke dipping northeast at 26 degrees cuts the flows near the top of the olivine-phyric group. Some of the basalt flows in the west side of the road-cut have clinkery scoriaceous tops.

76.0 64.7 A 30-foot (9 m) sheet of pinkish acid quartz porphyry concordant with the basalt flows outcrops in the east side of the Highway 17 road-cut. The rock bears phenocrysts of quartz and kaolinized feldspar and shows some secondary copper colours. No contacts were found at this outcrop but the body is interpreted as the eastward continuation of an intrusive quartz porphyry on the lakeshore.

76.3 64.4 Stop 4: Lower Division oligomictic basalt breccia. This breccia outcrops in both sides of the road-cut and is a jumble of poorly sorted angular and subangular Keweenawan basalt fragments of both fine- and coarse-grained types set in a matrix of fine basaltic debris mixed with some silty material; this red-brown silty material is sometimes concentrated into well-laminated lenses which may show crossbedding. Some of the basalt fragments have irregularly rounded, amoeboid forms suggesting that they were still plastic when incorporated into the breccia, and others are vesicular. Rare angular fragments of red siltstone also occur in the breccia but no fragments of basement rocks or acid volcanics have been found in it. On the shore this deposit passes up into an upper zone of fine-grained well-laminated material which is presently interpreted as the product of explosive eruption of basalt into a body of water because of its similar appearance to peperites and hyaloclastites. Veins of "razor-blade" calcite cut the breccia.

The thin Lower Division acid tuff horizon (Fig. 3) outcrops beneath the breccia and can be seen 450 feet (135 m) north of it in the low cleared ground immediately east of the Highway 17 embankment.

77.4 63.3 Stop 5: Great Conglomerate and flows of the Upper Division. The spotty ophite flows near the top of the Lower Division (Fig. 3) are poorly exposed in the Highway 17 road-cut and are better seen on the lakeshore. The highway passes close to a small cobble beach just over one-half mile south of the basalt breccia outcrop; this bay is bounded to the east by a flow of fine-grained olivine-poor basalt forming a prominent north-northwest rib. The red sandy base of the "Great Conglomerate" rests on this flow and can be seen in the water close to the shore. On the west side of this small bay the two lowest Upper Division flows are intercalated with the "Great Conglomerate"; these are feldsparphyric olivine-poor tholeiite flows (SiO_2 49.5%, MgO 5.5%, Na_2O 2.8%, K_2O 0.5%) with occasional thin flow laminae and gabbroic inclusions. The flows have scoriaceous tops and are separated by a thin layer of red sandstone.

The "Great Conglomerate" occurs above these flows and its main features can be seen within a short distance of the two basalt flows. At the base of the conglomerate is a sandy zone which passes up into conglomerate bearing large rounded clasts of Archean and Keweenawan rocks in a sandy matrix. Some well-laminated sandy layers, some showing crossbedding, occur in the main part of the conglomerate.

78.1 62.6 Stop 6: Basic-acid composite intrusion. This north-dipping sheet outcrops in a small cleft to the west of the

78.1 (cont.) 62.6 Highway 17 embankment. The thin basal zone of fine grained basic rock can be seen chilled against Upper Division basalt on the south side of the cleft. Notice the flow lamination, and inclusion of basic selvage material and rare conglomerate pebbles in the pink acid rock near the basic/acid interface. White rhyolite outcrops in the bank at the head of the gully, and a northwest fault cuts basalt and conglomerate in another gully just south of the intrusion.

78.6 62.1 Stop 7: Upper Division conglomerate and copper-bearing basalts. Park in clear ground close to the shore west of the highway. The first outcrop northeastwards along the beach is a north-south rib of west-dipping conglomerate, broadly similar to the "Great Conglomerate". The two olivine-tholeiite flows beneath this conglomerate have good vesicular tops and basal pipe vesicles, and bear red-brown clastic crevice fillings. The upper of these two flows (SiO_2 49.9%, MgO 5.0%, Na_2O 3.8%, K_2O 0.4%) was found to be rich in copper (760 ppm) and silver (0.19 ppm) relative to the other Mamainse Point basalt flows.

At the south end of the clear ground are spoil heaps, old shafts and the remains of old buildings of the Mamainse Mine. The north-northwest Mamainse Vein outcrops on the beach and cuts thin flows of coarse diabasic and ophitic olivine tholeiite which bear occasional large amygdules containing quartz, agate, calcite, copper sulphides and native copper.

Southwestwards of the Mamainse Mine, the highway passes over coarse olivine tholeiites with intercalated conglomerates and rare parallel-feldspar flows, then swings southwards past the Mamainse Harbour fishing

80.5 60.2 station to continue along a shore causeway.

81.8 58.9 Stop 8: Rhyolite intrusion and Upper Division ophitic basalt. A short distance south of the causeway the highway is met by a road leading to the Sheridan Geophysics copper mine. Part of the old highway can be seen west of the new highway and this rests on a coarse ophitic olivine tholeiite flow in which individual augite crystals reach up to 2 cm in size.

81.6 59.1 A narrow bush track leaves the east side of the highway 1,250 feet (375 m) northwards of this point and a small bluff of compact pink-orange rhyolite (SiO_2 76.4%, MgO 0.1%, K_2O 6.0%, Na_2O 1.7%) with splintery jointing outcrops a short distance up this track. This rhyolite is tentatively interpreted as an intrusion and forms a high cliff which runs parallel to the east side of the highway.

83.3 57.4 Stop 9: Upper Division conglomerate and coarse ophitic basalt. South of the mine road the highway turns southwestwards over thick sand beach cover and runs close to the shore of Hibbard (Sand) Bay; just over a mile from

83.3 (cont.) 57.4 the gasoline service station it meets the shore at a small bay eroded in conglomerate and bounded to the east by a long basalt rib formed of coarse ophitic olivine tholeiite with clastic dykes. Immediately southwards of this bay the road passes through a cut which exposes two polymictic conglomerates separated by a coarse ophitic olivine tholeiite flow. There is a good continuous section of this flow, from its basal chilled zone (with pipe vesicles) to its vesicular top; the topmost 12 inches (30 cm) of conglomerate beneath the basalt have been indurated by baking, and the flow is cut by a small fault.

84.3 56.4 One mile southwards of this conglomerate locality the highest basalt flows in the Mamainse Point section are exposed in the high promontory of Coppermine Point just west of a small settlement on a stretch of the old highway; these flows are fine-grained olivine-poor tholeiites. Here the road turns southeastwards and runs almost parallel to the strike of the flows.

85.6 55.1 <u>Stop 10:</u> <u>Acid intrusion cutting Upper Division basalts</u>. This felsitic acid intrusion cuts faulted diabasic olivine-tholeiite flows dipping westwards in the east side of the highway road-cut just north of the Black Forest Motel; these flows are lower in the succession than those at Coppermine Point. The intrusion outcrops as a 55-foot (16.5 m) -thick sheet dipping northwest at about 30 degrees and forms the northern part of a body with crescentic outcrop shape. The margin of the felsite has good flow lamination and encloses small angular xenoliths of basalt; the rock of the centre portion (SiO_2 78.0%, MgO 0.1%, K_2O 1.8%, Na_2O 1.5%) is unlaminated and bears yellow-green patches of epidote and chlorite. Epidote, chlorite, calcite and some copper colours occur in the upper contact zone.

Thin irregular apophyses of the pink felsite can be seen 250 feet (75 m) north of the main outcrop and felsite also outcrops on the west side of the highway and on the shore. The thicker southern limb of the acid intrusion outcrops near the Black Forest Motel on the east side of the road-cut 1,500-2,350 feet (450-705 m) southwards of the described outcrop and can be traced westwards on to the beach.

88.4 52.3 Southwards of the acid intrusion, the highway swings eastwards and passes from scattered outcrops of Upper Division basalts into sand covered ground.

88.8 51.9 A bush road leaves the highway and runs northward through large gravel pits towards a high hill a mile away topped by a tall radio mast; this hill is formed of resistant rhyolite bodies intruding basalt and conglomerate near the base of the Upper Division.

APPENDIX II

CHEMICAL ANALYSES OF THE MAMAINSE POINT AREA VOLCANIC ROCKS

The results of 47 new analyses of Keweenawan volcanic rocks from the Mamainse Point area (including one of a basic dyke from Alona Bay) are given in Tables II-1 and II-2. These analyses were carried out by staff of the Analytical Chemistry Section, Geological Survey of Canada, and samples were analyzed for thirteen major and fifteen minor elements. SiO_2, TiO_2, Al_2O_3, total iron, MnO, CaO and K_2O were determined by X-ray fluorescence, using a fusion technique, and FeO, Na_2O, P_2O_5, CO_2 and total water by rapid chemical methods. MgO was determined by atomic absorption spectrophotometry. Minor elements were determined by spectrograph, and values for Sc, V, Cr, Co, Ni, Cu, Sr, Y, Zr and Ba are estimated by laboratory staff to be accurate to within $\pm$ 15 per cent of the figure reported; Zn, Ga, Ag, Sn, and Pb are accurate to within $\pm$ 30 per cent of the reported values.

The major element analyses were recalculated to 100 per cent CO_2- and H_2O-free, and molecular norms (given in Table II-2) were then calculated from these values using a computer program devised by T. N. Irvine. As the Mamainse Point area volcanic rocks are old and somewhat altered, the Fe_2O_3/FeO ratio was adjusted prior to norm calculation by setting the upper limit of Fe_2O_3 as: $\%Fe_2O_3 = \%TiO_2 + 1.5$ in the manner suggested by Irvine and Baragar (1971, p. 526). This adjustment was used to obtain an iron ratio representative of the primary composition of the rock.

The basalts

The high CO_2 and H_2O contents, and the great range in alkali content, sometimes within the same flow, of the flood basalt samples indicate that the flows have undergone metamorphism. The norms of eight basalts (AK 568A, 570, 604, 620, 637, 657, 725, and 731) show plagioclase ratios which are rather sodic for basalts (see Table II-2); this feature probably indicates alteration towards spilitic compositions brought about by burial metamorphism of the type discussed by Smith (1968, p. 210-211). Four samples (AK 732, 618, 638, and 700) bear normative nepheline, the first and last of these being alumina-rich rocks with abundant feldspar. In view of the subjection of these basalts to processes of burial metamorphism and hydrothermal metamorphism which have probably altered their alkali contents, it seems unwise at present to label them as true alkali-olivine-basalts according to the usage of Poldervaart (1964, p. 232).

No obvious differences in major or minor element chemistry were found to exist between the fine-grained and coarse-grained basalt types distinguished in the main part of this paper. These two types are however represented by different symbols in Figure II-1.

When compared to the average continental tholeiite of Manson (1968), the average Mamainse Point basalt is richer in TiO_2 and Fe_2O_3, and poorer in Al_2O_3 (see Table 1).

Stratigraphic variation in chemistry of the basalts

The stratigraphic variation of 9 major elements with height in the lava pile is shown in Figure II-1; it should be borne in mind that this variation may be partly due to lateral variation, as it was not possible to sample a complete continuous section across the strike of the entire lava pile. MgO shows a slight decrease from base to top of the section, and this probably reflects the greater abundance of olivine (now altered) in the lowest flows. Total iron and TiO_2 increase slightly towards the top of the section. SiO_2, CaO and Al_2O_3 show little vertical variation, but the feldsparphyric "Daisy Stone" stands out as a high alumina value near the base of the pile. The alkali elements show a very erratic vertical distribution which is felt to be due to differing degrees of alteration at different levels of the pile.

The minor elements show no obvious vertical variation, except for Cr and Ni, which reach their highest values near the base of the section. This feature suggests that these elements are concentrated in the olivine-rich Lower Division basalts; Cr and Ni are known to enter magnesian olivine in large amounts (Deer, Howie and Zussman, 1962, v. 1, p. 5; Taylor, 1965, p. 169-173; Simkin and Smith, 1970). The high Cu values found in the median levels of the pile have already been mentioned in the main part of this paper.

The acid rocks

The analyzed Mamainse Point area acid rocks outline a limited range of compositions, but the wide range of alkali and lime contents seen within this silicic suite may also be the result of burial metamorphism and leaching under local hydrothermal conditions. Apart from their lower Na_2O content, the compositions of the Mamainse Point area acid rocks compare closely with those of Iceland and Nockolds' average calc-alkali rhyolite (see Table 1).

Key to chemically analyzed samples

(see Fig. II-2 for sample sites)

Basalt lava flows

LOWER DIVISION

AK 519 Dark medium- to coarse-grained ophitic basalt with pseudomorphs after olivine phenocrysts; from median level of thin pahoehoe flow on Mica Bay shore, 190 feet above base of section.

733 Dark medium-grained basalt from outcrop on east side of bush road near eastern margin of Keweenawan area.

732 Feldsparphyric "Daisy Stone" basalt from large block close to AK 733 locality.

832 Dark medium-coarse basalt with scattered pseudomorphs after olivine phenocrysts; from non-feldsparphyric zone in "Daisy Stone" flow, along bush road crossed by power line. Sample is from about 680 feet above base of lava section.

735 Fine-grained basalt from small outcrop to east of bush road in eastern part of Keweenawan area, about 940 feet above base of section.

558 Fine-grained basalt with scattered feldspar microphenocrysts, from 6 feet above base of flow on Lake Superior shoreline, 3,200 feet above base of section.

568A Fine-grained basalt with scattered feldspar microphenocrysts; composite sample of base and centre of flow on shore, 3,600 feet above base of section.

570 Fine-grained aphyric basalt; composite sample of flow forming stack at west end of shore rib, 3,670 feet above section base.

586A Fine-grained aphyric basalt; composite sample from median level of flow on shoreline 4,400 feet above base of section.

589A Medium-grained ophitic basalt, crowded with strikingly regular spheroidal feldspar-pyroxene intergrowths which give rock a spotted appearance: Composite sample from median level of flow on shore 4,560 feet above section base; this flow belongs to the "spotty ophites" of Figure 3.

604 Fine-grained aphyric basalt; composite sample from lower part of flow on shore 5,150 feet above base of section.

UPPER DIVISION

610 Fine-grained basalt with abundant feldspar phenocrysts up to 5 mm in length; from lowest flow in thin flow group intercalated with "Great Conglomerate" on shore 5,980 feet above base of section.

616 Coarse-grained dark ophitic basalt; sample from near top of flow on shore 7,140 feet above base of section.

618 Coarse-grained ophitic basalt from basal part of flow on shore 7,290 feet above base of section.

619 Coarse-grained basalt from median level of same flow as AK618.

620 Fine-grained basalt from median level of flow on shore 7,320 feet above base of section.

628 Medium-grained basalt from lower part of flow on shore 7,640 feet above base of section.

633 Medium-grained basalt from median level of same flow as AK628.

638 Medium-grained basalt from base of flow on shore cut by carbonate veins bearing native copper; 7,750 feet above base of section.

637 Medium-grained basalt from median level of same flow as AK638.

783 Medium-grained ophitic basalt from flow at north end of Sheridan Geophysics open pit working, about 8,050 feet above base of section.

647 Medium-grained ophitic basalt from basal part of pahoehoe flow on shore, 8,920 feet above base of section.

657 Fine-grained "parallel feldspar" basalt from flow on shore, 9,380 feet above base of section (see Fig. 3).

661 Fine-grained aphyric basalt from basal part of flow on shore 9,510 feet above section base.

669 Fine-grained basalt from flow on shore 10,090 feet above section base.

700 Coarse-grained diabasic basalt from lower part of pahoehoe flow resting on coarse conglomerate on shore; 13,390 feet above base of section.

725 Fine-grained basalt from flow on shore south of picnic ground; 13,570 feet above base of section.

707 Fine-grained basalt from median level of flow forming shore bluff immediately south of tombolo at Coppermine Point; 14,060 feet above section base.

731 Fine-grained basalt from median level of flow on shore west of Sawpit Bay; 14,300 feet above base of section.

<u>Intrusions</u>

515 Medium- to coarse-grained diabase from centre of 20-foot basic dyke at western extremity of Keweenawan shore section, Alona Bay.

713 Fine-grained aphyric basalt from basic dyke which cuts Upper Division basalt flows on Highway 17 near the Cottrell Cove rhyolite body.

622 Fine-grained aphyric basalt from 2-foot basic lower selvage of composite sheet; on shore near Mile 62 north from Sault Ste Marie on Highway 17 (see Stop 6).

624 Grey-white rhyolite from centre of composite sheet edged by AK 622; from outcrop at top of beach.

<u>Acid bodies</u>

355 Finely crystalline pink rhyolite from 6 feet above lower contact of acid inclined sheet cutting Upper Division basalt flows on Highway 17 near Cottrell Cove (see Stop 10).

596 Pink rhyolite from centre of near-vertical acid dyke cutting Lower Division basalts on shore.

751 Dark red banded rhyolite from outcrop on northeast shore of small lake by bush road from Pancake River mouth.

767 Pink rhyolite from east side of bush road running northeastwards from old camp site to northeast of Sheridan Geophysics mine.

791 Pinkish flow-banded rhyolite from body outcropping near Upper Division basalt flows on Sheridan Geophysics mine road to east of Highway 17.

808 Orange rhyolite with some flow-banding, from sheet-like body outcropping in sawmill yard east of Highway 17.

812 Pink flow-banded rhyolite from body with circular outcrop plan between Highway 17 and bush road to gravel pits.

813 Fine-grained pink-orange rhyolite from sheet-like body in Upper Division basalts; along bush road from Highway 17 east of Hibbard Bay (see Stop 8).

814 Fine-grained purple-grey banded rhyolite from small outcrop in bush road east of Highway 17.

815 Altered red rhyolite showing folded flow-lamination in face on old Highway 17 section to east of new Highway 17 near Coppermine Point.

819A Orange rhyolite from small intrusion cutting coarse conglomerate about 300 feet southwards of microwave relay tower topping hill north of Pancake Bay.

820 Grey feldsparphyric rhyolite from outcrop on road to microwave relay tower.

823 Vitreous dark red rhyolite from acid body on shore, Sawpit Bay.

828 Pink-grey feldsparphyric rhyolite with faint flow lamination from small ? sheet; south end of small lake on bush road which crosses "Daisy Stone" flow.

Table II-1

Chemical analyses of Mamainse Point area volcanic rocks (minor elements in p.p.m.)

	AK	Basalt lava flows										
Field number	519	733	732	832	735	558	568[A]	570	586[A]	589[A]	604	610
GSC Analysis number	1610	1638	1655	1653	1639	1611	1612	1613	1614	1615	1617	1618
Height in feet above base of section	190	570	680	680	940	3200	3600	3670	4400	4560	5150	5980
SiO_2	50.6	45.4	45.9	46.5	46.9	50.9	48.5	51.2	53.9	47.8	51.2	47.9
TiO_2	1.22	1.33	1.53	2.31	1.79	1.35	1.39	1.31	0.68	0.81	1.59	0.62
Al_2O_3	14.2	10.2	20.5	14.2	11.9	16.1	16.5	14.0	15.5	17.0	14.3	18.7
Fe_2O_3	3.8	3.9	4.8	5.4	5.0	5.8	5.2	6.4	3.3	3.8	5.6	5.8
FeO	5.0	8.2	5.6	9.0	7.8	4.5	4.8	4.3	5.6	7.7	6.5	4.0
MnO	0.15	0.16	0.06	0.17	0.18	0.20	0.21	0.19	0.15	0.19	0.18	0.20
MgO	6.4	15.4	5.8	7.3	12.5	6.7	7.9	5.9	7.7	8.1	5.2	5.3
CaO	13.3	9.7	7.3	8.5	8.4	8.7	6.2	5.5	6.1	10.2	7.2	10.9
Na_2O	2.2	0.9	3.3	1.6	1.7	2.9	4.0	3.5	2.0	2.2	3.4	2.7
K_2O	0.3	0.4	2.2	1.6	0.7	1.0	0.9	2.3	2.0	0.2	1.3	0.5
P_2O_5	0.11	0.16	0.12	0.18	0.18	0.14	0.14	0.17	0.06	0.06	0.27	0.05
H_2O^T	1.9	3.5	1.9	3.7	2.4	2.8	4.3	2.7	3.9	3.3	1.9	1.7
CO_2	2.8	0.1	0.05*	1.1	0.05*	0.2	1.7	1.0	1.0	0.[illegible]	0.1	0.1
Totals:†	102.0	99.4	99.1	101.6	99.5	101.3	101.7	98.5	101.9	101.9	98.7	98.5
Sc	24	26	21	30	32	23	24	29	29	35	25	35
V	360	250	280	420	290	290	270	280	230	270	300	260
Cr	550	1500	91	180	810	72	69	28	77	110	56	77
Co	36	73	34	39	57	39	38	30	32	45	37	28
Ni	180	860	150	170	520	85	85	27	100	160	49	35
Cu	150	260	130	120	130	36	190	140	150	150	110	11
Zn	75	48	26	57	29	135	92	88	83	78	100	114
Ga	14	13	12	11	11	11	10	9.9	9.1	12	11	9.5
Sr	280	170	440	20	190	300	510	330	160	160	310	210
Y	<20	<20	<20	22	<20	NF	NF	<20	21	NF	24	<20
Zr	120	100	99	160	130	84	54	150	96	43	140	30
Ag	0.16	.086	0.12	0.10	0.088	0.12	0.17	0.15	0.12	0.13	0.10	0.[illegible]
Sn	1.1	1.9	1.4	1.4	1.6	1.2	0.89	1.2	1.3	1.0	1.3	1.1
Ba	280	77	20	770	120	350	360	1300	290	170	400	190
Pb	5.8	3.0	14	3.5	2.2	6.0	4.5	[illegible].1	5.7	3.3	11	8.7

Table II-1 (cont.)

	Basalt lava flows											
Field number	616	618	619	620	628	633	638	637	783	647	657	661
GSC Analysis number	1619	1620	1621	1622	1625	1626	1628	1627	1642	1629	1630	1631
Height in feet above base of section	7140	7290	7290	7320	7640	7660	7750	7750	8050	8920	9380	9510
SiO_2	46.5	33.9	47.2	47.8	47.6	49.1	36.0	47.6	49.4	45.6	46.5	47.0
TiO_2	1.89	2.46	2.49	3.11	2.57	2.62	3.12	3.22	2.38	1.88	2.68	3.35
Al_2O_3	14.5	11.8	12.7	11.9	12.8	12.9	11.2	11.6	13.0	14.6	14.8	11.2
Fe_2O_3	4.9	4.6	11.0	7.9	8.7	8.1	6.0	10.5	12.7	6.1	10.4	10.2
FeO	6.7	9.0	4.2	7.6	5.7	6.8	9.5	6.4	3.0	6.5	2.9	6.1
MnO	0.17	0.40	0.22	0.20	0.23	0.25	0.53	0.21	0.18	0.18	0.15	0.21
MgO	4.6	7.7	3.6	5.7	4.2	5.0	4.1	4.8	5.8	4.3	2.2	4.2
CaO	9.4	13.8	9.3	6.6	10.2	8.4	12.8	6.8	5.7	10.7	8.2	8.1
Na_2O	2.0	1.8	2.4	2.6	2.2	2.0	1.8	3.6	2.0	2.1	3.0	2.2
K_2O	0.2	0.4	0.4	0.2	0.4	0.2	0.8	0.4	1.3	0.1	1.8	0.6
P_2O_5	0.19	0.23	0.24	0.22	0.23	0.22	0.29	0.25	0.22	0.19	0.74	0.31
H_2O^T	3.6	4.5	2.9	3.2	2.7	3.5	3.5	2.6	3.4	2.5	1.0	2.7
CO_2	4.3	8.5	4.3	1.5	3.6	3.3	8.0	3.3	2.6	3.8	2.8	3.0
Totals:†	99.0	99.1	101.0	98.5	101.1	102.4	97.6	101.4	101.7	98.6	97.2	99.2
Sc	36	52	48	52	42	51	53	48	53	32	26	52
V	300	400	380	460	430	360	460	470	36	300	120	470
Cr	110	87	75	66	75	79	40	39	170	75	NF	48
Co	35	47	41	38	45	45	43	45	42	50	31	43
Ni	66	61	53	31	57	55	37	41	47	150	19	41
Cu	170	390	150	240	350	150	760	270	94	420	31	530
Zn	90	95	80	120	84	120	83	78	83	120	90	72
Ga	16	15	11	15	14	17	10	5.1	12	9.7	8.2	11
Sr	220	140	190	180	210	200	150	260	150	220	260	160
Y	23	34	32	39	32	30	42	43	27	23	37	47
Zr	120	170	160	180	160	160	210	200	150	120	340	220
Ag	0.26	0.19	0.16	0.12	0.20	0.14	0.15	0.19	0.083	0.11	0.13	0.17
Sn	1.7	1.7	1.1	2.1	1.4	1.7	1.5	1.5	1.6	1.3	1.1	1.5
Ba	100	120	130	150	150	110	160	170	220	120	790	250
Pb	6.6	13	5.5	13	18	17	11	9.1	12	8.4	13	8.3

Table II-1 (cont.)

	Basalt lava flows					Intrusions				Acid bodies	
Field number	669	700	725	707	731	515	713	622	624	355	596
GSC Analysis number	1632	1633	1636	1634	1637	1609	1635	1623	1624	1654	1616
Height in feet above base of section	10.090	13.390	13.570	14.060	14.300	---	---	---	---	---	---
SiO_2	43.7	40.7	45.5	44.9	49.8	45.4	48.7	47.5	75.1	72.6	80.6
TiO_2	3.34	1.45	4.26	3.74	3.02	1.26	1.97	2.35	0.09	0.07	0.46
Al_2O_3	11.9	17.4	15.3	15.6	13.0	15.1	15.4	13.8	12.0	12.3	7.3
Fe_2O_3	12.3	3.7	10.5	7.1	9.3	1.9	3.9	4.9	0.8	1.1	3.3
FeO	5.7	4.8	4.9	6.3	5.6	5.4	5.0	7.3	0.1	0.3	1.7
MnO	0.23	0.13	0.27	0.26	0.20	0.36	0.22	0.27	0.05	0.03	0.08
MgO	2.6	2.0	5.2	5.6	4.4	4.8	3.5	6.8	0.5	0.1	0.6
CaO	10.0	14.4	6.9	9.9	7.7	10.7	10.6	6.4	1.5	3.5	0.9
Na_2O	2.1	1.9	3.1	2.4	3.7	2.2	2.3	3.2	0.4	1.4	0.1
K_2O	0.7	0.4	1.8	1.2	1.3	1.6	1.6	0.1	4.9	1.7	1.5
P_2O_5	0.32	0.14	0.88	0.79	0.32	0.14	0.42	0.27	0.01*	0.01*	0.09
H_2O^T	2.4	6.0	2.6	2.8	1.9	3.9	2.6	4.7	2.6	2.5	1.6
CO_2	5.2	6.8	0.2	0.1	1.0	6.0	5.1	2.4	0.9	2.6	0.4
Totals:†	100.5	99.8	101.4	100.7	101.2	98.8	101.[illegible]	100.0	99.0	98.2	98.6
Sc	58	26	32	37	53	32	30	37	NF	NF	10
V	470	250	410	460	480	360	230	400	NF	< 20	40
Cr	48	34	48	43	130	60	200	200	NF	NF	26
Co	43	36	45	50	43	31	38	45	NF	NF	NF
Ni	40	67	110	40	53	87	110	130	NF	NF	21
Cu	230	77	130	45	260	960	1200	280	13	19	860
Zn	96	160	170	67	82	100	110	120	34	30	96
Ga	11	13	13	9.9	9.5	13	7.4	9.1	11	20	13
Sr	160	190	350	400	390	230	410	250	20	19	NF
Y	46	< 20	42	20	42	20	20	31	< 20	42	NF
Zr	240	86	390	340	220	100	210	200	76	99	73
Ag	0.16	0.13	0.096	0.12	0.12	0.20	0.13	0.11	0.10	0.12	0.41
Sn	1.6	1.3	1.7	1.4	1.6	1.1	1.5	1.1	1.7	4.5	1.7
Ba	190	56	310	590	350	310	810	540	720	52	160
Pb	19	40	16	3.7	11	12	34	11	14	6.9	11

Table II-1 (cont.)

	Acid bodies											
Field number	751	767	791	808	812	813	814	815	819^{A}	820	823	828
GSC Analysis number	1640	1641	1643	1644	1645	1646	1647	1648	1649	1650	1651	1652
Height in feet above base of section	---	---	---	---	---	---	---	---	---	---	---	---
SiO_2	74.1	76.5	72.2	73.8	76.2	76.4	68.9	70.2	78.9	77.7	78.6	69.5
TiO_2	0.21	0.41	0.10	0.09	0.05	0.08	0.17	0.08	0.11	0.10	0.14	0.24
Al_2O_3	13.1	13.0	12.8	13.9	13.6	13.4	12.6	12.3	11.6	12.1	11.1	13.7
Fe_2O_3	2.4	1.0	1.9	0.9	2.0	0.2	4.5	1.6	1.1	1.9	1.9	1.5
FeO	0.7	0.4	0.6	1.3	0.3	1.3	0.05*	0.05*	0.4	0.1	0.1	0.1
MnO	0.04	0.03	0.05	0.04	0.04	0.03	0.03	0.04	0.03	0.05	0.02	0.06
MgO	0.1	0.1	0.5	0.05*	0.1	0.1	0.05*	0.05*	0.3	0.3	0.1	0.5
CaO	0.7	0.6	3.0	1.4	0.2	0.8	3.7	5.9	0.5	0.9	0.4	2.8
Na_2O	2.7	2.8	0.2	1.8	1.0	1.7	0.05*	0.1	1.7	0.3	0.1	0.2
K_2O	5.6	4.6	5.9	6.0	7.4	6.0	0.3	0.2	3.9	5.4	1.1	6.8
P_2O_5	0.01*	0.01*	0.01*	0.01*	0.01*	0.01*	0.01*	0.01*	0.01*	0.01*	0.01*	0.04
H_2O^T	0.6	0.8	1.7	1.0	0.7	0.7	4.8	4.2	1.4	1.5	3.9	1.9
CO_2	0.4	0.4	2.1	0.6	0.05*	0.6	2.7	4.6	0.2	0.6	0.1	2.2
Totals:†	100.7	100.7	101.1	100.9	101.7	101.3	97.9	99.3	100.2	101.0	97.6	99.5
Sc	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	<5
V	<20	22	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
Cr	13	<10	<10	<10	<10	<10	<10	<10	NF	NF	NF	NF
Co	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF
Ni	17	14	11	<10	<10	<10	<10	14	NF	NF	NF	NF
Cu	15	10	11	12	48	38	28	31	15	20	14	23
Zn	26	<10	63	80	25	27	21	NF	17	31	30	100
Ga	10	9.9	17	15	10	11	22	16	10	13	13	9.3
Sr	54	33	16	110	17	11	16	11	14	NF	15	29
Y	95	67	81	89	70	53	48	47	<20	22	42	<20
Zr	390	350	190	190	120	120	130	120	81	81	90	20
Ag	0.13	0.07	0.094	0.09	0.14	0.14	0.12	0.13	0.13	0.11	0.48	0.18
Sn	2.2	2.8	4.8	2.9	2.8	2.8	8.0	7.6	2.4	1.9	3.7	1.2
Ba	1300	1200	280	86	690	540	36	58	240	290	35	1400
Pb	8.1	5.3	13	30	16	14	8.0	4.4	7.0	4.8	7.0	35

Table II-2

Chemical analyses (recalculated to 100 per cent H_2O- and CO_2-free) and molecular norms of Mamainse Point area volcanic rocks

	AK	Basalt lava flows				
Field number	519	733	732	832	735	558
GSC Analysis number	1610	1638	1655	1653	1639	1611
Height in feet above base of section	190	570	680	680	940	3200
SiO_2	52.01	47.41	47.27	48.06	48.33	51.79
TiO_2	1.25	1.39	1.58	2.39	1.84	1.37
Al_2O_3	14.60	10.65	21.11	14.67	12.26	16.38
Fe_2O_3	3.91	4.07	4.94	5.58	5.15	5.90
FeO	5.14	8.56	5.77	9.30	8.04	4.58
MnO	0.15	0.17	0.06	0.18	0.18	0.20
MgO	6.58	16.08	5.97	7.54	12.88	6.82
CaO	13.67	10.13	7.52	8.78	8.65	8.85
Na_2O	2.26	0.94	3.40	1.65	1.75	2.95
K_2O	0.31	0.42	2.26	1.65	0.72	1.02
P_2O_5	0.11	0.17	0.12	0.19	0.18	0.14
Totals:	99.99	99.99	100.00	99.99	99.98	100.00
Q	3.65	---	---	---	---	0.94
Or	1.84	2.45	13.34	10.02	4.27	6.05
Ab	20.51	8.38	22.89	15.21	15.74	26.64
An	29.07	23.46	35.50	28.41	23.49	28.62
Ne	---	---	4.48	---	---	---
C	---	---	---	---	---	---
Fo	---	11.77	12.14	0.31	7.43	---
Fa	---	2.94	5.30	0.16	2.14	---
En	6.73	20.29	---	16.98	20.01	14.77
Fs	2.25	5.07	---	8.89	5.78	6.01
Di	23.23	16.25	0.46	7.87	11.35	8.31
He	7.75	4.06	0.20	4.12	3.28	3.38
Mt	2.95	3.07	3.25	4.22	3.55	3.05
Il	1.76	1.92	2.18	3.41	2.57	1.92
Hm	---	---	---	---	---	---
Ap	0.24	0.35	0.26	0.40	0.39	0.30
Normative Plagioclase Composition	58.63	73.68	60.79	65.14	59.88	51.79
Normative Colour Index	44.68	65.36	23.53	45.96	56.11	37.45
Poldervaart's Number	-2.63	-4.03	8.16	-4.41	-3.52	-2.31
Solidification Index	36.16	53.47	26.73	29.32	45.13	32.06

Table II-2 (cont.)

	Basalt lava flows					
Field number	568[A]	570	586[A]	589[A]	604	610
GSC Analysis number	1612	1613	1614	1615	1617	1618
Height in feet above base of section	3600	3670	4400	4560	5150	5980
SiO_2	50.66	54.03	55.57	48.74	52.92	49.55
TiO_2	1.45	1.38	0.70	0.83	1.64	0.64
Al_2O_3	17.23	14.77	15.98	17.33	14.78	19.34
Fe_2O_3	5.43	6.75	3.40	3.87	5.79	6.00
FeO	5.01	4.54	5.77	7.85	6.72	4.14
MnO	0.22	0.20	0.15	0.19	0.19	0.21
MgO	8.25	6.23	7.94	8.26	5.37	5.48
CaO	6.48	5.80	6.29	10.40	7.44	11.27
Na_2O	4.18	3.69	2.06	2.24	3.51	2.79
K_2O	0.94	2.43	2.06	0.20	1.34	0.52
P_2O_5	0.15	0.18	0.06	0.08	0.28	0.05
Totals:	100.00	100.00	99.98	99.99	99.98	99.99
Q	---	---	6.16	---	1.88	---
Or	5.50	14.43	12.22	1.21	8.06	3.08
Ab	37.09	33.32	18.56	20.21	32.00	25.22
An	25.22	16.64	28.33	36.77	20.88	38.95
Ne	---	---	---	---	---	---
C	---	---	---	---	---	---
Fo	11.94	0.43	---	4.97	---	4.12
Fa	3.85	0.22	---	2.57	---	2.62
En	4.91	13.74	21.23	12.44	11.50	5.58
Fs	1.58	6.90	7.99	6.43	7.60	3.54
Di	3.39	5.92	1.48	7.64	7.09	8.30
He	1.09	2.97	0.56	3.95	4.68	5.28
Mt	3.12	3.11	2.36	2.47	3.39	2.31
Il	2.00	1.93	0.98	1.15	2.32	0.90
Hm	---	---	---	---	---	---
Ap	0.30	0.38	0.13	0.17	0.59	0.11
Normative Plagioclase Composition	40.47	33.31	60.42	64.53	39.49	60.70
Normative Colour Index	31.89	35.23	34.60	41.63	36.58	32.65
Poldervaart's Number	2.72	-0.63	-10.43	-1.86	-1.99	1.02
Solidification Index	34.65	26.34	37.38	36.82	23.64	28.96

Table II-2 (cont.)

	Basalt lava flows					
Field number	616	618	619	620	628	633
GSC Analysis number	1619	1620	1621	1622	1625	1626
Height in feet above base of section	7140	7290	7290	7320	7640	7660
SiO_2	51.07	39.38	50.35	50.94	50.19	51.36
TiO_2	2.08	2.86	2.66	3.31	2.71	2.74
Al_2O_3	15.92	13.71	13.55	12.68	13.50	13.49
Fe_2O_3	5.38	5.34	11.73	8.42	9.17	8.47
FeO	7.36	10.45	4.48	8.10	6.01	7.11
MnO	0.19	0.46	0.23	0.21	0.24	0.26
MgO	5.05	8.94	3.84	6.08	4.43	5.23
CaO	10.32	16.03	9.92	7.03	10.76	8.79
Na_2O	2.20	2.09	2.56	2.77	2.32	2.09
K_2O	0.22	0.46	0.43	0.21	0.42	0.21
P_2O_5	0.21	0.27	0.26	0.23	0.24	0.23
Totals:	100.00	99.99	100.01	99.98	99.99	99.98
Q	7.08	---	6.43	7.54	6.38	9.74
Or	1.33	---	2.64	1.31	2.60	1.29
Ab	20.26	---	24.05	25.80	21.70	19.57
An	33.86	27.09	25.35	22.34	26.23	27.95
Ne	---	11.45	---	---	---	---
C	---	---	---	---	---	---
Fo	---	11.42	---	---	---	---
Fa	---	4.98	---	---	---	---
En	10.02	---	6.32	14.29	6.56	11.35
Fs	6.12	---	6.59	8.29	5.22	8.18
Di	8.63	19.75	9.56	6.21	12.35	7.40
He	5.27	8.62	9.98	3.60	9.83	5.34
Mt	4.00	4.89	4.66	5.33	4.67	4.70
Il	2.97	4.05	3.87	4.79	3.93	3.98
Hm	---	---	---	---	---	---
Ap	0.45	0.57	0.56	0.51	0.53	0.50
Normative Plagioclase Composition	62.56	100.0	51.31	46.41	54.73	58.81
Normative Colour Index	37.01	53.70	40.97	42.50	42.57	40.94
Poldervaart's Number	-7.80	9.57	-5.45	-7.88	-5.52	-10.36
Solidification Index	25.00	32.77	16.67	23.75	19.81	22.62

Table II-2 (cont.)

	Basalt lava flows				
Field number	638	637	783	647	657
GSC Analysis number	1628	1627	1642	1629	1630
Height in feet above base of section	7750	7750	8050	8920	9380
SiO_2	41.79	49.86	51.63	49.43	49.80
TiO_2	3.62	3.37	2.49	2.04	2.87
Al_2O_3	13.00	12.15	13.59	15.83	15.85
Fe_2O_3	6.96	11.00	13.27	6.61	11.14
FeO	11.03	6.70	3.13	7.05	3.11
MnO	0.61	0.30	0.19	0.19	0.16
MgO	4.76	5.03	6.06	4.66	2.36
CaO	14.86	7.12	5.96	11.60	8.78
Na_2O	2.09	3.77	2.09	2.28	3.21
K_2O	0.93	0.42	1.36	0.11	1.93
P_2O_5	0.34	0.26	0.23	0.21	0.79
Totals:	99.99	99.98	100.00	100.01	100.00
Q	---	2.22	7.46	4.08	2.91
Or	5.74	2.57	8.37	0.66	11.83
Ab	4.45	35.13	19.54	21.06	29.93
An	24.40	15.56	24.66	33.66	24.01
Ne	9.09	---	---	---	---
C	---	---	---	---	---
Fo	2.24	---	---	---	---
Fa	1.96	---	---	---	---
En	---	10.11	16.35	7.78	3.75
Fs	---	8.13	11.44	6.01	4.17
Di	21.47	8.57	2.14	10.96	6.00
He	18.79	6.89	1.50	8.46	6.67
Mt	5.86	5.36	4.41	3.95	4.86
Il	5.27	4.88	3.61	2.93	4.15
Hm	---	---	---	---	---
Ap	0.74	0.57	0.50	0.44	1.72
Normative Plagioclase Composition	84.57	30.70	55.79	61.51	44.51
Normative Colour Index	55.59	43.95	39.47	40.09	29.59
Poldervaart's Number	7.90	-1.59	-10.73	-4.31	-0.93
Solidification Index	18.47	18.68	23.39	22.51	10.84

Table II-2 (cont.)

	Basalt lava flows					
Field number	661	669	700	725	707	731
GSC Analysis number	1631	1632	1633	1636	1634	1637
Height in feet above base of section	9510	10,090	13,390	13,570	14,060	14,300
SiO_2	50.28	47.04	46.77	46.14	45.91	50.64
TiO_2	3.58	3.60	1.67	4.32	3.82	3.07
Al_2O_3	11.98	12.81	19.99	15.52	15.95	13.22
Fe_2O_3	10.91	13.24	4.25	10.65	7.26	9.46
FeO	6.53	6.14	5.52	4.97	6.44	5.69
MnO	0.22	0.25	0.15	0.27	0.27	0.20
MgO	4.49	2.80	2.30	5.27	5.73	4.47
CaO	8.67	10.76	16.55	7.00	10.12	7.83
Na_2O	2.35	2.26	2.18	3.14	2.45	3.76
K_2O	0.64	0.75	0.46	1.82	1.23	1.32
P_2O_5	0.33	0.34	0.16	0.89	0.81	0.32
Totals:	99.98	99.99	100.00	99.99	99.99	99.98
Q	8.72	4.13	---	---	0.29	1.18
Or	3.99	4.74	2.78	11.14	7.46	8.05
Ab	22.23	21.59	18.02	29.13	22.64	34.77
An	21.30	24.03	44.37	23.57	29.69	15.73
Ne	---	---	1.21	---	---	---
C	---	---	---	---	---	---
Fo	---	---	---	1.56	---	---
Fa	---	---	---	0.51	---	---
En	8.22	3.56	---	11.06	10.98	7.47
Fs	6.51	5.74	---	3.60	2.77	5.10
Di	9.67	9.31	12.97	3.76	10.54	10.49
He	7.66	15.00	10.83	1.22	2.66	7.16
Mt	5.71	5.79	3.62	6.30	5.76	4.95
Il	5.25	5.33	2.37	6.21	5.47	4.40
Hm	---	---	---	---	---	---
Ap	0.73	0.77	0.34	1.93	1.74	0.70
Normative Plagioclase Composition	48.92	52.67	71.12	44.72	56.73	31.15
Normative Colour Index	43.03	44.74	29.79	34.23	38.17	39.57
Poldervaart's Number	-7.96	-3.22	4.25	0.19	-0.78	0.21
Solidification Index	18.03	11.11	15.62	20.39	24.78	18.11

Table II-2 (cont.)

	Intrusions			
Field number	515	713	622	624
GSC Analysis number	1609	1635	1623	1624
Height in feet above base of section				
SiO_2	51.09	52.02	51.14	78.70
TiO_2	1.42	2.10	2.53	0.09
Al_2O_3	16.99	16.45	14.86	12.57
Fe_2O_3	2.14	4.17	5.27	0.84
FeO	6.08	5.34	7.86	0.10
MnO	0.40	0.23	0.29	0.05
MgO	5.40	3.74	7.32	0.52
CaO	12.04	11.32	6.89	1.57
Na_2O	2.48	2.46	3.44	0.42
K_2O	1.80	1.71	0.11	5.13
P_2O_5	0.16	0.45	0.29	0.01
Totals:	100.00	99.99	100.00	100.00
Q	---	5.53	3.05	50.35
Or	10.70	10.31	0.64	31.47
Ab	22.34	22.50	31.30	3.90
An	30.10	29.40	25.06	8.01
Ne	---	---	---	---
C	---	---	---	3.95
Fo	1.85	---	---	---
Fa	0.82	---	---	---
En	4.49	3.23	18.25	1.50
Fs	1.98	1.18	7.04	---
Di	16.05	14.61	4.39	---
He	7.09	5.33	1.69	---
Mt	2.25	3.95	4.38	0.18
Il	1.99	2.99	3.57	0.14
Hm	---	---	---	0.49
Ap	0.33	0.96	0.62	0.02
Normative Plagioclase Composition	57.39	56.64	44.46	67.26
Normative Colour Index	36.52	31.29	39.33	2.30
Poldervaart's Number	1.29	-3.71	-4.22	-47.73
Solidification Index	30.19	21.47	30.49	7.46

Table II-2 (cont.)

	Acid bodies						
Field number	355	596	751	767	791	808	812
GSC Analysis number	1654	1616	1640	1641	1643	1644	1645
Height in feet above base of section							
SiO_2	77.97	38.41	74.35	76.92	74.23	74.33	75.52
TiO_2	0.07	0.48	0.21	0.41	0.10	0.09	0.05
Al_2O_3	13.21	7.56	13.14	13.07	13.16	14.00	13.48
Fe_2O_3	1.18	3.41	2.41	1.01	1.95	0.91	1.98
FeO	0.32	1.76	0.70	0.40	0.62	1.31	0.30
MnO	0.03	0.08	0.04	0.03	0.05	0.04	0.04
MgO	0.11	0.62	0.10	0.10	0.51	0.05	0.10
CaO	3.76	0.93	0.70	0.60	3.08	1.41	0.20
Na_2O	1.50	0.10	2.71	2.81	0.21	1.81	0.99
K_2O	1.83	1.55	5.62	4.62	6.07	6.04	7.33
P_2O_5	0.01	0.09	0.01	0.01	0.01	0.01	0.01
Totals:	99.99	99.99	99.99	99.98	99.99	100.00	100.00
Q	51.85	72.04	33.18	39.09	40.69	34.91	39.20
Or	11.19	9.82	33.92	27.88	37.22	36.56	44.66
Ab	13.98	0.99	24.83	25.76	1.91	16.65	9.16
An	19.25	4.29	3.49	2.98	15.81	7.09	0.95
Ne	---	---	---	---	---	---	---
C	2.20	4.94	1.50	2.62	0.75	2.16	4.01
Fo	---	---	---	---	---	---	---
Fa	---	---	---	---	---	---	---
En	0.31	1.83	0.28	0.28	1.47	0.14	0.28
Fs	---	2.90	0.64	---	0.18	1.36	0.005
Di	---	---	---	---	---	---	---
He	---	---	---	---	---	---	---
Mt	0.69	2.27	1.83	0.15	1.78	0.97	1.65
Il	0.11	0.71	0.30	0.58	0.15	0.13	0.07
Hm	0.39	---	---	0.62	---	---	---
Ap	0.02	0.21	0.02	0.02	0.02	0.02	0.02
Normative Plagioclase Composition	57.92	81.19	12.33	10.38	89.19	29.86	9.36
Normative Colour Index	1.50	7.71	3.05	1.63	3.59	2.60	2.01
Poldervaart's Number	-40.13	-49.81	-27.10	-29.10	-48.92	-33.04	-41.47
Solidification Index	2.17	8.33	0.87	1.12	5.49	0.50	0.93

Table II-2 (cont.)

	Acid bodies						
Field number	813	814	815	819[A]	820	823	828
GSC Analysis number	1646	1647	1648	1649	1650	1651	1652
Height in feet above base of section							
SiO_2	76.38	76.25	77.54	80.06	78.60	84.00	72.82
TiO_2	0.08	0.19	0.09	0.11	0.10	0.15	0.25
Al_2O_3	13.40	13.94	13.59	11.77	12.24	11.86	14.35
Fe_2O_3	0.20	4.98	1.77	1.12	1.92	2.03	1.57
FeO	1.30	0.06	0.05	0.41	0.10	0.11	0.11
MnO	0.03	0.03	0.04	0.03	0.05	0.02	0.06
MgO	0.10	0.06	0.05	0.30	0.30	0.11	0.52
CaO	0.80	4.09	6.52	0.51	0.91	0.43	2.93
Na_2O	1.70	0.06	0.11	1.72	0.30	0.11	0.21
K_2O	6.00	0.33	0.22	3.96	5.46	1.18	7.12
P_2O_5	0.01	0.01	0.01	0.01	0.01	0.01	0.04
Totals:	100.00	100.00	99.99	100.00	99.99	100.00	99.98
Q	38.59	63.19	60.46	50.99	51.63	76.25	35.67
Or	36.32	2.08	1.37	24.15	33.64	7.35	43.45
Ab	15.62	0.53	1.04	15.98	2.84	1.01	1.94
An	4.00	21.50	33.95	2.53	4.64	2.17	14.73
Ne	---	---	---	---	---	---	---
C	2.99	7.04	1.54	4.22	4.76	11.16	1.19
Fo	---	---	---	---	---	---	---
Fa	---	---	---	---	---	---	---
En	0.28	0.16	0.16	0.87	0.87	0.31	1.49
Fs	1.85	3.14	---	---	---	---	---
Di	---	---	---	---	---	---	---
He	---	---	---	---	---	---	---
Mt	0.21	2.05	0.10	0.81	0.81	0.60	---
Il	0.11	0.28	0.13	0.16	0.15	0.22	0.27
Hm	---	---	1.21	0.26	0.63	0.89	1.13
Ap	0.02	0.02	0.02	0.02	0.02	0.02	0.09
Normative Plagioclase Composition	20.37	97.60	97.02	13.66	62.03	68.13	88.36
Normative Colour Index	2.46	5.63	1.60	2.10	2.46	2.02	2.89
Poldervaart's Number	-34.86	-50.57	-51.88	-38.36	-49.30	-52.05	-48.51
Solidification Index	1.07	1.01	2.50	4.05	3.75	3.03	5.49