PETROGRAPHY AND PROVENANCE

OF AN

ARCHEAN CONGLOMERATE

PETROGRAPHY AND PROVENANCE
OF AN
ARCHEAN CONGLOMERATE,
MANITOU LAKE,
NORTHWESTERN ONTARIO

by

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ABSTRACT

The Archean "Loose Pebble Bay" conglomerate, Manitou Lake, northwestern Ontario, contains a variety of clast types, not all of which can be readily ascribed to local lithologies. This study was undertaken to determine the modal clast composition of the conglomerate, and investigate the origin of the clasts. The conglomerate lies near the top of a stratigraphic sequence which includes mafic and felsic volcanic rocks, iron formations, conglomerates, sandstones and argillites. The conglomerate unit itself consists of interbedded conglomerate and sandstone, and probably represents a channel-fill deposit of an ancient submarine fan.

Modal percentages of clast types were obtained using a line-intercept method. They indicate that most of the debris in the conglomerate can be reasonably attributed to uplift and erosion of the lateral equivalents of the underlying stratigraphy, except for the granitoid clasts, which have no known origin within the area.

Petrographic examinations of the clasts indicate that field identifications must be confirmed with thin section investigations.

The modal composition of granitoid clasts was determined utilizing both thin sections and stained slabs. Most of the granitoid clasts are granodiorite, or lie just within the granite field, adjacent to the granodiorite field. Textural studies of the granitoid clasts suggest that gneissic and allotriomorphic-granular textured rocks may have formed by deformation or partial recrystallization along grain boundaries of previously hypidiomorphic-granular rocks. Textures generally indicate intrusive origin and slow cooling, although two granophyric samples may have solidified at relatively shallower depths than the other granitoid rocks.

The textures and compositions of most of the granitoid clasts suggest that they were derived from one intrusive body. Intrusion of such a body into the volcanic-sedimentary belt, followed by uplift and erosion, would account for the presence in the "Loose Pebble Bay" conglomerate of granitic clasts and clasts similar to the underlying rocks. However, no evidence of such an intrusion has been found in the Manitou Lake area, and two of the granitoid clasts are noticeably different in composition from the others. The possibility of a pre-existing sialic basement cannot be ruled out.

ACKNOWLEDGEMENTS

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TABLE OF CONTENTS

FIGURES

TABLES

INTRODUCTION

During the summers of 1972 and 1973 the author assisted R. Teal in the detailed mapping of a sequence of Archean sedimentary rocks which lies along the eastern edge of Manitou Lake, Ontario (Fig. 1). This work, together with that of previous workers (Pettijohn, 1937; Thomson, 1933) has outlined a thick conglomeratic unit near the top of this sedimentary sequence (Fig. 2). It is a polymictic conglomerate, containing a larger variety of clast types than other conglomerates in the area (Teal, 1972). Because of this and the fact that the clasts, especially granitoids, could not all be readily ascribed to local lithologies, this study was undertaken to determine the modal clast composition of the conglomerate, and investigate the origin of the clasts through petrographic analysis.

Because of a paucity of official geographic names, some locality names had to be invented. Some of the clasts in the conglomerate under study often weather in such a way that they can be removed by hand, so R. Teal named the bay just south of the major outcrop studied, "Loose Pebble Bay" and the conglomerate, the "Loose Pebble Bay" conglomerate (Fig. 3). This name appears in quotation marks throughout this work because it has no official status and is only familiar to those directly connected with this work and that of R. Teal.

Fig. 1 : Location and general geology of the study area. Geology after Thomson (1933).

Sedimentary rocks of the 'Manitou Series'

Mainly volcanic rocks

Granite

● 'Loose-Pebble Bay' conglomerate

Area of Fig. 2.

Major Faults

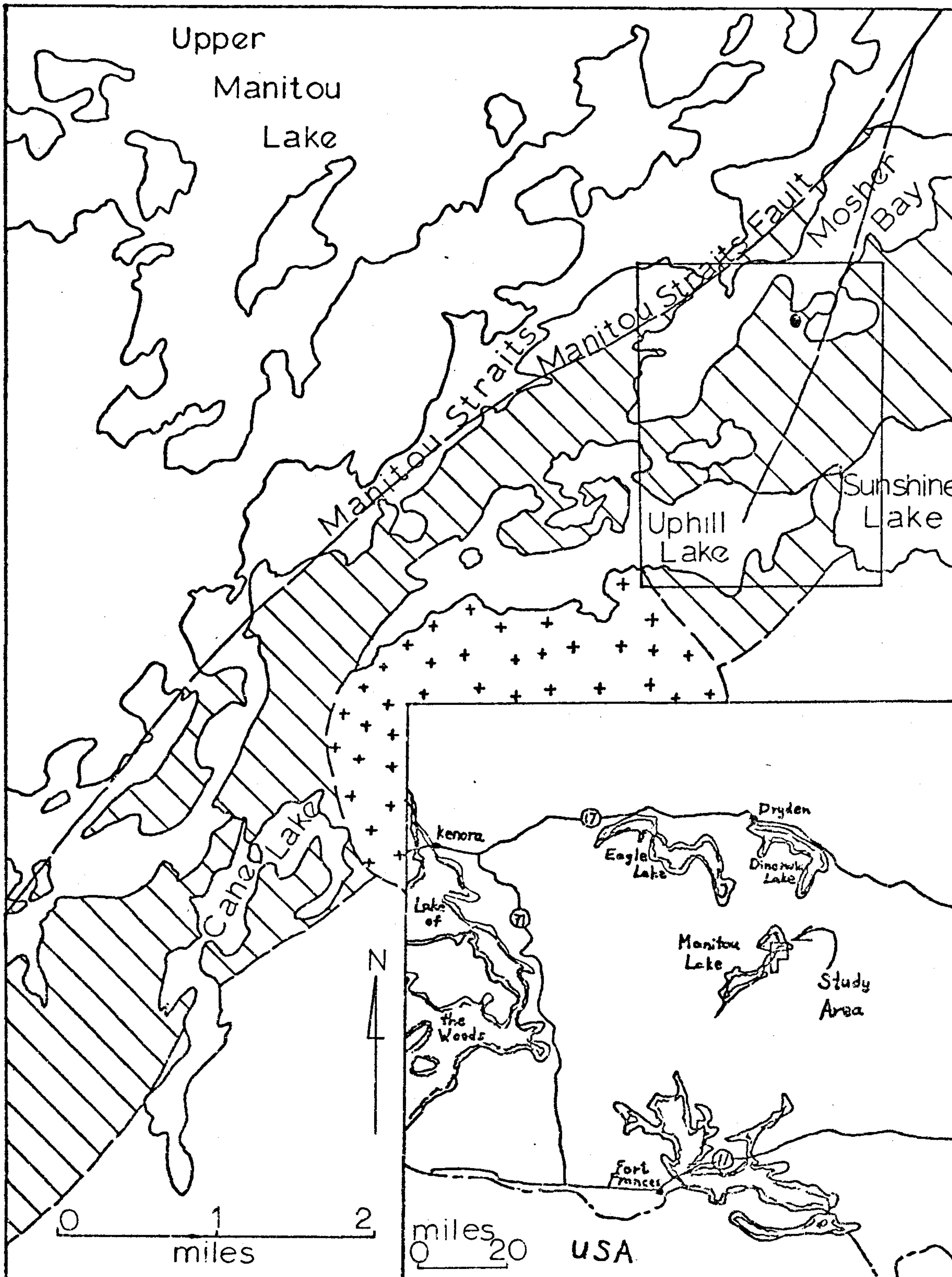
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Fig. 2 : Geology of the 'Loose-Pebble Bay' - Uphill Lake area, after R. Teal (1973).

Conglomerate with interbedded sandstone

Interbedded sandstones and argillites

Iron Formation

Interbedded argillite, sandstone, and conglomerates

Interbedded sandstones, conglomerates and tuff

Argillite

Basalt

Felsic volcanic rock

Agglomerate

Bedding strike and dip

Bedding strike and vertical dip

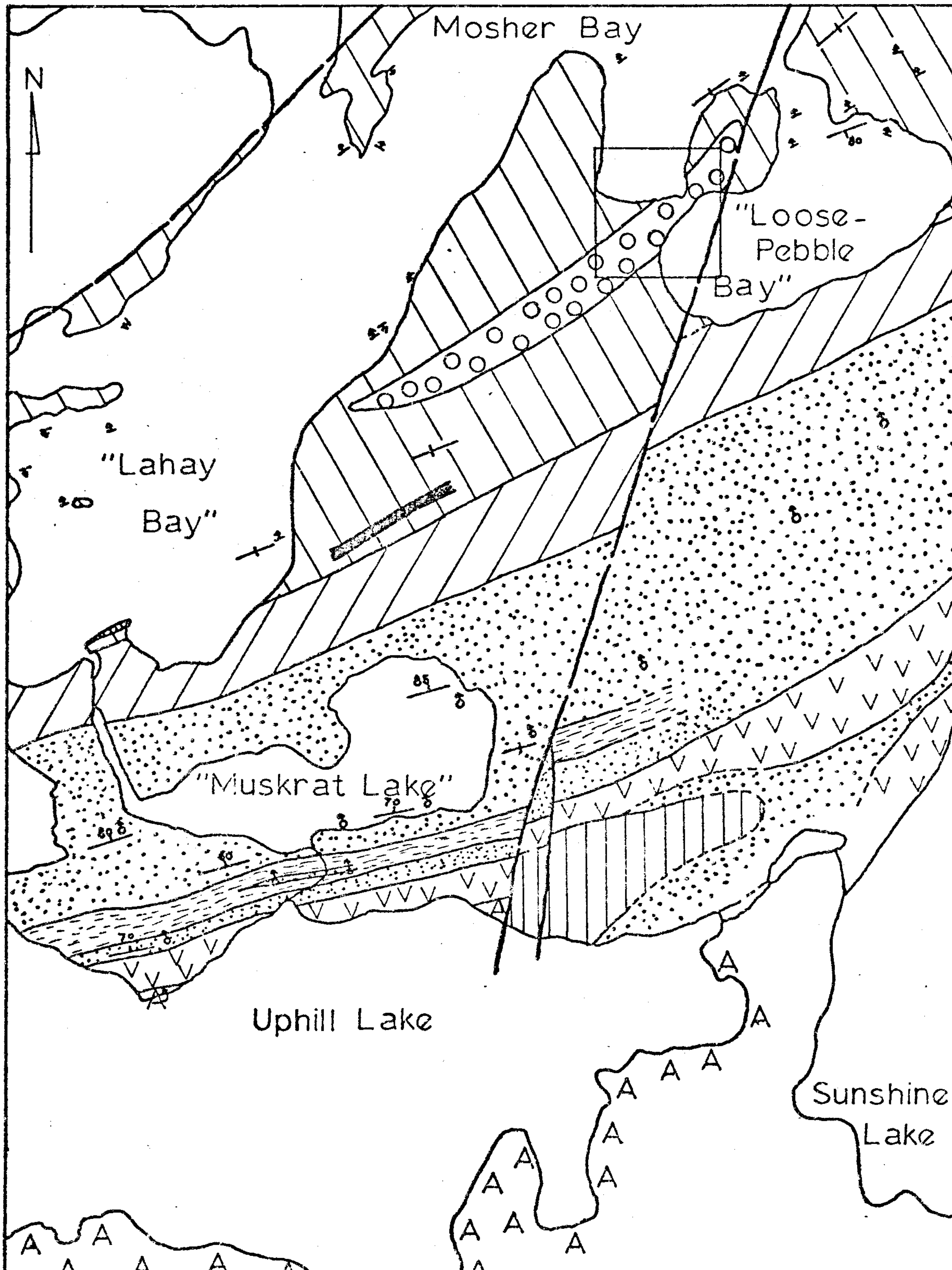
Stratigraphic tops determined by crossbedding

Stratigraphic tops determined by graded bedding

Fault

Area of Fig. 3.

Scale : 4 inches = 1 mile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Uphill Lake
Sunshine
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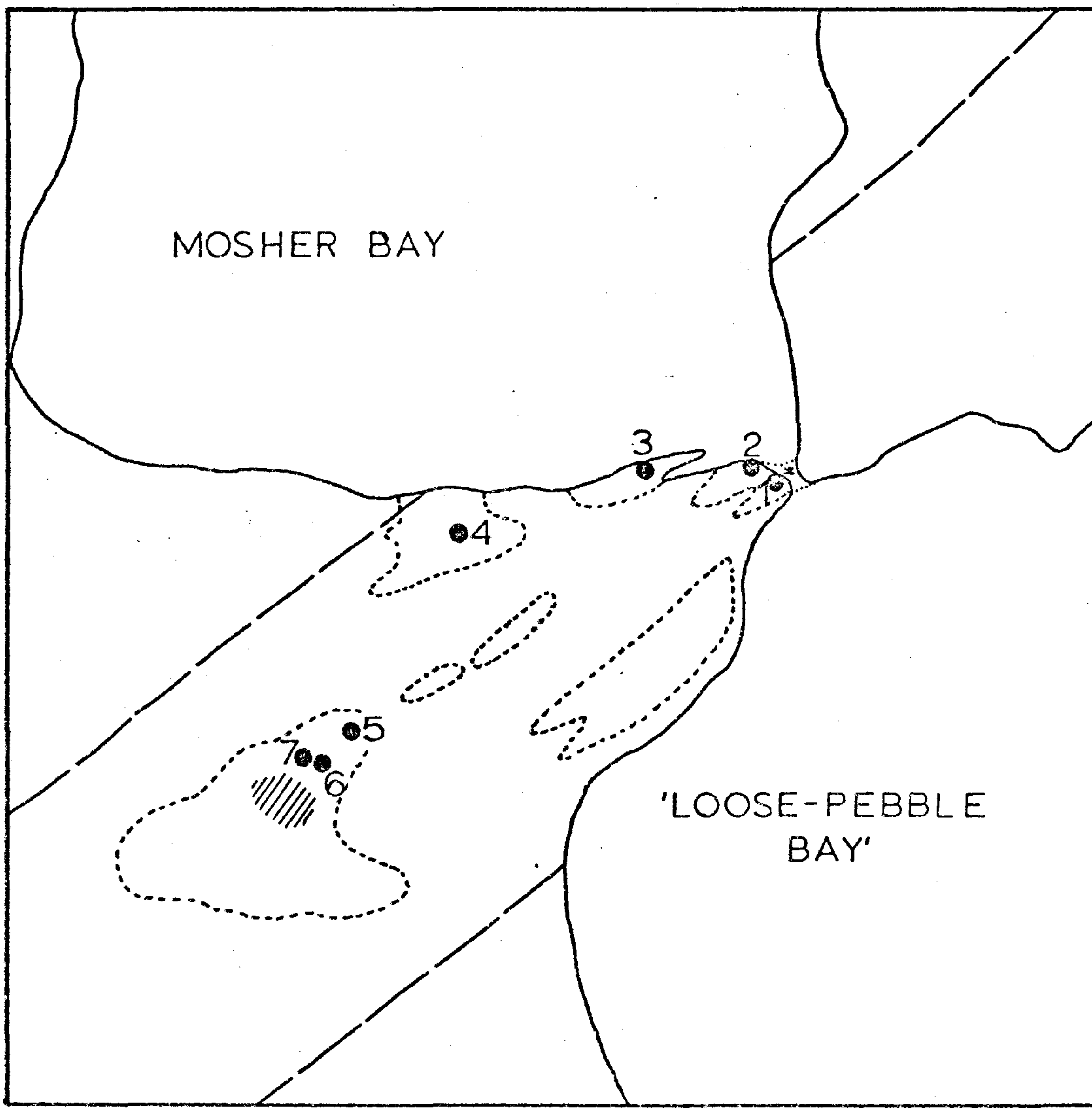

Fig. 3 : Major outcrops of the "Loose Pebble Bay" Conglomerate, showing the location of clast composition measurements. Outcrop. Boundaries of the "Loose Pebble Bay" Conglomerate. Area of sample collection.

PREVIOUS WORK

J. E. Thompson (1933) described the geology of the Manitou Lake area, including the "Loose Pebble Bay" conglomerate, but he does not distinguish it from the other sediments on his map. Pettijohn (1937) studied the sediments between Mosher Bay and Sunshine Lake (Fig. 1), dividing the sediments into six divisions of which one is the "Loose Pebble Bay" conglomerate. In 1972 and 1973 C. E. Blackburn of the Ontario Division of Mines mapped portions of the Manitou Lake area at a scale of 4 in. to 1 mi., and will continue this mapping in 1974. R. Teal is presently studying the sedimentary and pyroclastic rocks of the stratigraphic section which includes the "Loose Pebble Bay" conglomerate.

Archean conglomerates were studied in the Kirkland Lake area by Bass (1961), who concluded that the "plutonic" clasts were actually of volcanic and subvolcanic origin. However, Donaldson and Jackson (1965) showed that the conglomerates in the North Spirit Lake area reflect a significant plutonic provenance.

A conglomerate similar in both its sedimentological setting and its composition to the "Loose Pebble Bay" conglomerate has been described by Walker and Pettijohn (1971) in the Minnitaki Lake area. They concluded that a granitic provenance is indicated for this conglomerate.

GEOLOGICAL SETTING

The conglomerate studied lies in the northern (upper) portion of a sequence of pyroclastic and sedimentary rocks within the Manitou Lake-Stormy Lake metavolcanic-metasedimentary belt (Fig. 1). This Archean greenstone belt consists of thick volcanic and sedimentary sequences which are intruded by porphyry dikes, granitic stocks, and granitic rocks of marginal batholithic domes (Blackburn, 1973). The belt is arcuate in form, approximately 12 miles wide and about 50 miles long. On its north side it joins volcanic rocks extending towards Dryden (Fig. 1)(Davies and Pryslak, 1967).

Metamorphism is generally considered to be in the greenschist facies (R. Teal, 1974, personal communication), although emplacement of intrusions has locally raised the metamorphism to the amphibolite facies (Blackburn, 1973).

The Manitou Straits Fault, a major schist zone trending northeast-southwest through the middle of the belt (Fig. 1), divides the belt into two areas in which the geological successions differ substantially (Blackburn, 1973). Since the conglomerate is contained in the south-eastern portion of the belt, only that portion will be discussed.

Stratigraphy

The stratigraphy and environmental interpretations outlined below are based on the recent work of R. Teal (1972, 1973) and C. E. Blackburn (1973).

The lowest part of the stratigraphy is represented by an unknown thickness of mafic volcanic and minor intercalated sedimentary rocks. Some of the mafic lavas are pillowed, and the sedimentary rocks are turbidites (R. Teal, 1973), hence this part of the stratigraphy is submarine.

The volcanic rocks are overlain, apparently conformably, by about 1000 m of agglomerate containing rounded mafic and felsic volcanic clasts. This unit shows little bedding or other sedimentary structures.

The agglomerate is followed by a 100 m thick porphyritic, amygdaloidal mafic volcanic unit which represents one or more subaerial lava flows. This unit joins at its east end with a much thicker accumulation of similar lavas and minor intercalated volcanogenic sediments.

The lavas are followed by about 800 m of interbedded sandstones, conglomerates, tuffs and tuff-breccias (Fig. 2). In the Uphill Lake area the sandstones and conglomerates are composed exclusively of volcanic debris, although there may be minor plutonic and sedimentary clasts at the extreme eastern and southwestern ends of the unit. This unit shows good bedding and in places is extensively crossbedded. It was deposited subaerially. In the "Muskrat Lake" area the sandstone and conglomerate unit is interrupted by about 70 m of thinly bedded siltstone and argillite of possible lacustrine origin. This siltstone-argillite unit does not extend eastward beyond the western end of Sunshine Lake.

The sandstone and conglomerate unit is followed transitionally by about 200 m of interbedded argillite, sandstone and conglomerate.

This in turn is followed by a unit of unknown thickness, composed largely of interbedded medium and fine sandstone, siltstone and argillite having turbidite characteristics. Near the base of this unit there are minor magnetic iron formations. The unit also contains a number of conglomeratic lenses. The occurrence of these lenses within the finer grained turbidites strongly suggests that the conglomerates represent channel fill deposits in a submarine fan otherwise composed of sandstone-argillite turbidites. The largest of these conglomerate lenses, the "Loose Pebble Bay" conglomerate, is the subject of this study.

The "Loose Pebble Bay" Conglomerate

The "Loose Pebble Bay" conglomerate is a poorly sorted polymictic conglomerate containing granitoid, mafic and felsic volcanic, porphyry, quartz, chert, sandstone, argillite and iron formation clasts, set in a matrix (about 40 per cent by volume) of medium to coarse grained graywacke (Fig. 4). The clasts are generally well rounded, and range in size from one-half to more than 20 cm, averaging about 3 cm. Interbedded with the conglomerate are medium to coarse grained quartzose graywacke beds varying from 20 to 100 cm in thickness. There is a faint but noticeable foliation in the graywacke beds and the matrix of the conglomerate. However, most of the pebbles have apparently retained their original shape, except the more ductile ones such as the mafic volcanic and sedimentary clasts, which have been flattened in the plane of the foliation.

This entire conglomerate-sandstone unit is about 90 m thick and 1300 m long. Other conglomerate units within the turbidites are generally similar, but much smaller: less than 40 m thick and ranging from 50 to 1000 m long.

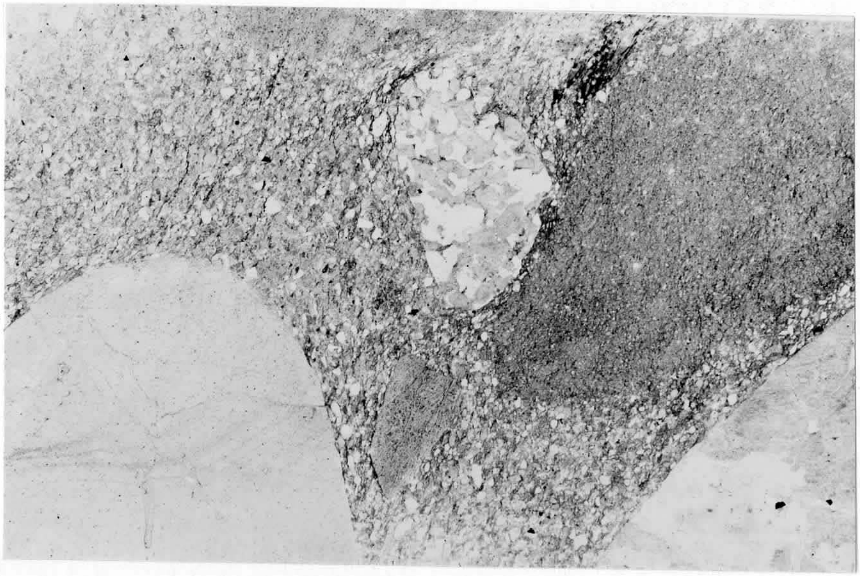

Fig. 4. Thin section S-7, showing the medium to coarse grained graywacke matrix, dark greenstone pebble (upper right), pale felsite (lower left), and mottled granitic clast (upper centre). The "banding" in the felsite is an artifact of the staining of the section for feldspar. Plane polarized light, X 4.

FIELD STUDIES

The outcrop chosen for study was a prominent bluff forming part of the peninsula between "Loose Pebble Bay" and Mosher Bay (Fig. 3). The outcrop is free of trees and larger vegetation, but the surface was obscured by moss and tenacious lichen. Attempts to remove the lichen were generally unsatisfactory, so only a limited number of exposures suitable for the identification of smaller clasts were obtained. The best exposures were at the base of a recently-fallen tree, and along the water line.

Method

In some studies (e.g. Callander, 1970; Boutcher et al, 1966) the relative numbers of different clast types have been counted and recorded for Archean conglomerates as a basis for qualitative evaluation of provenance. However, because the clast types are not equally distributed with regard to clast size, such number counts are not reliable estimates of volume per cent composition (Donaldson and Jackson, 1965).

Point counting on a regularly spaced grid has been used to obtain volume estimates of the composition of conglomerates (R. Teal, 1971; Turner, 1972).

For this study, in order to obtain a maximum amount of data from the outcrop, a line-intercept method suggested by R. G. Walker (1973, personal communication) was adopted. At each station a number of traverse lines spaced 10 cm apart and arranged perpendicular to the strike of the beds were drawn on the outcrop with a felt-tipped marker. The number and length of the traverses varied depending on the exposure at the station. A measuring tape was laid along each traverse line; and the intercepts of the edges of each pebble with the line, and the identity of the pebble, were recorded.

Volume estimates of the composition were obtained by accumulating the lengths of intercepts of clasts of each composition. The volume compositions were then converted to percentage compositions.

Exposure sufficiently good to permit detailed compositional measurements proved to be quite limited, and it was very difficult to obtain the last few tens of centimeters of measurement. Nevertheless a total of 40 m of measurement was obtained.

A number of apparently different types of granitoid clasts were observed in the outcrop, and as it was not possible to classify these more precisely in the field, samples were collected for thin sectioning. The samples were selected to represent a wide range of apparent granitic types.

Although only a single gneissic granitic clast had been recognized in the clast composition measurements (Location 7 of Table 1), examination of the collected samples revealed a number of gneissic clasts.

A few samples of other clast types were also collected in order to check on the field identification.

The samples were collected wherever they could be removed from the outcrop.

Results

The location of each station at which measurements were taken is shown in Fig. 3. The compositional data have been compiled in Table 1. The clast types were distinctive in outcrop except for the intermediate volcanic clasts, which were distinguished from the dark green mafic and pale felsic clasts mainly on the basis of their medium gray green colour.

Initial examination of the conglomerate did not reveal any noticeable variation in the proportions of clast types or the ratio of clasts to matrix between

Table 1 : Percentages of clast types and matrix in the "Loose Pebble Bay" Conglomerate.

LOCATION	BASALT	INTERMEDIATE	FELSITE	FELSIC FELDS	PORPHYRY QUARTZ	GRANITOID	QUARTZ	IRON FM.	CHERT	SANDSTONE	ARGILLITE	MATRIX
1 (5.5)	.4	2.6	13.0	.8	3.2	32.4		7.3	1.0	2.2	3.5	33.7
2 (4.5)	.2	3.4	14.3		.8	19.1	1.0	4.1	3.4	4.2	1.6	47.7
3 (4.9)	3.2	.7	34.3	.1	6.8	4.4		3.5	7.3	2.7		37.0
4 (5.0)	4.3	4.3	19.3	4.9	8.9	4.0		4.1	7.4			42.8
5 (6.0)	1.1	2.3	15.9	2.9	2.6	11.7	2.0	10.5	3.7	1.6	1.1	44.8
6 (6.0)	.6	1.0	14.9	1.7	4.7	14.7	.3	4.4	1.8	4.6	.3	51.1
7 (8.1)	3.1	.8	14.5	2.1	4.3	10.8	.6	9.9	2.5	6.1	.4	45.1

Locations shown in figure 3.

Numbers in brackets are the number of meters measured at each station.

FELSIC PORPHYRY : FELDS - feldspar phenocrysts

QUARTZ - quartz and feldspar phenocrysts

ARGILLITE - siltstone and mudstone, occasionally showing bedding and, more rarely, graded bedding.

different areas; however, the data shows considerable variation between stations (Table 1). Despite this variation some trends in the composition are apparent. All outcrops have a high proportion of matrix, and the predominant clasts are generally felsites. Granitoid clasts are also abundant at some of the stations. The other constituents vary over a wide range, but each is generally less than 10 per cent.

Discussion

The composition of the conglomerate, in terms of clast types, was studied in order to determine possible sources.

Most of the clast types observed appear to correspond to rock types exposed in the underlying stratigraphy. The basalt clasts resemble the lava flows lower in the section, and the felsites are similar to those found in the tuff-breccias. The iron formation found in the lower part of the turbidites is virtually identical to the iron formation clasts in the conglomerate. Sedimentary clasts may have been derived from the walls of the channel which now contains the conglomerate. Clasts similar to the porphyries identified in the conglomerate have been observed in the agglomerate and tuff-breccia units.

Another possible source for the porphyry clasts is a stock in the nearby Stormy Lake greenstone belt. This porphyry was eroded before the deposition of a sedimentary sequence probably equivalent to the Manitou Lake belt (Thompson, 1933; Bertholf, 1946).

A possible source for the granitoid pebbles, however, cannot be found in the rocks presently exposed in the area. All the local granitic and gneissic bodies show intrusive contacts with the greenstone belt.

PETROGRAPHY OF THE NON-GRANITIC CLASTS

A number of varieties of non-granitic clasts were studied in thin section, chiefly as a check on the field identification. Not all the clast types shown in Table 1 were represented, due to difficulty in removing the more-fragile clasts (particularly the sedimentary clasts) from the matrix.

Considerable alteration was observed in most sections studied. The mafic minerals are extensively chloritized. Many of the feldspars are altered, either to saussurite or to a grayish material too fine grained to identify.

Chert

Only one chert clast was studied. This clast is made up of very fine grained, equigranular, interlocking quartz, with minor fibrous material and opaque grains. This fragment may be either recrystallized sedimentary chert or an acidic volcanic clast; the texture does not reveal its origin.

Another specimen, which was identified as chert in hand specimen, proved to be a felsic volcanic clast containing minute laths of plagioclase (up to 0.01 mm in size) and smaller, irregular quartz grains in an extremely fine grained pale groundmass.

Turner (1972) had similar difficulties with the distinction between true chert and fine grained felsic volcanic fragments.

Iron Formation

The iron formation examined is fine grained and consists of black and purple bands which, under the microscope, proved to be made up of minute euhedral to anhedral opaque grains in a fine groundmass of microcrystalline quartz. Banding is a result of variation in the size and density of the opaque grains. Since the specimen is distinctly magnetic, the opaque grains are presumed to be mainly magnetite.

Similar magnetic iron formation occurs lower in the stratigraphic section (Fig. 2).

Felsic Porphyries

Both quartz and quartz-feldspar porphyries were observed in thin section. They consist of euhedral phenocrysts in a fine-grained matrix; matrix and phenocrysts are generally highly altered. The thin sections were not stained to determine feldspar types.

The quartz-feldspar porphyry studied contains large phenocrysts of quartz and feldspar up to 3 mm in diameter. Many of the feldspars show distinct, although often complex, twinning. The plagioclase composition is about An_{30}. Partially-resorbed quartz is common, and chloritized mafic grains are also present. Opaque grains are commonly associated with the chlorite. Phenocrysts, of varying sizes, appear to make up about 85 per cent of the section, and about 75 per cent of the phenocrysts are feldspars (mainly plagioclase). The matrix appears to be made up of fine grained feldspars, with quartz and other grains, in similar proportions to the phenocrysts. Secondary carbonate is present throughout this section.

Fig. 5 is a print of a thin section of a quartz-feldspar porphyry, showing textures, and Fig. 6 is a photomicrograph showing partially-resorbed quartz.

The feldspar porphyries, of which several sections were studied, are somewhat different in texture. They contain smaller (up to 1.5 mm) feldspar grains, many of which are plagioclase (about An_{32}), and variable proportions of largely altered mafic grains which appear

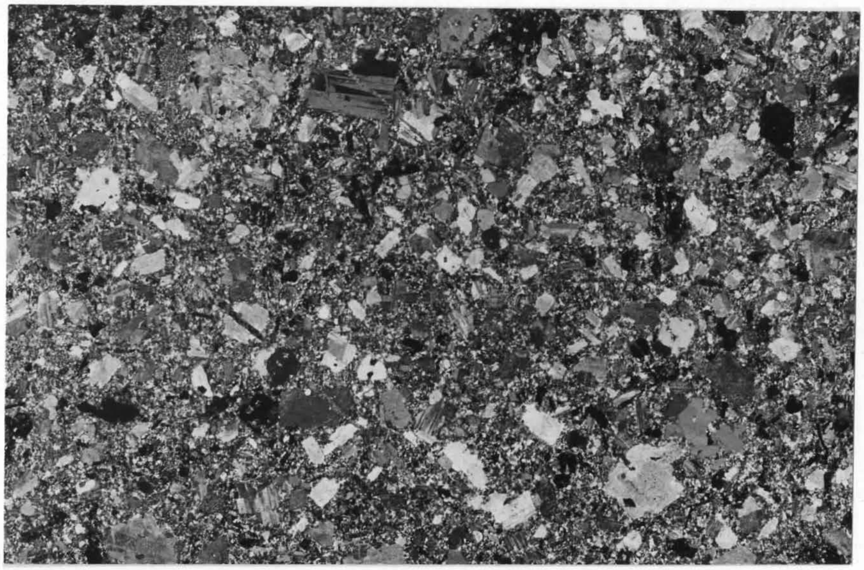

Fig. 5. Thin section of a quartz-feldspar porphyry, showing the quartz (clear white and black) and feldspar (gray or twinned) in a fine-grained groundmass. Crossed nicols, X 4.

Fig. 6. Photomicrograph of section S-1, showing a partially resorbed quartz phenocryst (lower right), and the fine-grained matrix. Crossed nicols, X 30.

to have been hornblende. The feldspars are at least twice as common as the amphiboles. The groundmass, which makes up about 40 per cent of the sections, is much finer grained and more altered than that of the quartz-feldspar porphyry. A few minute plagioclase grains, and very minor patches of quartz, were identified in the groundmass but most of it was too altered and too fine grained to identify.

Figure 7 shows a typical feldspar porphyry in plane polarized light, and Fig. 8 (crossed nicols) shows an area of the same porphyry cut by a carbonate-filled vein.

Fine Grained Felsic Volcanic Clasts

Fine grained felsic volcanic clasts were identified in the field on the basis of grain size and pale weathering colour. This class includes both very fine grained and truly aphanitic felsic clasts, as opposed to those which are distinctly porphyritic.

A felsic volcanic clast which was mistaken for chert in hand specimen has already been mentioned; a somewhat coarser sample (grains up to 1 mm in diameter) was also studied.

This section contains grains of euhedral plagioclase, anhedral untwinned feldspar, and mafic minerals

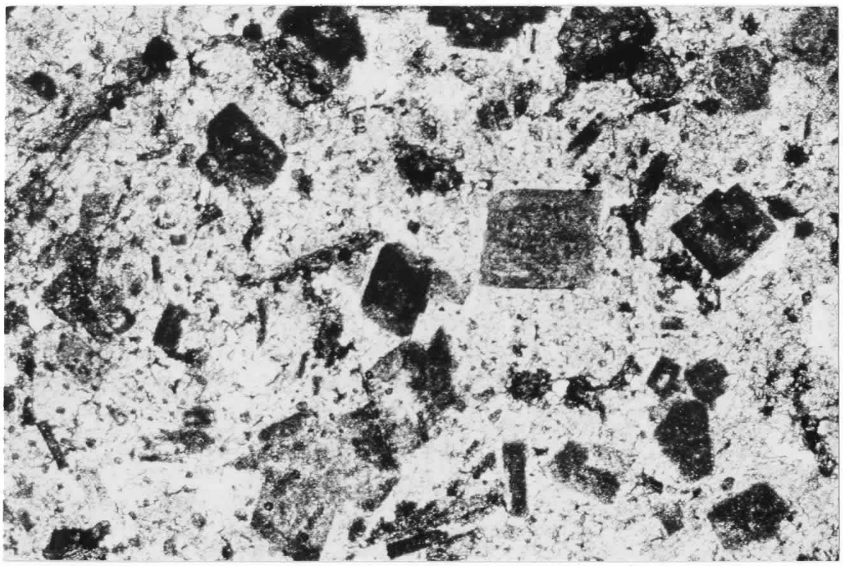

Fig. 7. Typical feldspar porphyry, showing euhedral feldspar grains (dark) in a very fine grained groundmass. Plane polarized light, X 30.

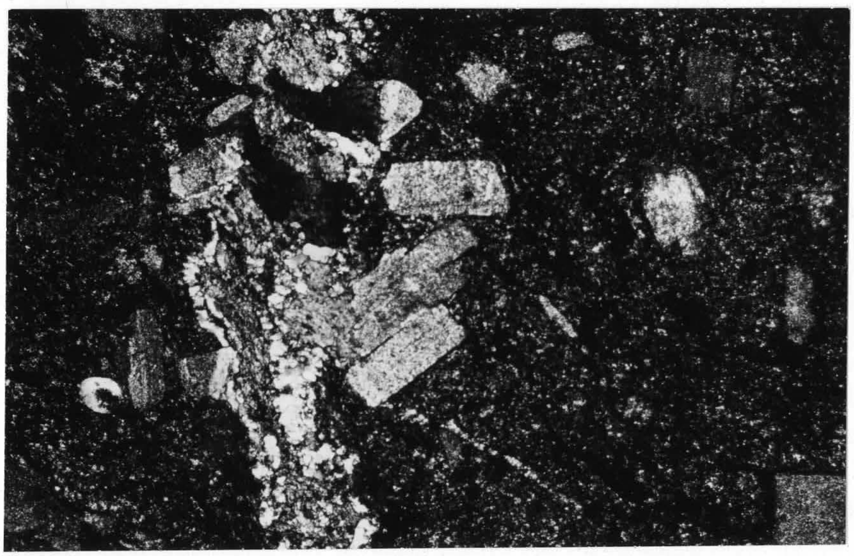

Fig. 8. Photomicrograph of a feldspar porphyry cut by a carbonate vein. Crossed nicols, X 30.

in a finer groundmass (Fig. 9). Carbonate is present throughout. The sample shows distinct banding (Fig. 10) which in thin section appears to be reflected in more intensive alteration of the darker bands. Williams, Turner and Gilbert (1954) note that in felsic volcanics, of dacitic to rhyolitic composition, fluidal banding may be accentuated by alteration; hence the banding observed in the specimen is possibly fluidal in origin.

Intermediate Volcanic Clasts

A clast tentatively identified (on the basis of gray-green weathering colour in the hand specimen) as an intermediate volcanic was studied. However, in thin section this specimen was not distinctively different from the felsic volcanic clasts described above. No other "intermediate" volcanic clasts were available for study, but it does appear that the distinction between intermediate and other volcanic clasts on the basis of colour alone is unreliable.

Mafic Volcanic Clasts

A number of samples of mafic volcanics (identified in hand specimen on the basis of deep green weathering

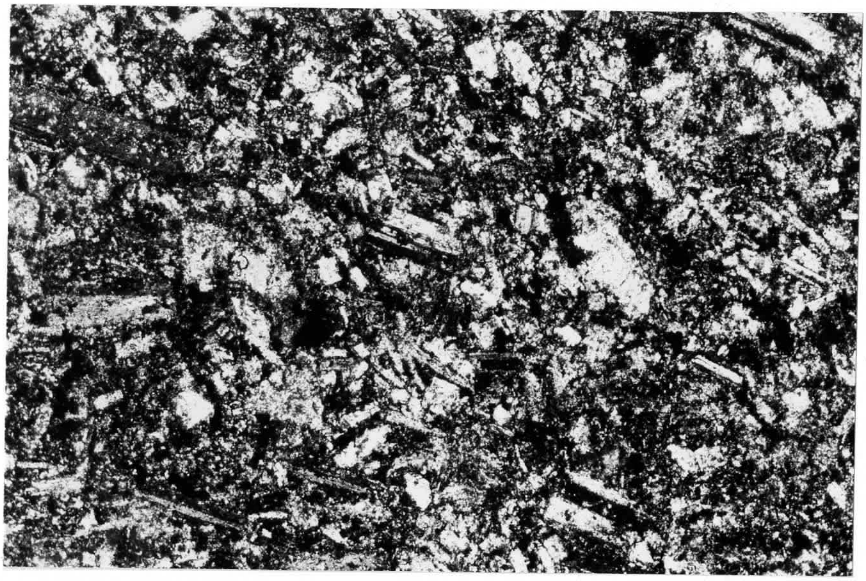

Fig. 9. Photomicrograph of a felsic volcanic clast showing euhedral plagioclase (twinned) and mafic minerals (black) in a finer groundmass. Crossed nicols, X 80.

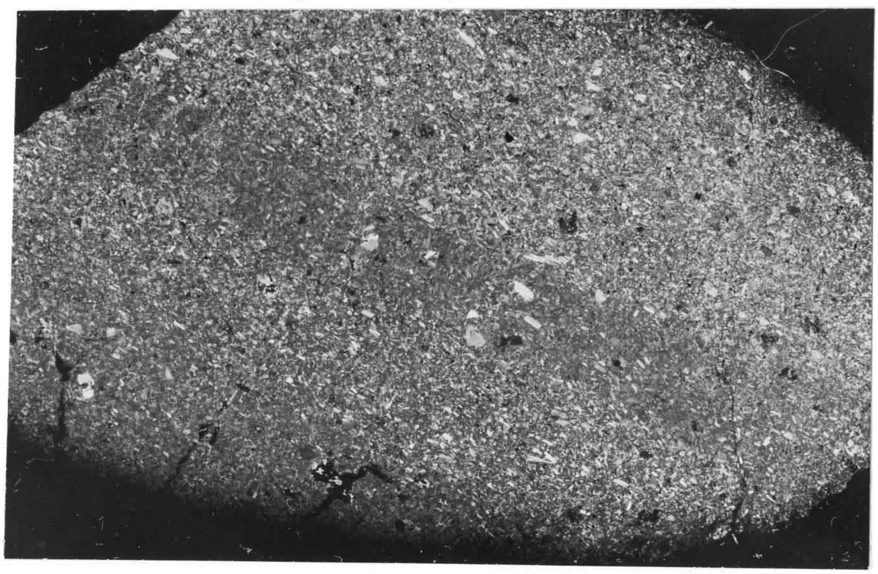

Fig. 10. Felsic volcanic clast showing distinct banding. Crossed nicols, X 4.

colour) were studied. All are highly altered.

Fig 11 is a photomicrograph of one of these samples. Its appearance is typical — thoroughly altered plagioclase laths, generally showing sub-parallel alignment, with dark, finer grained interstitial material. The large pale patches are secondary carbonate alteration. Small interstitial grains of epidote or opaque minerals are present in some of these sections. Textures generally appear to have been trachytic to pilotaxitic in the sections studied.

Fig. 12 shows a typical mafic volcanic clast.

Discussion

Thin section studies pointed out several problems in the field identification of clasts.

It is difficult to distinguish between chert and fine grained felsic volcanic clasts without thin section study, yet this is an important distinction with respect to the origin of the clasts, as true chert is sedimentary.

The field distinction, based on weathering colour in outcrop, between felsic and intermediate volcanic clasts also proved unreliable, although felsic and mafic volcanic clasts were readily distinguishable.

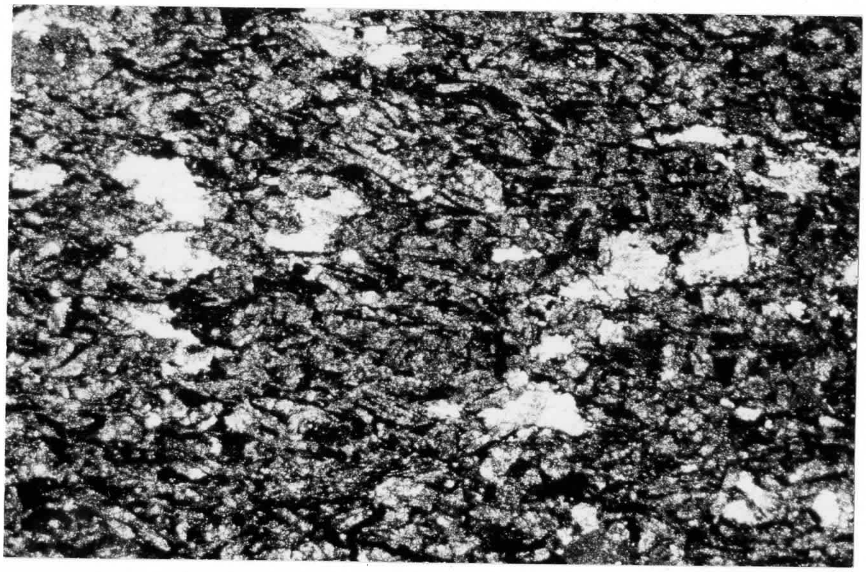

Fig. 11. Photomicrograph of a mafic volcanic clast, showing the altered feldspar laths. Crossed nicols, X 30.

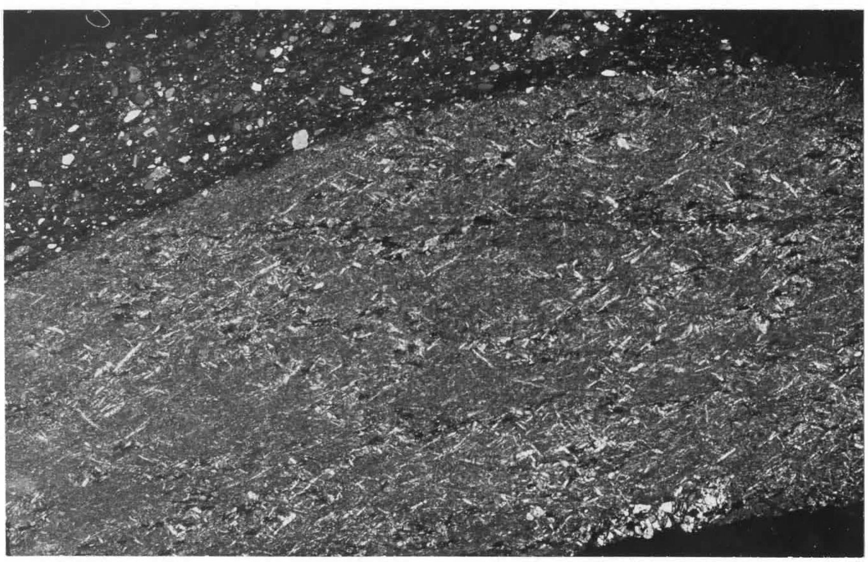

Fig. 12. A typical mafic volcanic clast with some graywacke matrix attached (lower right). Crossed nicols, X 4.

PETROGRAPHY OF GRANITOID CLASTS

Eleven granitoid clasts, selected from the field samples on the basis of differences from each other in their appearance in hand specimen, were thin sectioned for examination under the petrographic microscope in order to classify them more precisely and shed light on their possible origins.

Methods

Modal Composition

In order to differentiate between quartz, plagioclase and K-feldspar, the thin sections were stained with sodium cobaltinitrite and amaranth solutions, using the method outlined in Appendix 1. Plagioclase stains pink in amaranth, and K-feldspar stains yellow in sodium cobaltinitrite (Laniz et al, 1964).

Due to reasons still unclear, the staining was ineffective, and the procedure served only to etch the feldspars. Feldspars could be distinguished from quartz, but the plagioclase and K-feldspar could not be differentiated, unless albite or microcline twinning, or perthitic texture, were evident. Due to extensive alteration, many of the feldspar grains showed no twinning at all. It was felt that further attempts at staining would be destructive to the thin sections, so the sections were point counted for quartz, feldspars, and the other components.

A Leitz binocular microscope and mechanical stage were used for point counting. Approximately 500 points were counted from each thin section, in rows 5 mm apart with a 0.3 mm spacing between points. Turner (1972) obtained satisfactory results on granitoid clasts from a similar conglomerate by counting 400 points per thin section, therefore the number of points counted in this study is probably sufficient.

Because of the failure of the thin section staining to distinguish between plagioclase and K-feldspar, the slabs from which the thin sections had been cut were stained for feldspars using the technique of Birk (1971), Appendix 2. The K-feldspar stained excellently in all cases, but the plagioclase stains were somewhat less satisfactory. The slabs were then photographed, using slide duplicating film. The slides were projected onto a large sheet of graph paper, mounted on a metal surface, and approximately 500 points were counted on each slide using a small magnet as a marker.

Textures

Textures of the thin sections were studied using a Zeiss Student Microscope.

Results

Modal Composition

From the point counting of the thin sections, estimates of the amounts of quartz, feldspars, and other components were obtained, as tabulated in Appendix 3. Unless twinning or perthitic texture was evident, all feldspar was classed as "untwinned feldspar".

Estimates of the amounts of K-feldspar in each thin section were obtained from point counts of the slabs. The bright-yellow K-feldspar projected well onto the graph paper and could be readily identified. However, the pale grayish-pink plagioclase and grayish-white quartz were not always readily distinguishable. The points counted were therefore classified as "yellow" (K-feldspar), "pink" (plagioclase), and "gray" (plagioclase, quartz and others), as tabulated in Appendix 4.

As a result of point counts of both slabs and thin sections, estimates of the percentages of quartz, K-feldspar and minor components in the sections were obtained. It was therefore a simple matter to calculate the percentage of plagioclase in the thin sections, by the method outlined in Appendix 6.

An estimate of the actual modal composition of the thin sections, as calculated from data in Appendices 3 and 4, is given in Table 2.

Using this data the granitoid samples were classified according to the system proposed by Streckeisen (1967) and by the IUGS Subcommission on the Systematics of Igneous Rocks (1973), as shown in Fig. 13.

Samples S-6 and S-13 contain more than 10 per cent of quartz-feldspar intergrowths (Table 2). On the basis of textural evidence (see page 46), these quartz-feldspar intergrowths are considered to be granophyric and therefore have been included with K-feldspar for the purpose of plotting the compositions on Fig. 13.

The other samples contain less than 5 per cent quartz-feldspar intergrowths, which is considered myrmekite (see page 37), and is included with plagioclase in Fig. 13.

Textures

Textures of the granitoid rocks were studied in thin section in order to complete their classification and shed further light on their possible origins.

All sections showed considereble alteration,

Table 2 : Modal analyses of granitoid clasts.

	S-2	S-3	S-4	S-6	S-11	S-12	S-13	S-14	S-15	S-16	S-17
Quartz	29.6	43.9	31.7	33.1	27.8	32.2	32.5	31.5	27.7	30.6	28.2
Plagioclase	41.0	15.4	47.3	39.7	24.4	38.9	38.9	47.3	40.2	41.5	43.8
Alkali Feldspar	10.3	23.0	7.7	.1	20.7	15.6	.1	13.0	11.2	17.5	19.8
Microcline	3.2	6.0	10.2	.8	18.6	3.7		1.8	2.3	.4	tr
Perthite	10.0	.6		1.5		1.2	2.6	1.9	10.2	3.8	.8
Quartz-Feldspar Intergrowths		3.5	.2	13.0	2.2		12.1	1.1	tr	.6	1.8
Chlorite	3.2	5.7	1.9	6.2	.6	6.2	5.6	1.7	7.0	3.6	4.1
Biotite		.2	.7	.2	4.3		.2				.4
Amphibole	.2			tr	.4	1.0			tr	tr	
Sphene		.4		.4	.4	.2			tr		
Epidote					tr	.3					.2
Zircon		tr			tr					.2	
Opaque	.4	1.2	.2	2.1	tr	.5	1.1	.4	tr	.2	.2
Altered	1.9	.2	.4	2.8	.4		5.5	1.3	1.3	1.7	1.0

tr = trace: present, but not intercepted.

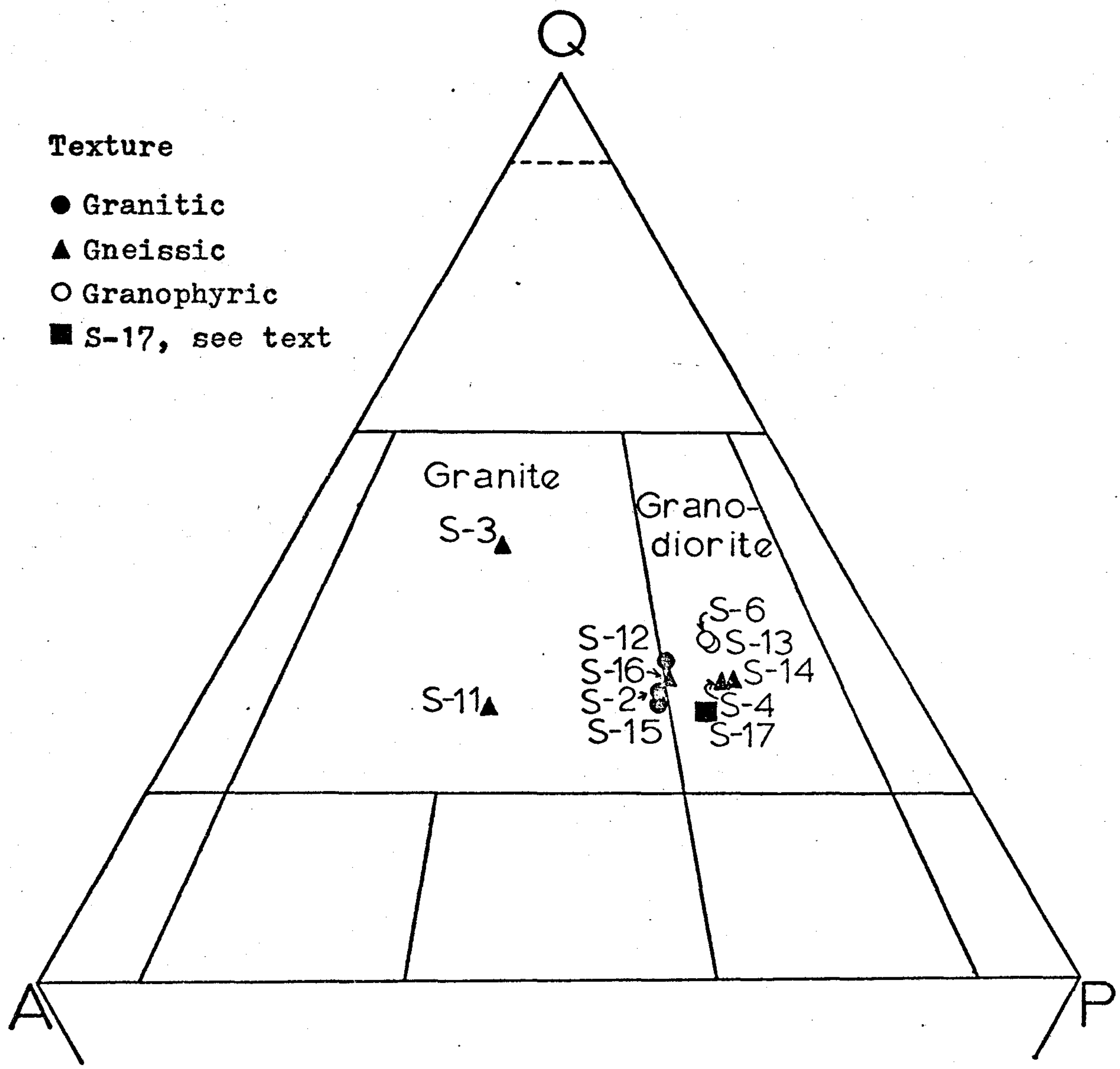

Fig. 13 : Modal classification of the granitoid clasts. Classification scheme after Streckeisen (1967) and the IUGS Subcommission on the Systematics of Igneous Rocks (1973).

with clouded feldspars and, in most cases, chloritization of the mafic minerals. Secondary carbonate is present in all sections. Due to elimination of much of the twinning by alteration, plagioclase compositions were difficult to determine. However, although very few extinction angles could be measured from most sections, the results consistently show a plagioclase composition of An_{27-32}. Only a single sample (S-14), from which but a single measurement was available, shows an anorthite content (An_{23}) outside of this range.

Sections S-6 and S-13 contain considerable amounts of quartz-feldspar intergrowths. These are discussed in part (d), page 46.

The other sections contain only a small amount of quartz-feldspar intergrowth (Table 2). Since the thin section staining was not effective, it was not possible to determine with certainty whether this intergrowth is myrmekitic (plagioclase and quartz) or granophyric (K-feldspar and quartz). These intergrowths are, however, tentatively identified as myrmekitic on the basis of the vermicular habit of the quartz, their association with apparent "mortar" (cataclastic) textures in some of the thin sections, and the "plug-like" form shown by many of the intergrowths (Fig. 14) (Shelley, 1964).

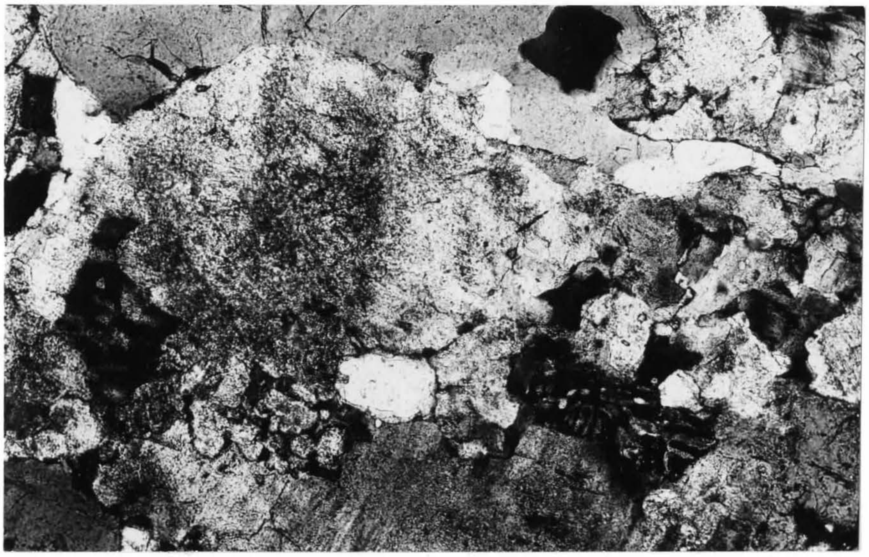

Fig. 14. Photomicrograph of gneissic granite showing myrmekite (lower right) and possible cataclastic texture (lower left). Crossed nicols, X 80.

Four distinctly different textures were observed in thin section:

(a) hypidiomorphic-granular

(b) gneissic

(c) "allotriomorphic-granular", and

(d) granophyric.

(a) Hypidiomorphic-granular Texture

Three of the eleven sections, S-2 and S-15 (granites) and S-12 (granodiorite) showed hypidiomorphic-granular texture, described by Williams, Turner and Gilbert (1954) as the commonest granitic texture (Figs. 15 and 17). In all three of the sections, euhedral to subhedral plagioclase grains about 1 to 1.5 mm in diameter are surrounded by anhedral alkali feldspar (commonly microcline or perthite), and anhedral quartz (Figs. 15 and 16). The K-feldspar and quartz grains generally average a little smaller than the plagioclase. In sections S-15 and S-12, areas of slightly coarser grain size occur, with plagioclase grains up to about 4 mm in diameter.

In section S-15 a small amount of biotite still remains; the rest has been chloritized. In the other sections all biotite has been altered to chlorite pseudomorphs.

In all three sections grain boundaries are

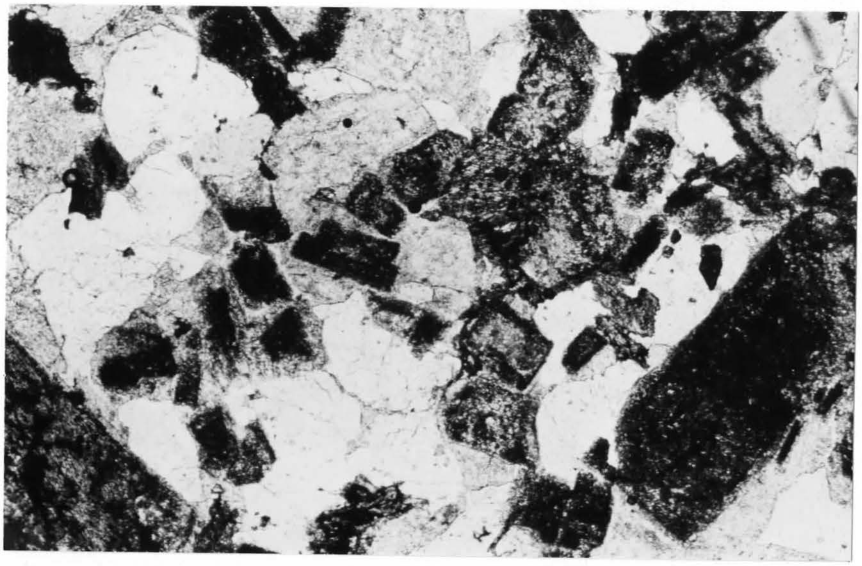

Fig. 15. Photomicrograph of granite, showing hypidiomorphic-granular texture. Plane polarized light, X 30.

Fig. 16. Photomicrograph of the same specimen as Fig. 15, showing perthite (top) and quartz (bottom) surrounding subhedral plagioclase. Crossed nicols, X 80.

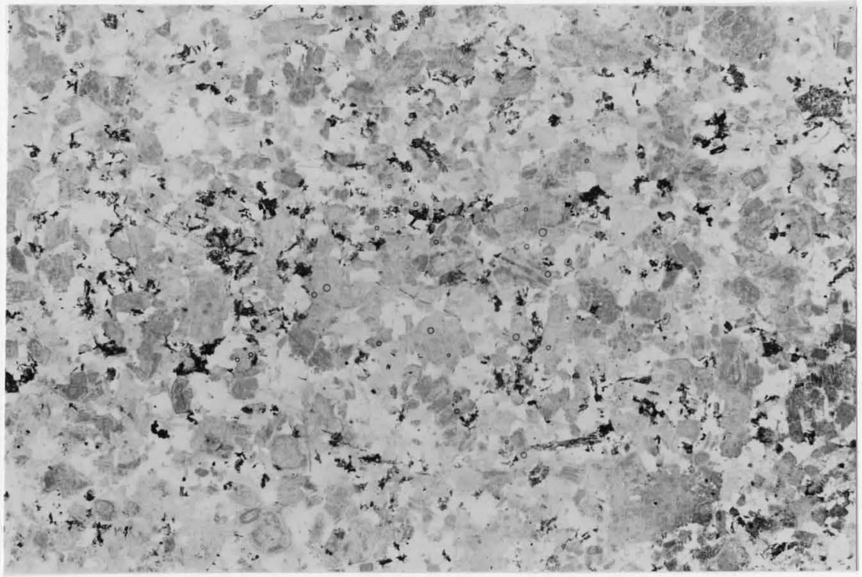

Fig. 17. Sample S-2, showing typical hypidiomorphic texture. Plane polarized light, X 4.

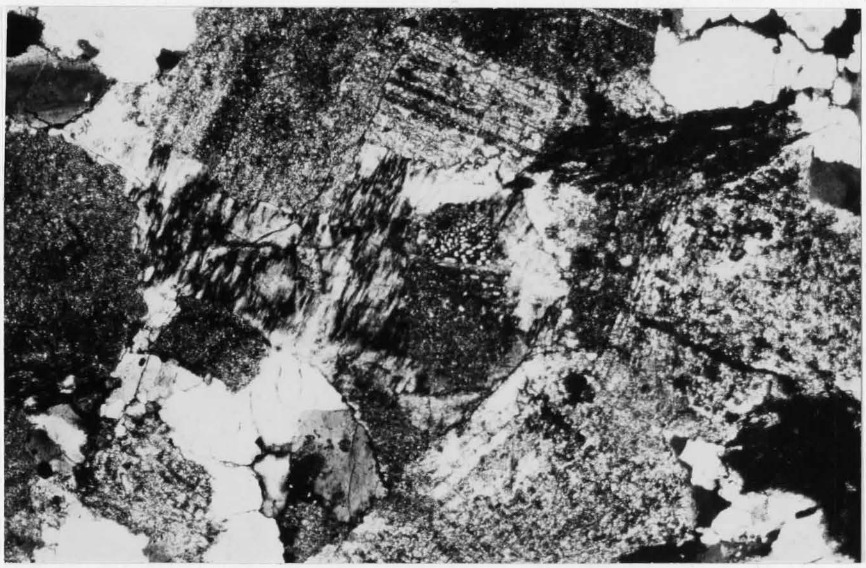

Fig. 18. Photomicrograph of a small coarse granite pebble, showing reaction between perthite and euhedral plagioclase grain (upper centre). Crossed nicols, X 30.

generally distinct; however, some reaction seems to have occurred, in a few areas, between plagioclase and quartz or plagioclase and K-feldspar, as shown by some of the plagioclase grain boundaries in Fig. 18.

It may be seen from Fig. 15 that the plagioclase grains tend to be more altered than the K-feldspar. This is the case in all the thin sections wherever the two feldspars are distinguishable.

(b) Gneissic Texture

Sections S-3 and S-11 (granite) and S-14 (granodiorite) show a distinctly gneissic texture, in which quartz and feldspars form elongate parallel masses (Figs. 19 and 20).

There are two grain sizes present. Quartz and feldspar grains averaging 1 mm in diameter make up most of the section, but their boundaries are marked by patches of small rounded feldspar and quartz grains averaging 0.25 mm in diameter (Fig. 14).

Plagioclase and K-feldspar frequently cannot be distinguished from each other in the thin sections. Examination of the stained slabs shows that in S-14 subhedral to anhedral plagioclase grains are surrounded by an irregular network of K-feldspar and by anhedral quartz. In S-3 and S-11 the gneissosity seems more pronounced, and K-feldspar and plagioclase form separate,

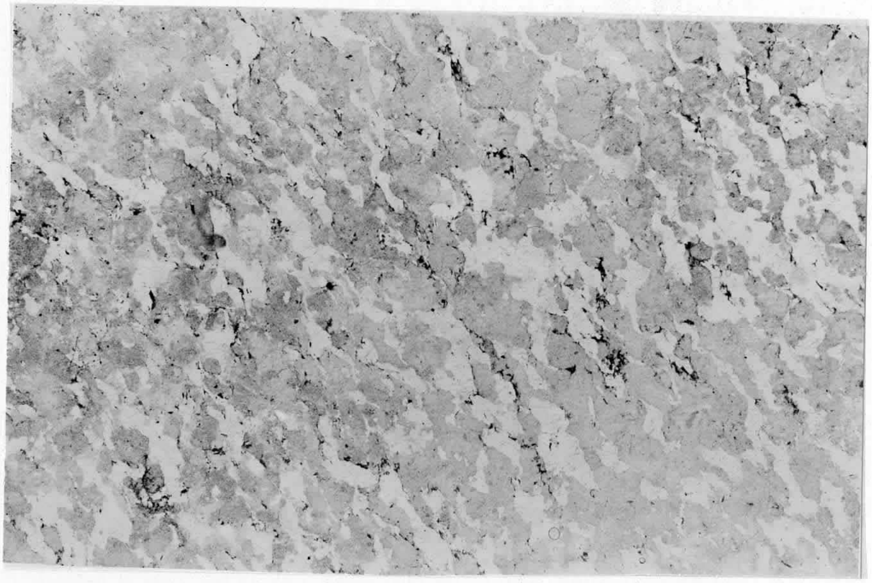

Fig. 19. Granodiorite S-14, showing gneissic texture.
Plane polarized light, X 4.

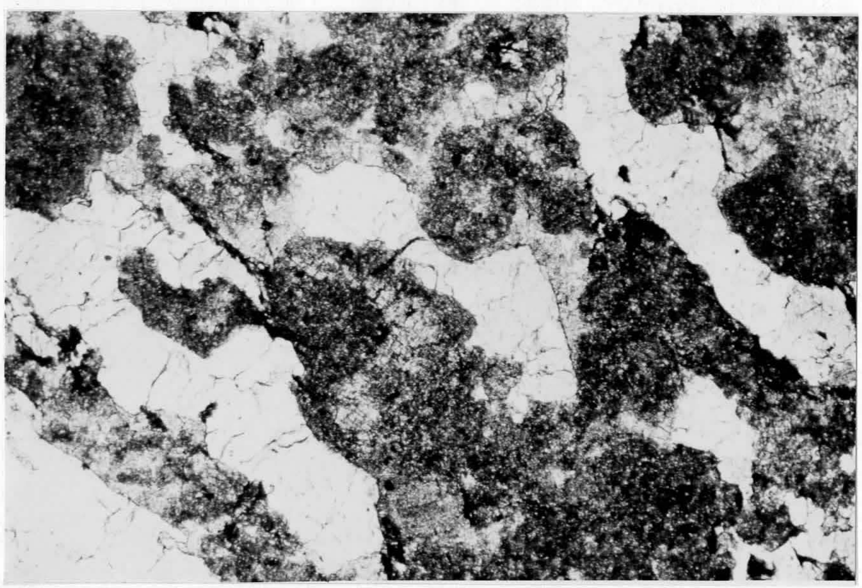

Fig. 20. Photomicrograph of the same sample as Fig. 19, showing alteration of the feldspars.
Plane polarized light, X 30.

anhedral masses.

In section S-11 much of the biotite is unaltered (Fig. 21), whereas in the other sections it has generally been replaced by chlorite.

(c) "Allotriomorphic-granular" Texture

Three of the granodiorite sections (S-4, S-16 and S-17) consist of interlocking anhedral quartz and altered feldspar masses, resembling a coarse allotriomorphic texture.

Remnants of twinning still visible in the feldspar masses, together with the intensity of alteration, suggest that the darker areas in the centres of the masses are plagioclase, while the less-altered outer portions are K-feldspar including microcline and perthite. Rarely, the darker central areas show subhedral form. Examination of the stained slabs confirms this distribution of the feldspars, showing subhedral plagioclase grains surrounded by interlocking quartz and K-feldspar.

Irregular interlocking grain boundaries, often characterized by the presence of small quartz and feldspar grains and quartz-feldspar intergrowths, are common in the "allotriomorphic-granular" sections.

In these samples the larger grains average 1 to 2 mm in diameter, while the smaller (boundary) grains

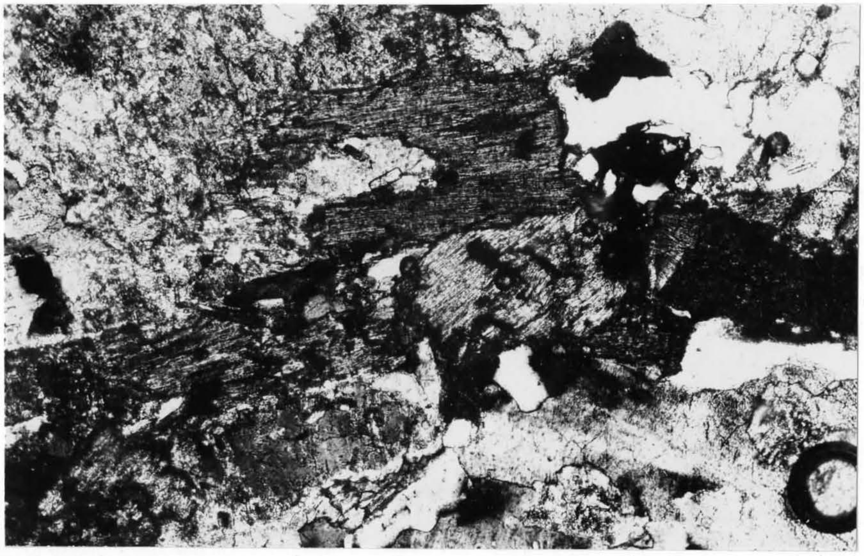

Fig. 21. Biotite in gneissic granite. Crossed nicols, X 80.

average 0.25 to 0.5 mm.

Sections S-4 and S-16 are gneissic in hand specimen, showing banding defined by variation in the proportions of K-feldspar and plagioclase. S-17 shows no gneissosity.

(d) Granophyric Texture

Sections S-13 and S-6 show hypidiomorphic texture, with euhedral to subhedral plagioclase and anhedral quartz grains surrounded by a fine grained quartz-feldspar intergrowth (Figs. 22, 23). The quartz and plagioclase grains average about 1 mm in diameter.

Modal analysis of the stained slabs shows about 15 per cent K-feldspar in each of these sections (Appendix 4), although only very minor quantities of K-feldspar (as perthite and microcline) may be seen in thin section. Furthermore, in the stained slabs, the yellow K-feldspar is distributed in a fine network molded about the other grains. This suggests that the quartz-feldspar intergrowths are composed of K-feldspar and quartz rather than plagioclase and quartz. Hence, these intergrowths are granophyric, not myrmekitic.

Discussion of Granitoid Petrography

The granitoid clasts all contain a considerable

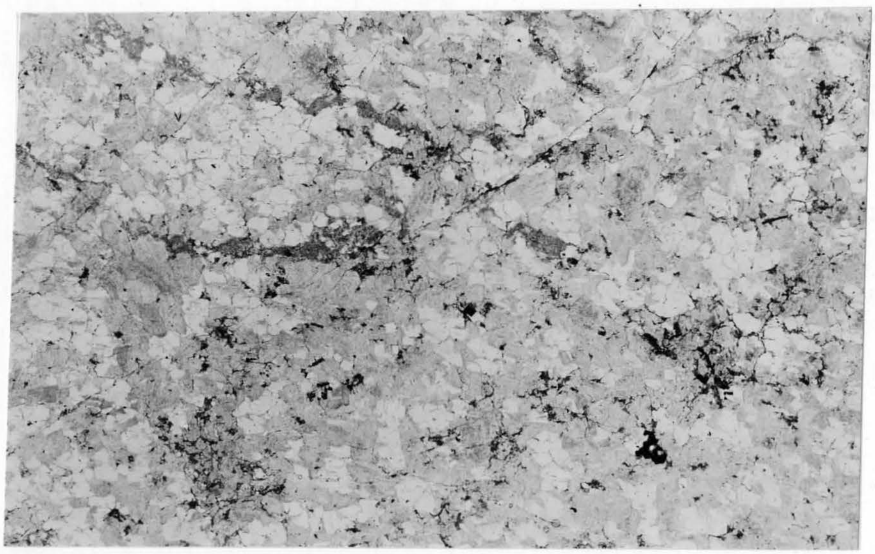

Fig. 22. Granophyric rock. Plane polarized light, X 4.

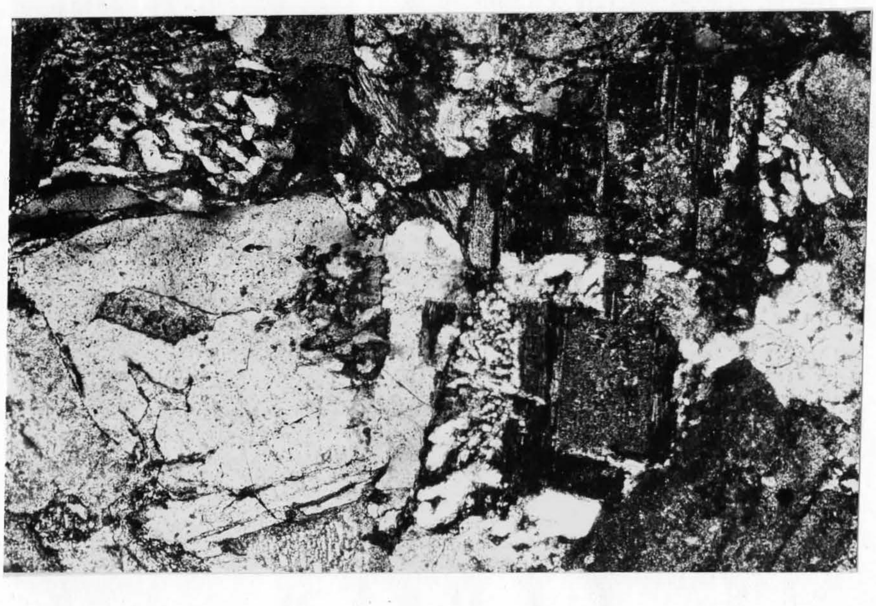

Fig. 23. Photomicrograph of the same sample as Fig. 22, showing granophyric texture. Crossed nicols, X 80.

amount of K-feldspar (Table 2). Samples S-3 and S-11 contain about 30 and 40 per cent K-feldspar, respectively, and the other samples average about 20 per cent. Donaldson and Jackson (1965) found granitoid clasts from Archean conglomerates at North Spirit Lake to be relatively free of K-feldspar, and Bass (1961) reported that granitoid clasts studied from Archean conglomerates in western Quebec and eastern Ontario are extremely low in potassium. However, Turner (1972), in a study of Archean granitoid clasts from the Abram Lake area, reports that up to 30 per cent of the feldspar is microcline; and Walker and Pettijohn (1971) report about 15 per cent alkali feldspar in granitoid pebbles from an Archean conglomerate at Minnitaki Lake.

Four of the granitoid clasts from the "Loose Pebble Bay" conglomerate are granite, and seven are granodiorite (Fig. 13). Nine of the 11 samples plot as a tight group straddling the granite-granodiorite line, and the points representing the samples with granophyric texture are virtually superimposed. Despite attempts in the field and in the laboratory to select different granitoid clasts for analysis in order to cover the full range of compositions, all but two of the samples are closely grouped, suggesting considerable compositional homogeneity among the granitoid clasts of the "Loose

Pebble Bay" conglomerate.

In those specimens with hypidiomorphic-granular texture, the euhedral form of the plagioclase indicates that plagioclase is an early-crystallizing magmatic phase.

It appears that the non-hypidiomorphic-granular specimens studied have undergone either deformation or post-crystallization reactions between the grains. Traces of albite and microcline twinning, and perthite, indicate that, with the possible exception of the gneissic specimens S-3 and S-11, the grains are present in the same general relation to each other as in the hypidiomorphic-granular specimens; that is, plagioclase surrounded by K-feldspar and quartz. The plagioclase grains are often rounded to irregular, however, and the presence of fine-grained aggregates of quartz and feldspars with rare myrmekite along the boundaries of the larger grains suggests either crushing or reactions between the grains with partial recrystallization and growth of myrmekite. Shelley (1964) states that myrmekite is commonly associated with mortar (cataclastic) textures and suggests its origin by the recrystallization of quartz in albite exsolving from orthoclase. It seems possible, therefore, that the "allotriomorphic-granular" specimens, and the gneissic specimen S-14, are deformed equivalents of the hypidiomorphic-granular rocks.

The granitic texture and medium grain size of the hypidiomorphic-granular specimens indicate relatively slow cooling within an intrusive body. The specimens with gneissic and "allotriomorphic-granular" textures could represent the deformed border phase of such an intrusion.

Barker (1970) states that "myrmekite seems restricted to plutonic (igneous and metamorphic) rocks that contain modal K-feldspar", while "granophyric intergrowths occur . . . in epizonal and extrusive rocks". The two granophyric specimens studied may therefore have solidified at relatively shallow depth compared to the other specimens.

All of the textures observed might be expected to occur in a single intrusion — the hypidiomorphic-granular texture at moderate depth, the gneissic and "allotriomorphic-granular" textures as marginal phases, and the granophyric texture at the shallowest level.

This suggests the possibility that the granitoid clasts are cogenetic, which bears upon the question of possible sources for these rocks.

Even though the granitic bodies surrounding the greenstone belts are generally in intrusive or fault contact with the belts (Ojakangas, 1972), it has commonly been assumed that granitic sources were highlands flanking the greenstone belts (for example, Pettijohn, 1943; Donaldson and Jackson, 1965; Goodwin, 1968; Walker and Pettijohn, 1971). Such an assumption implies a pre-existing sialic crust.

However, in the Vermilion volcanic-sedimentary belt, granitic detritus can be traced to a granite which apparently intruded the volcanic-sedimentary sequence during volcanism and sedimentation (Ojakangas, 1972). Turner and Walker (1973) suggest a similar origin for granitic debris in the Abram-Minnitaki greenstone belt sediments, on the basis of mafic volcanic xenoliths found in granitoid boulders.

Nine of the eleven granitoid clasts from the "Loose Pebble Bay" conglomerate have proved to be remarkably similar in composition (Fig. 13), and differences in their textures, as described above, may be explained in terms of different positions of emplacement within a single intrusion.

It is possible, therefore, that these granitoid clasts may have had their origin in a pluton which intruded the Manitou Lake greenstone belt during sedimentation, and was unroofed and eroded.

No trace of such an intrusive body has been found, however; and more than one intrusion would likely be required to account for the presence of the two samples, S-3 and S-11, which are distinctly different in composition from the remaining nine samples.

A pre-existing sialic crust, having a relatively-uniform composition over much of the area from which the granitoid clasts found in the "Loose Pebble Bay" conglomerate were eroded, therefore remains a possible source for the clasts. Such a large source area could readily account for the compositional variations observed.

It has been assumed, above, that since the compositions of the granophyric rocks plot in the same area as the compositions of most of the other granitoid clasts, their origins are probably similar. This is not necessarily true. Granophyric intergrowth is known to occur in the upper portions of large differentiated gabbroic intrusions, such as the Skaergaard (Hyndman, 1972), and this texture is also known to result from incorporation of sediments and granites into basaltic magma (Barker, 1970). Formation by metasomatic replacement has also been proposed (Barker, 1970).

It appears that the final fraction of melt from which granophyric rocks form may bear little relation to the initial magma, and any meaningful speculations as to the origin of a particular granophyric rock would have to be based on studies of the original igneous body, rather than a single clast from it.

Origin of Granitic Magma

It is generally believed that large volumes of granite may result from partial fusion of high-grade metamorphic rocks (Winkler, 1967; Marmo, 1971; Fyfe, 1973). A number of variables affecting the conditions of formation have been experimentally investigated. On the basis of such experimental investigations, Von Platen (1965) states that "we cannot use the melting diagram of the simple system Or-Ab-Q-H_2O when discussing complex natural rocks".

Winkler and Von Platen (1960) studied partial melting of clays, shales and graywackes at partial pressures of water of 2000 and 4000 bars, and found anatectic temperatures to decrease from 700°C at 2000 bars to 680°C at 4000 bars. (These conditions are similar to those proposed for the upper amphibolite facies of regional metamorphism).

Von Platen (1965) suggested that the Ab/An ratio of plagioclase also controls the minimum melting temperature and orthoclase content of the melt, so that both minimum melting temperature and orthoclase content increase with increasing An content. This correspondence between the An content of plagioclase and the temperature of melting is also noted by Winkler (1967).

Von Platen (1965) also studied the effect of the substitution of a small amount of HCl in a fluid phase initially composed entirely of H_2O, and found that at a fluid pressure of 2000 bars, the presence of 0.05 moles per litre of HCl reduced the minimum melting temperature, when the Ab/An ratio was held constant, for rocks of all plagioclase compositions.

Thus it appears that the minimum melting temperature of a rock is a function of P_{H2O}, the Ab/An ratio of the plagioclase, and the presence of volatiles, as well as temperature.

Brown and Fyfe (1970) investigated the effects of varying total pressure and temperature on the composition of granitic melts produced from dry and water saturated mixtures of granitic and dioritic compositions, noting decomposition temperatures and pressures of the hydrated phases present. The mixtures contained either 10 per cent (granitic composition) or 50 per cent (dioritic composition) of the major water bearing phases of high-grade metamorphic rocks (muscovite, biotite and hornblende).

The results of these experiments are shown in Fig. 24. Brown and Fyfe concluded that, "As average crustal rocks in their high grade metamorphic state contain most of their water in biotite and hornblende, the shaded area of Fig. 24 might be the major area of production of

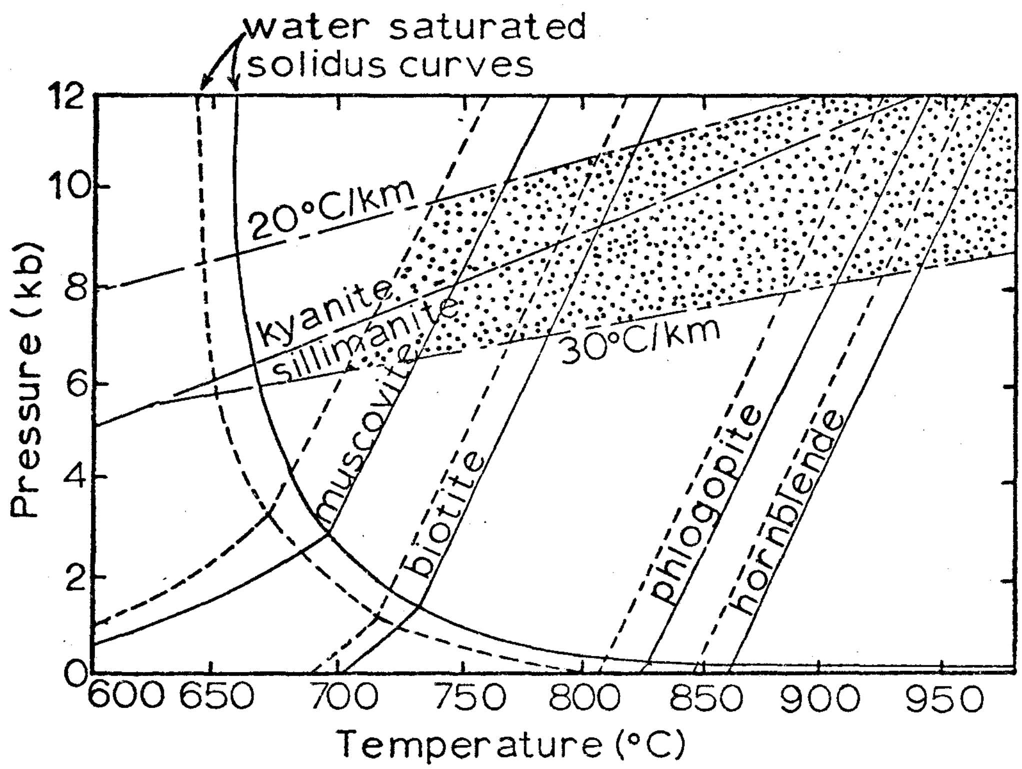

Fig. 24 : Beginning of melting in granitic (dashed lines) and dioritic (solid lines) compositions (after Brown and Fyfe, 1970). The shaded area is a probable region for maximum magma generation under modern thermal gradients.

large masses of granitic liquids. This region, found in these studies, is in striking accord with the information from migmatite regions and the temperature of extrusion of acid rocks."

Fig. 24 shows that a series of melting reactions, involving muscovite, then biotite, and finally hornblende, would occur. The amount of hydrated phases and easily-fusible fractions present in the volume of rock affected influence the amount of melt produced (Brown, 1970; Fyfe, 1973).

Brown and Fyfe (1970) analyzed the early melt fractions produced in the experiments, and found remarkable similarity of the melts produced. With decreasing pressure and temperature, the liquids changed gradually from granodioritic to granitic composition; these results are summarized in Fig. 25.

From this figure it may be seen that melts similar in composition to the "Loose Pebble Bay" granitoids studied were produced at pressures of about 7 to 8.5 kb, and temperatures of about 750 to 850^{o}C. With an average geothermal gradient of about 30^{o}C/km, this would correspond to a depth of melting of about 27 km.

Granites are commonly associated with orogenic regions, however, and the geothermal gradient could be much higher, up to 50^{o}C to 100^{o}C/km (Tihor, 1973), so that

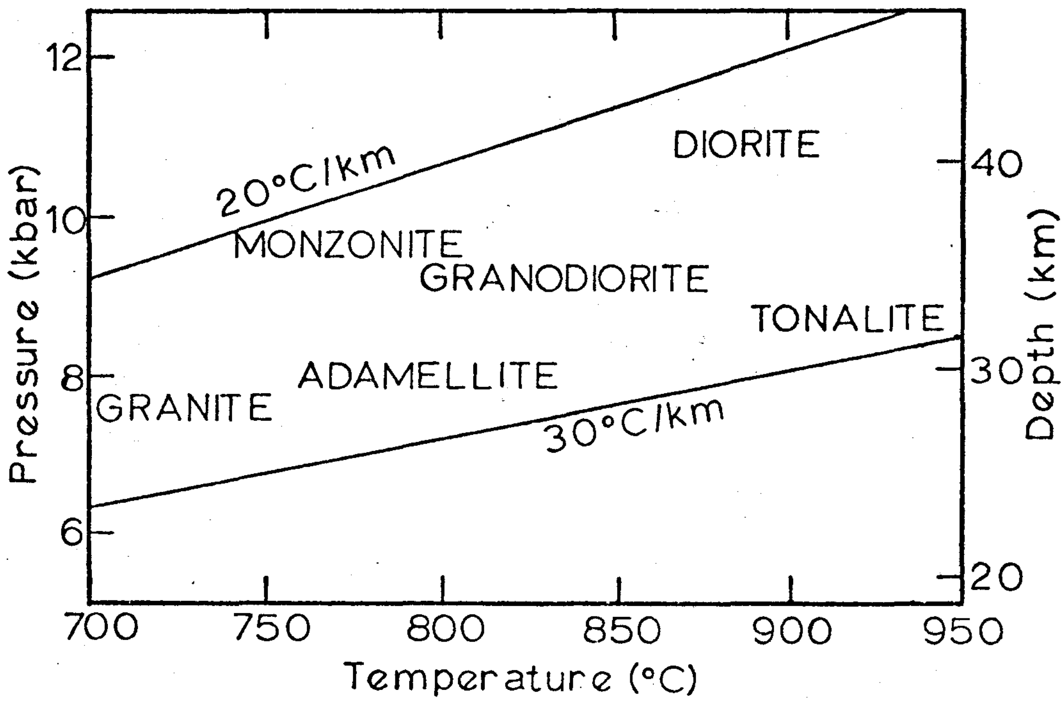

Fig. 25: Compositional trends of liquids formed by the Melting process of Fig.24 (after Brown, 1970).

a depth of magma generation as shallow as 8 km would be conceivable. In support of this, Fyfe (1973) suggests that the rate of heat production in the Archean may have been substantially greater than the modern rates, so that melting may have taken place at shallower levels.

Few speculations can be made as to the depth of emplacement of the igneous bodies from which the "Loose Pebble Bay" conglomerate clasts were eroded, or the depth of erosion in the source area; textures of the granitoid clasts imply only relatively slow cooling.

However, Brown (1970) suggests that since granitic melts require more water for saturation than granodioritic melts, their production will generally be more limited than the production of the drier melts, and the granitic melts, if formed at the lowest temperature of crustal fusion, "cannot rise far (rapidly falling P) before being trapped by their melting curve (water saturated solidus) and being forced to crystallize". Brown therefore suggests that true granitic melts tend to remain deeper in the crust, while drier granodioritic to dioritic melts can rise to shallower levels before crystallizing, and may even form eruptive rocks.

SUMMARY AND CONCLUSIONS

Determination of the percentages of clast types in the "Loose Pebble Bay" conglomerate has shown that most of the conglomerate can be accounted for in terms of the underlying stratigraphy. Lithologies equivalent to mafic and felsic volcanic, porphyry, iron formation, and sedimentary clasts are all present in the rocks underlying the conglomerate. No source for the granitoid pebbles can be found among the local rocks.

Petrographic examination of the various clast types has pointed out the importance of supplementing field identifications with thin section studies. The very important distinction between sedimentary chert and volcanic felsites is uncertain without thin sections, and may be difficult even with them. Reliable separation of intermediate volcanic clasts from either mafic or felsic volcanic clasts is not possible from field criteria.

Modal analysis reveals a general homogeneity in composition of the granitoid clasts of the "Loose Pebble Bay" conglomerate.

The samples of granitoid clasts have been divided into four textural types:

(a) hypidiomorphic-granular

(b) gneissic

(c) "allotriomorphic-granular", and

(d) granophyric

It is suggested that the rocks showing gneissic and allotriomorphic-granular texture represent originally-hypidiomorphic-granular rocks which have been deformed and/or partially recrystallized along grain boundaries.

The granophyric specimens may have solidified at relatively shallower depths compared to the other granitoid specimens, whose granitic and gneissic textures indicate intrusive origin and relatively slow cooling.

All of these textures might be observed in one pluton: the granitic texture at moderate depth, the gneissic and allotriomorphic textures at the margins, and the granophyric texture at a high level. Compositional similarity between nine of the 11 samples also suggests that these rocks could have originated from a single granitic pluton.

Intrusion of a pluton into the volcanic-sedimentary sequence, followed by uplift and erosion, would account for the presence in the "Loose Pebble Bay" conglomerate of both the granitic clasts and the clasts with lithologies similar to those of the underlying stratigraphic sequence.

No evidence of such an intrusive body has been found at Manitou Lake, however, and the presence of two granitic clasts noticeably different in composition from the others suggests that a single small source might not be adequate to account for the clast types observed.

The presence of a sialic basement, external to the volcanic-sedimentary belt, cannot be ruled out.

By means of comparisons with published experimental data it is suggested that the "Loose Pebble Bay" granitoid clasts formed from melts produced at pressures of about 7 to 8.5 kb and temperatures of about 750 to 850°C. However, the relationship between the positions of initial melt and final emplacement is complex and not readily apparent.

APPENDIX 1

Feldspar Staining Technique for thin sections

(Laniz et al, 1964)

TIME	PROCEDURE	EXPLANATION
	thin section (no cover)	
15 seconds	etch in HF vapor	
15 seconds	immerse in Na-cobaltinitrite conc. solution	K-feldspars turn yellow
briefly	rinse in tap water	
	immerse in $BaCl_2$ solution (5% by weight)	
	dip in distilled water	
1 minute	immerse in amaranth solution	plagioclases turn red (except An_o)
	dip once in water	
	sweep away excess amaranth with compressed air	

APPENDIX 2

Feldspar Staining Technique for slabs

(Birk, 1971)

TIME	PROCEDURE	EXPLANATION
	rock slab	
	clean with organic solvent	
30 seconds	etch in 80% HF	etches quartz to frosty grey
	wash with distilled water	
1 minute	Na-cobaltinitrite conc. solution	K-feldspars turn yellow
	wash with distilled water	
15 seconds	5% $BaCl_2$ (by weight)	
	wash clean in distilled water	
1 minute	Amaranth Red conc. solution	plagioclases turn red (except An_o)
	wash under cold tap water	
	air dry	

APPENDIX 3

Modal analyses of granitoid clasts, from thin section

	S-2	S-3	S-4	S-6	S-11	S-12	S-13	S-14	S-15	S-16	S-17
Quartz	29.6	43.9	31.7	33.1	27.8	32.2	32.5	31.5	27.7	30.6	28.2
Plagioclase	9.6	5.5	16.9	13.1	4.9	14.3	12.8	1.8	9.8	16.6	17.9
Untwinned Feldspar	41.7	32.9	38.1	26.7	40.4	40.2	27.5	58.5	41.6	42.4	45.7
Microcline	3.2	6.0	10.2 (Microcline + Perthite)	.8	18.6 (Microcline + Perthite)	3.7		1.8	2.3	.4	tr
Perthite	10.0	.6		1.6		1.2	2.6	1.9	10.2	3.8	.8
Quartz-Feldspar Intergrowths		3.5	.2	13.0	2.2		12.1	1.1	tr	.6	1.8
Chlorite	3.2	5.7	1.9	6.2	.6	6.2	5.6	1.7	7.0	3.6	4.1
Biotite		.2	.7	.2	4.3		.2		tr		.4
Amphibole	.2			tr	.4	1.0			tr	tr	
Sphene	tr	.4		.4	.4	.2			tr		
Epidote		tr		tr	tr	.3	tr		tr		.2
Zircon		tr			tr					.2	
Opaque	.4	1.2	.2	2.1	tr	.9 (Opaque + Altered)	1.1	.4	tr	.2	.2
Altered	1.9	.2	.4	2.8	.4		5.5	1.3	1.3	1.7	1.0

tr = trace : present, but not intercepted.

APPENDIX 4

Modal analyses of granitoid clasts, from stained slabs.

	S-2	S-3	S-4	S-6	S-11	S-12	S-13	S-14	S-15	S-16	S-17
Pink	34.0	17.6	20.6		23.8	25.4	25.8	47.3	42.0	42.6	31.7
Gray	42.5	52.8	61.5	84.0	36.9	54.1	59.4	36.0	34.3	35.7	47.7
Yellow	23.5	29.6	17.9	15.4	39.3	20.5	14.8	16.7	23.7	21.7	20.6
Other				.6						1.0	

Slab S-6 did not stain well for plagioclase.

'Other' is probably pyrite

APPENDIX 5

Modal analyses of granitoid clasts, calculated from appendices 3 and 4, and equivalent to Table 2.

	S-2	S-3	S-4	S-6	S-11	S-12	S-13	S-14	S-15	S-16	S-17
Quartz	29.6	43.9	31.7	33.1	27.8	32.2	32.5	31.5	27.7	30.6	28.2
Plagioclase	41.0	15.4	47.3	39.7	24.4	38.9	40.2	47.3	40.2	41.5	43.8
Alkali Feldspar	10.3	23.0	7.7	.1	20.7	15.6	.1	13.0	11.2	17.5	19.8
Microcline	3.2	6.0	10.2 (Microcline + Perthite)	.8	18.6 (Microcline + Perthite)	3.7		1.8	2.3	.4	tr
Perthite	10.0	.6		1.5		1.2	2.6	1.9	10.2	3.8	.8
Quartz-Feldspar Intergrowths		3.5	.2	13.0	2.2		12.1	1.1	tr	.6	1.8
Chlorite	3.2	5.7	1.9	6.2	.6	6.2	5.6	1.7	7.0	3.6	4.1
Biotite		.2	.7	.2	4.3		.2		tr		.4
Amphibole	.2			tr	.4	1.0			tr	tr	
Sphene	tr	.4		.4	.4	.2			tr		
Epidote		tr		tr	tr	.3	tr		tr		.2
Zircon		tr			tr					.2	
Opaque	.4	1.2	.2	2.1	tr	.5 (Opaque + Altered)	1.1	.4	tr	.2	.2
Altered	1.9	.2	.4	2.8	.4		5.5	1.3	1.3	1.7	1.0

tr = trace : present, but not intercepted.

APPENDIX 6

An example of the reconciliation of modal analyses from thin sections and stained slabs (sample S-14). Data from appendices 3 and 4.

1) From the stained slab, K-feldspar = 20.5
   From the thin section, perthite = 1.2
   twinned microcline = 3.7
   4.9 = 4.9
   Hence, untwinned alkali feldspar = 15.6

2) The thin section contains 40.2 untwinned feldspar
   of which 15.6 is alkali feldspar (step 1),
   leaving 24.6 as untwinned plagioclase.

   The thin section contains 14.3 twinned plagioclase
   Hence, total plagioclase= 38.9

3) However, there is only 25.4 pink in the slab
   Consequently 13.5 of the grey must be unstained plagioclase.

4) The slab contains 54.1 grey
   of which 13.5 is unstained plagioclase (step 3),
   leaving 40.6 of the grey as quartz and other constituents.

5) The thin section contains a total of 40.3% quartz plus other constituents, so the thin section and slab are reconciled, with a 0.3% error.

6) Tabulate reconciled values in appendix 5.

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