MORPHOLOGY AND CHEMISTRY OF EARLY PRECAMBRIAN METABASALT FLOWS, UTIK LAKE, MANITOBA.

A Thesis

Presented to the

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of

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In Partial Fulfillment

of the Requirements

for the degree

Master of Science

by

ROY HARGREAVES

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ABSTRACT

A 400m thick, sequence of Early Precambrian, tholeiitic metabasalt flows consisting of interlayered massive and pillowed units was mapped in detail at Utik Lake, Manitoba.

Metamorphic grade is low to middle greenschist facies but most flows have preserved primary textures. A typical flow is composed of randomly oriented plagioclase laths (An_{55}) in a matrix of actinolite and minor iron-titanium oxide grains. The flows are aphyric, except for sparse pseudomorphosed pyroxene grains near the base of the thickest massive flow, and plagioclase microporphyritic textures in the lower parts of many massive flows. The central parts of other massive flows locally contain plagioclase laths with belt-buckle and swallow-tail morphologies suggestive of rapid cooling from a crystal-poor residual liquid in the flow. No chemical variations were observed across flows or between flows.

Flows consisting entirely of pillows have smooth to undulating upper surfaces and range in thickness from 1m to 100m. The thicker pillowed units may represent several pillowed flows, but flow contacts are difficult to define. Criteria which help define flow contacts include the presence of lateral zones of intrapillow cavities, conformable alteration zones, and thin (2cm) zones of hyaloclastite adjacent to pillow selvages.

Both discrete and interconnected two-dimensional pillow shapes are present but most pillows are probably interconnected in three dimensions. The pillows probably originated by a subaqueous budding process analogous to digitating subaerial pahoehoe toes.

Most massive flows have smooth upper surfaces and range in

thickness from 3m to 35m. Individual flows comprise three zones: (1) a basal chilled zone, (2) a central massive zone, and (3) an upper chilled zone. Both upper and lower chilled surfaces vary in thickness and are independent of flow thickness. Basal chilled zones locally contain incipient pillows.

Some massive flows have strongly altered flow-top breccias. The alteration involved calcium addition, and is characterised by the presence of diopside, minor epidote and clinozoisite in interfragmental areas and replacing original material. This alteration, and other alteration present as fracture fillings and clots in some pillowed flows, may represent reaction with ocean water.

Most massive and pillowed flows extend across the entire area, a distance of 500m. Other flows are less extensive and terminate within the map area. In one observed flow termination, a massive flow abruptly changed into an interconnected pillowed flow unit. In some massive flows with brecciated tops, the breccia is absent near the inferred termination of the flow.

CONTENTS

LIST OF FIGURES

LIST OF PLATES

LIST OF TABLES

INTRODUCTION

General Statement

The Superior Province of the Canadian Shield consists partly of sinuous, east-trending metavolcanic-metasedimentary sequences of Early Precambrian age. Volcanic, volcaniclastic and sedimentary material are present in varying amounts and vary in relative proportions from sequence to sequence. Most sequences are isoclinally folded and have faulted and/or intrusive contacts with the surrounding granitic rocks that make up most of the Superior Province. The sequences appear to be only remnants of large deformed volcanoes, but they are amenable to study because the upright isoclinal folds and glaciated surfaces provide good cross-sections, and because primary structures and textures are well preserved despite the folding and greenschist facies metamorphism. In order to understand better the history of these supracrustal rocks, the stratigraphy, morphology and depositional environments of individual units and of the sequences must be documented more fully. Recent major contributions in this field have been made by Barager (1968), Boutcher et al, (1966), Goodwin (1962; 1966; 1968a; 1968b) and Wilson et al, (1974) among others.

In this thesis, the author will document the vertical and lateral morphological variations in a 400m thick sequence of massive and pillowed basaltic flows. Chemical and petrographic variations through selected flows have been determined with special emphasis being placed on pre-metamorphism alteration. Recent investigations of Early Precambrian basaltic flows have also been made by Pearce (1974), Pearce and Birkett (1974), Gelinas and Brooks (1974), Pyke et al, (1973), Côté and Dimroth (1976), and Dimroth et al, (1978).

Processes of Subaqueous Basaltic Volcanism.

Subaqueous volcanism dominates modern volcanic regimes, but the processes are poorly known because of the inherrent difficulty of examination. Much of our data about subaqueous volcanism comes from uplifted subaqueous sequences. In this regard, the Early Precambrian metavolcanic sequences are excellent sources of information because the isoclinal folding has produced cross-sections through thick subaqueous sequences.

Many Early Precambrian and younger basaltic sequences consist of intimately interlayered massive and pillowed units but the precise relationship and genesis of these units is not well documented. In some areas the pillowed and massive units represent discrete flows but in other areas they are combined in various proportions to form complex flows (Dimroth et al, 1978; Côté and Dimroth, 1976; Cook, James and Mawdsley, 1931; and Wilson, 1942).

The origin of pillows is controversial, particularly in the Early Precambrian (Jones, 1968; Johnston, 1969) because until recently, (Moore et al, 1973; Moore, 1975), pillows had not been observed during formation. Many ideas on pillow development have been postulated since the inception of the term pillow by Cole and Gregory (1890) and many hypotheses were discussed in Lewis' (1914) classic paper. Some of these are hypothetical mechanisms whereas others are based on observed processes. Throughout the years, two schools of thought have developed and differ in whether pillows are discrete individuals (Johnston, 1969) or are connected to other pillows (Jones, 1968; Moore et al, 1973; Moore, 1975; Vuagnat, 1975). The controversy has arisen because many Early Precambrian exposures are two dimensional and show mainly discrete pillows whereas many younger flows have three-dimensional exposures and are mainly interconnected. Both types of pillows may exist, but the apparent discrete nature of many Early Precambrian pillows may be an artifact of the two-dimensional exposure, and incomplete examination.

Observations of advancing submarine pahoehoe flows at Hawaii (Moore, 1975) and of well exposed ancient pillowed flows (Jones, 1968) indicate that most if not all pillows are produced by a submarine mechanism similar to the digital advance of subaerial pahoehoe toes. By this mechanism, lava moves through interconnected lava tubes to the flow front where the tube ruptures and a small amount of lava is extruded to form a pillow. Each pillow is connected to other pillows except for a few pillows that break off to form discrete entities. The pillows generally trend downslope, but form a complex entrail-like pattern (Fig. 1). Because of this pattern, a two-dimensional section through a pillowed sequence will produce pillows that appear to be either discrete or interconnected, depending on the eroded view of the pillow. This is particulary important when determining the origin of pillows in glaciated sequences of the Canadian Shield where only two-dimensional pillow shapes are generally visible. Pillowed units eroded perpendicular to flow direction would exhibit many apparently discrete pillows and only a few pillows would show connections to other pillows. An eroded section parallel to the movement direction would also show many apparently discrete pillows because of the entrail-like pattern but there would be more connected pillows than in a perpendicular section (Fig. 1). Thus the presence of some interconnected pillows within a pillowed flow infers that most pillows in that flow are connected, and were formed by the digital advance of submarine pahoehoe.

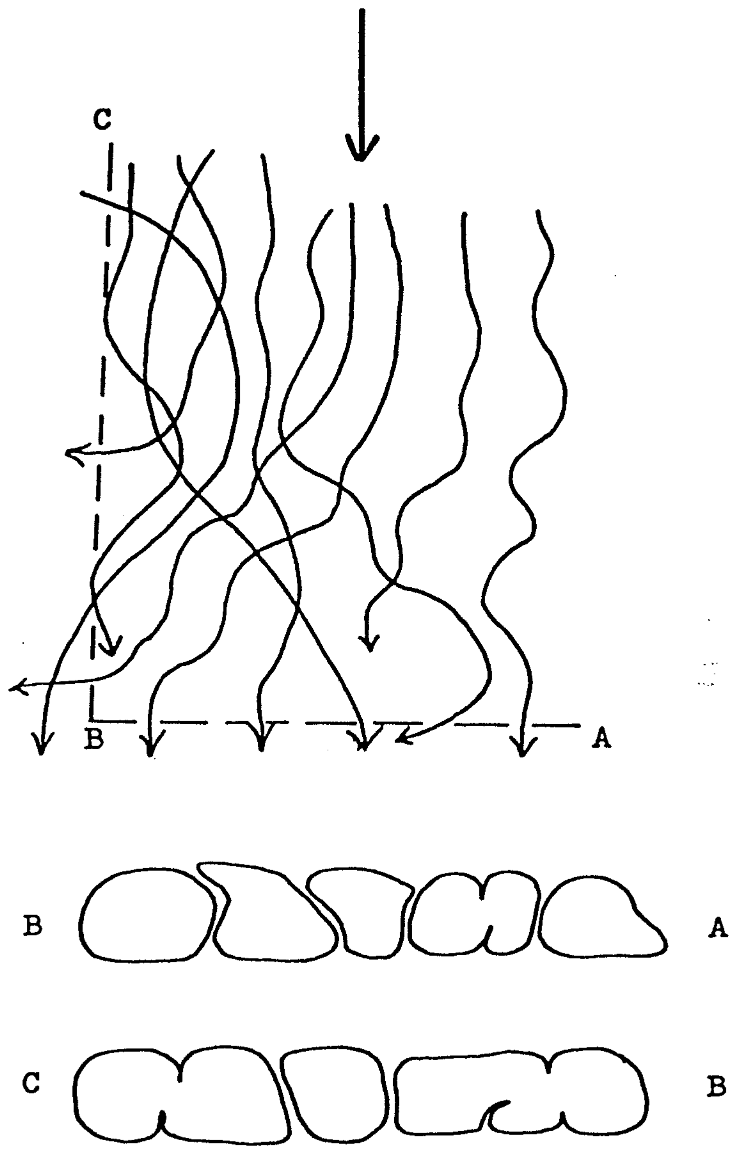


Figure 1. A plan view (top) and sections BA and CB through an entrail-like submarine pahoehoe flow. The curved lines in the plan view represent the paths taken by individual pillows and the arrow-heads indicate their movement direction. Section BA is perpendicular to the general movement direction (heavy arrow) and shows that the majority of pillows are apparently discrete entities whereas section CB parallel to movement direction shows the pillows to be mostly interconnected. Because of the curving of individual pillows, the section parallel to the general flow direction still shows pillows cross-sections rather than longitudinal sections.

The fact that differently oriented sections through a pillowed flow yield apparently different types of pillows partly explains why geologists cannot agree on whether pillows are discrete (Johnston, 1969) or interconnected (Jones, 1968).

LOCATION AND ACCESS

Utik Lake is 130km east of Thompson, Manitoba (Fig. 2). The area mapped is on Mistuhe Island, a recently burned island near the southern edge of the lake (Fig. 3). Access was by float-equipped aircraft from Thompson.

PREVIOUS WORK

Little geological work was done at Utik Lake prior to 1951 when Milligan (1952); Allen (1953); and Milligan and Take (1954) mapped various portions of the Utik Lake-Bear Lake area. Quinn (1955) also mapped the area as part of a regional geological study of the Knee Lake area. The most recent work was done by Weber (1974a, 1974b).

METHOD OF STUDY

An area $2km^2$ was mapped at various scales during the summers of 1974 (Hargreaves, 1974), 1975 (Hargreaves, 1975a, 1975b), and the fall of 1976 (Hargreaves, 1976). Three weeks were spent mapping the sequence on specially flown 1:4000 air photographs. Another seven weeks were required to map the aphyric sequence at 1:1200 scale. Three stratigraphic sections were measured, and 1:60 detailed outcrop maps were prepared where warranted.

Double fist-sized samples were collected at 2m vertical intervals through each massive flow in each section. Pillowed flows were sampled by collecting material from the centers of four similar-sized pillows

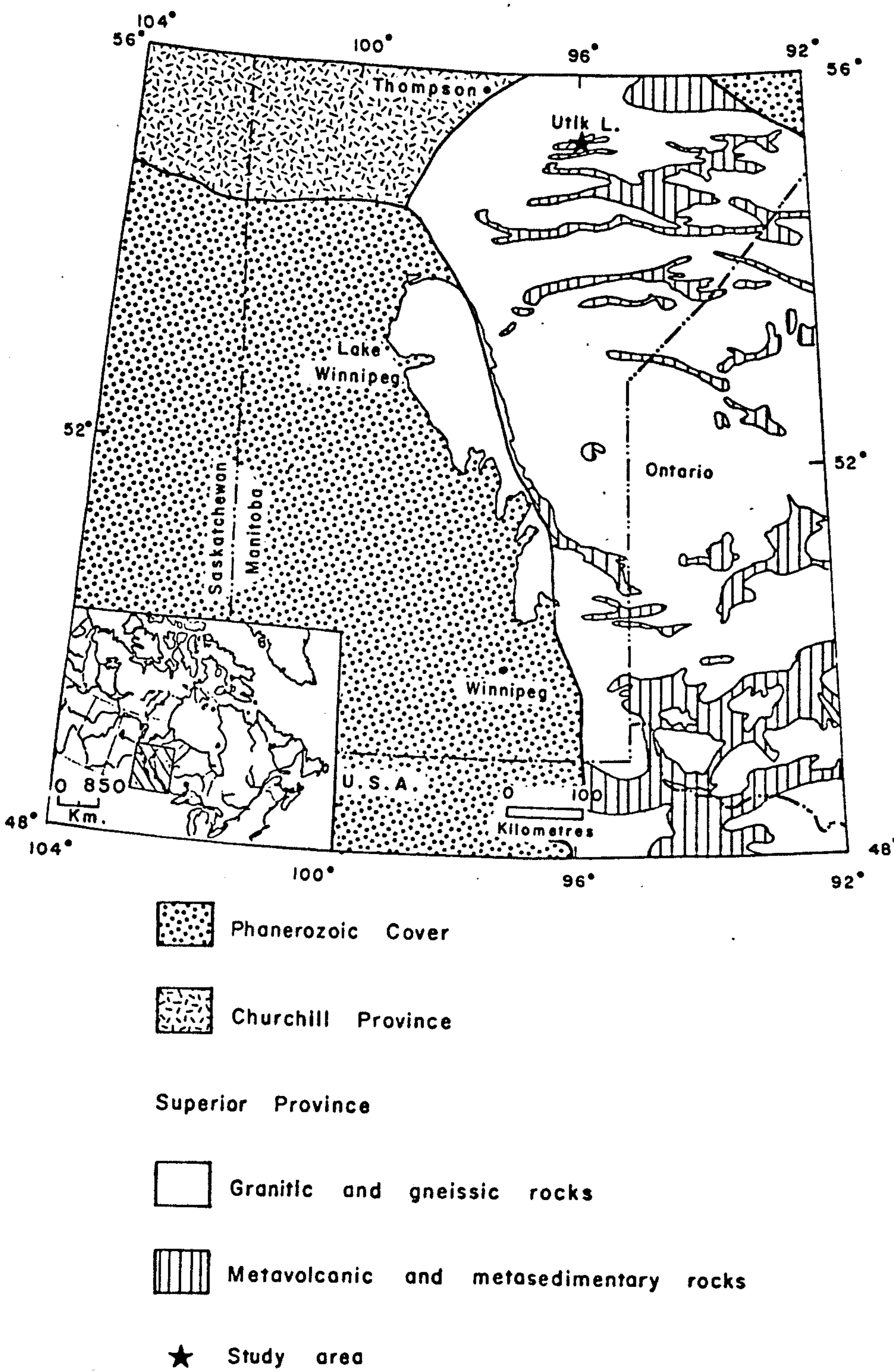
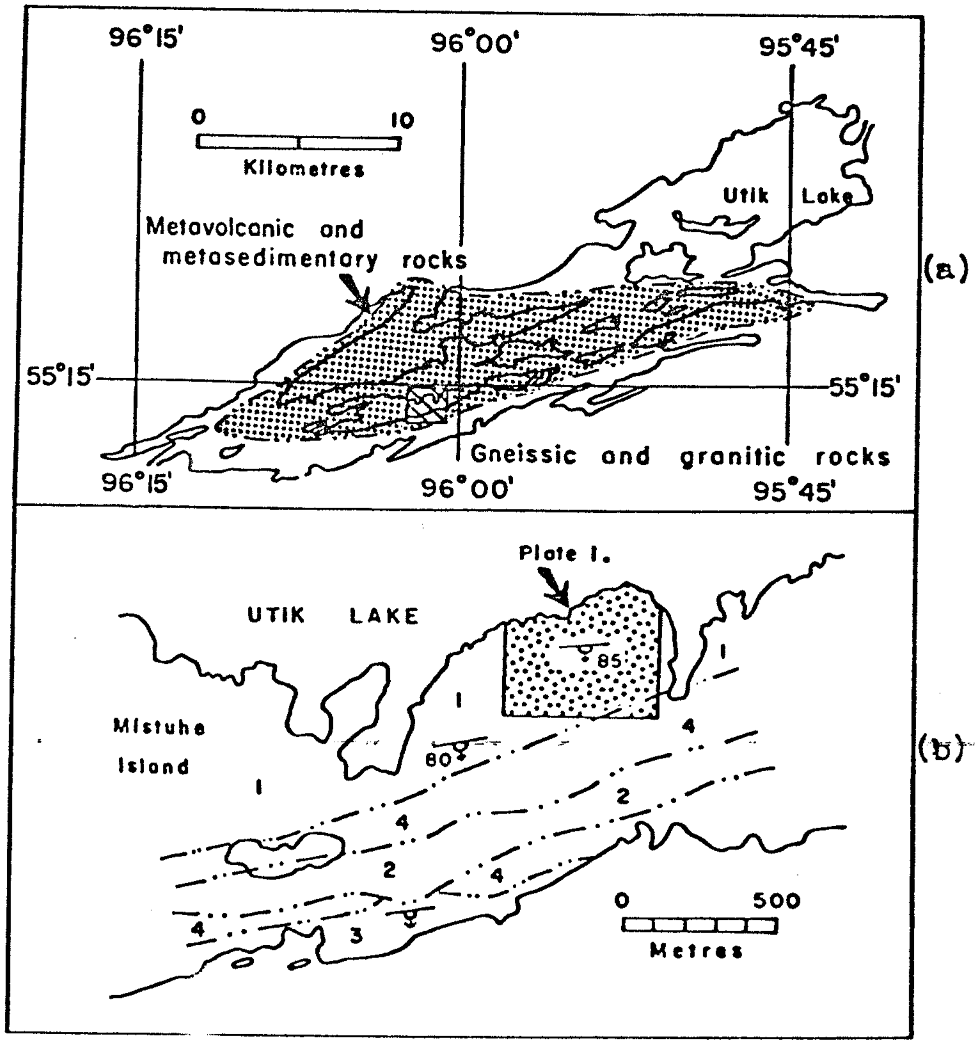


Figure 2. Map showing study area and regional geology.



4 Gabbro

3 Bedded intermediate tuff, lapillistone and pillowed porphyritic basalt

2 Massive and pillowed porphyritic basalt with iron formation

1 Interlayered massive and pillowed aphyric basalt with flow-top breccia

—··— Geological contact

85 Strike and dip of inclined pillowed lava flows, top known

Figure 3. The local geology of (a) Utik Lake and (b) Mistuhe Island outlining the area of intensive study.

(1m to 1.5m in length) in order to establish consistency. The selvages, amygdules, variolites and interpillow and intrapillow cavity material were also sampled where possible.

Over 400 thin sections were examined and 24 samples were chemically analysed. The analyses were carried out in the Department of Earth Science Laboratories, University of Manitoba under the supervision of K. Ramlal utilising X-Ray Fluorescence and wet chemical techniques.

PHYSIOGRAPHY

An extensive cover of glacial drift, sand, and clay has left much of Utik Lake with very low relief, and only along the southern edge of the lake does relief exceed 25m. Local wave action has cleaned most shoreline exposure, but inland exposures are rare and where present are heavily lichen-covered.

A forest fire in 1973 on Mistuhe Island destroyed the vegetation, and removed the lichen cover from inland outcrops which are more abundant than in most other parts of the Utik Lake area. In the intensively studied area (Plate 1) exposure is about 20 percent and is exceptionally clean. Swamps and muskegs are dry, permitting easy access to the center of the island.

ACKNOWLEDGEMENTS

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Capable assistance was rendered in the field by T. McDonald, C. Cutforth and U. Hamann in 1974; and by the late W. Foidart in 1975. The author would also like to thank S.R. Smith, who accompanied him in the field during the fall of 1976.

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GEOLOGIC SETTING

The Utik Lake metavolcanic-metasedimentary sequence is thought to be a continuation of the Hayes River Group (Milligan and Take, 1954), first documented by Wright (1925) at Island Lake. The portion exposed at Utik Lake is wedge-shaped and has a maximum width of 5km (Fig. 3). It is an east-trending, vertically dipping, south-facing homocline. Four mafic volcanic cycles are exposed, each separated by a period of quiescence, during which volcanically derived conglomerate, greywacke and mudstone were deposited. Numerous synvolcanic gabbro and quartz-feldspar porphyry plutons intruded the volcanic sequence, and are most likely related to volcanism higher in the sequence. Large massive to foliated granodiorite plutons with cupolas of alaskite intruded the sequence and now form its margins. These granitic plutons separate the metavolcanic-metasedimentary sequence from an extensive gneissic terrain.

The metavolcanic rocks are generally poorly exposed, but exceptionally good exposure occurs on Mistuhe Island where the uppermost volcanic cycle is exposed. Formations exposed on Mistuhe Island include:

Formation	Description	Thickness (metres)
4	Differentiated metagabbro sill	300
3	Bedded intermediate tuff, lapillistone and pillowed porphyritic basalt flows	90
2	Massive and pillowed porphyritic basalt flows with interflow iron formation	110
1	Interlayered massive and pillowed aphyric basalt flows	400

On Mistuhe Island the formations trend 085°, are vertically dipping and become successively younger southward (Fig. 3b). Although the sequence is part of an isoclinal fold, flow-top breccias and pillows are only slightly deformed. Metamorphic grade varies from hornblende-hornfels facies south of the island to albite-epidote-hornfels facies along the northern shore. Foliation is absent, with plagioclase laths and actinolite growths having felted and random habits respectively.

Formation 1 consists of intimately interlayered massive and pillowed aphyric basalt flows. Massive flows range in thickness from 3m to 35m, and pillowed flows from 1m to 100m, although some of the thicker pillowed sequences may represent several flows.

In formation 2, massive and pillowed porphyritic flows range in thickness from 2m to 27m, and contain tabular plagioclase phenocrysts or xenocrysts up to 4cm long. Further west, the phenocrysts are up to 12cm long. The phenocrysts are concentrated in a 1m to 2m thick zone near the top of the flows where they form up to 15 percent of the flow. They decrease in abundance downward, and the average phenocryst content is about 3 percent. Most phenocrysts are recrystallised and partly altered to sericite, but one relatively fresh crystal was Labradorite (An_{60}). Locally, porphyritic massive flows are separated by penecontemporaneously deformed iron formation units. Basalt immediately below the iron formation is commonly altered to a fine-grained, white to rusty weathering material containing abundant garnet and anthophyllite (Weber, 1974a). Similar white weathering material occupies joints and fractures in the upper part of the flow.

Pillowed porphyritic flows increase in abundance southward relative to massive flows, and are interlayered with bedded intermediate tuff, lapillistone, and iron formation of formation 3.

A differentiated metagabbro sill (formation 4) and smaller related sills were emplaced along the contact between formations 1 and 2. Four distinct zones are present in the main sill: (1), a basal clotted gabbro, (2) coarse-grained gabbro, (3) medium-grained gabbro, and (4) a capping pegmatitic gabbro. Gravity settling appears to have been the main agent of differentiation, and the pegmatitic gabbro was the last part of the sill to crystallize.

A minor swarm of feldspar porphyry dikes striking 170° occurs within the aphyric flow sequence along the north shore of the island. These grey-coloured dikes rarely exceed 1m in width, and can be traced across two or three flows. One such dike near the top of the aphyric sequence contained xenoliths of massive medium-grained granite.

Only formation 1 is well exposed and commonly shows complete sections through one or more flows on the larger outcrops. Exposures of this type are essential to flow morphology studies, and the remainder of this thesis will be devoted to these aphyric flows.

GENERAL PETROGRAPHY

The aphyric basalt in formation 1 weathers deep olive green and is black on fresh surfaces. It is fine to medium-grained (up to 2mm) and consists of 30 to 40 percent plagioclase, 55 to 65 percent actinolite, 5 percent iron-titanium oxide, and minor sphene, biotite and epidote. Plagioclase is the only mineral that retains its primary shape of felted laths and microlites, but primary textures are not preserved in all flows. The actinolite forms blades and prisms that probably replaced original pyroxene and glass.

FLOW TYPES

Thirty-six flows have been recognized in formation 1 (Plate 1, in pocket). Of these, 13 are pillowed and comprise 38 percent of the sequence; the remaining 23 flows are massive (Table 1). Massive flows are of two basic types: simple flows that have lower and upper chilled zones but lack other major structural features, and complex flows which have an upper flow-top breccia. Both types of massive flows can have incipient pillows in their lower chilled zones (Fig. 4). The three flow types are interlayered as either single flows or sequences of several flows (Plate 1), and are treated collectively from this point onwards.

Flows range in thickness from 3m to 35m for massive flows and from 1m to 100m for pillowed flows, although some of the thicker pillowed units may represent several flows.

Simple Massive Flows

These flows have a very fine-grained (0.05mm) basal chilled zone up to 30cm thick. Incipient basal pillows are present locally in the chilled zone and appear as attached pillow-like forms or deeply

Table 1. Types of Flows in Formation 1

(1) This includes the lowermost 26 flows on Plate 1, for which thickness data are most reliable.

Flow Type	Total number	Total thickness	Percentage of Sequence[1] by number	by thickness
Pillowed flows	13	135m	38%	46%
Massive flows (total)	23	265m	62%	54%
Simple massive flows (total)	13	112m	31%	23%
with chilled base and top	13		27%	20%
with chilled base and top and basal incipient pillows	2		4%	3%
Complex massive flows (total)	10	153m	31%	31%
with flow-top breccia	10		23%	16%
with flow-top breccia and basal incipient pillows	2		8%	15%

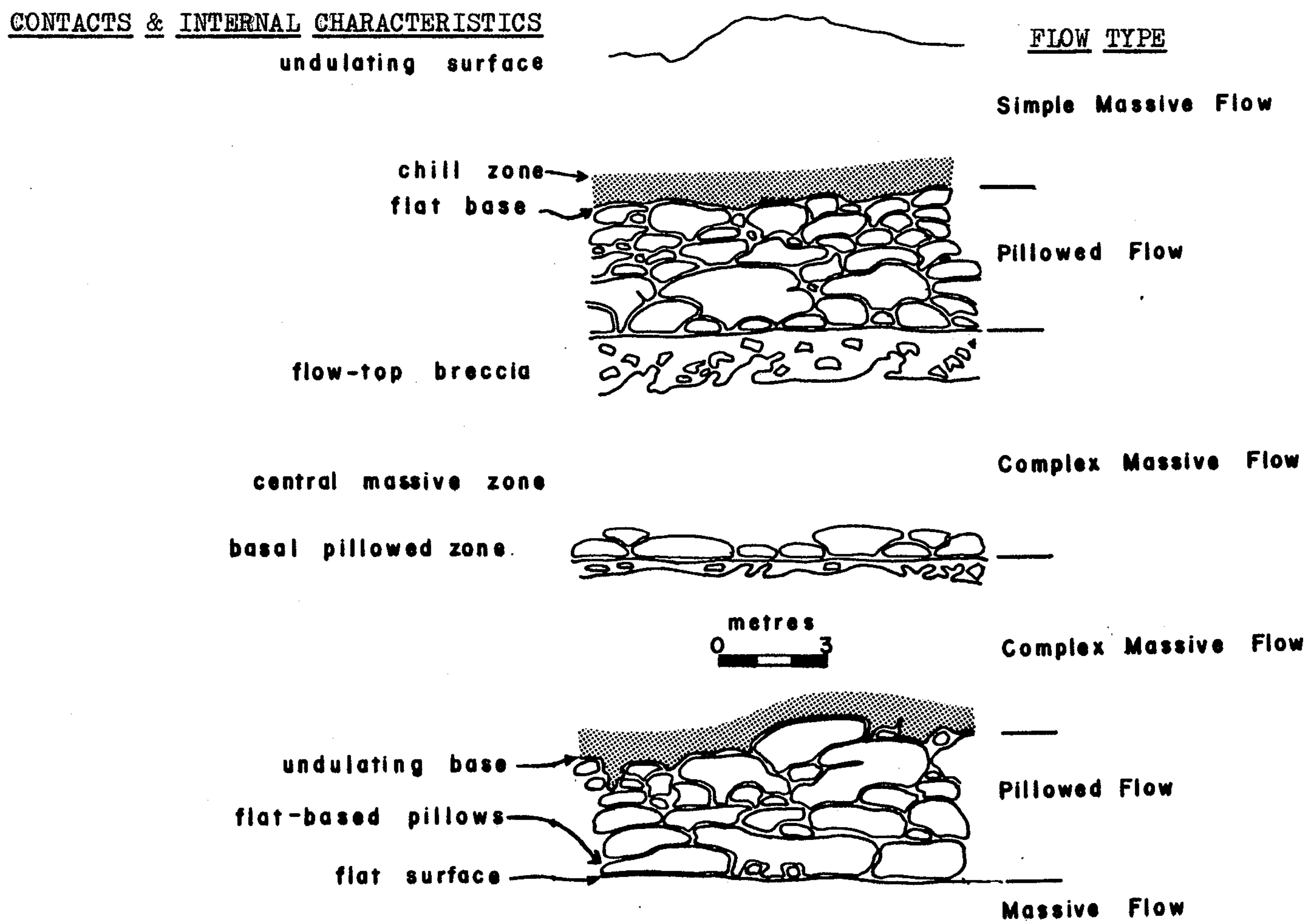

Figure 4. Composite section showing the various types of flows in formation 1, their internal characteristics, and the nature of their contacts.

re-entrant selvages that resemble the sides and bases of pillows (flow 21 in Fig. 5). The incipient pillows form a one pillow thick, discontinuous layer less than 0.5m thick. They may represent rapid digital advance of the flow where the upper selvages of the basal pillows, and any higher pillows have been remelted by the hot interior of the flow.

Basal chilled zones weather lighter green than the bulk of the flow and grade rapidly upward into a coarser central zone where groundmass plagioclase is up to 2mm long (Fig. 6). The upper chilled zone weathers dark green, and is the same colour as the interior of the flow. It is not readily apparent in outcrop, but a very fine grain size (0.05mm) was noted in the matrix. Quartz-filled amygdules are rarely present.

In the upper surface of flow 3 (Plate 2, in pocket) cooling fractures 1mm to 1m wide (Fig. 7) and up to 2m deep were observed. These fractures have a spacing of 15cm and vary from perpendicular to slightly inclined to the flow surface; minor subsidiary fractures parallel to the flow surface are also present. A white weathering calcium-rich diopside-epidote-clinozoisite alteration lines the fractures. Some of the wider fractures (0.3m to 1m in width) contain pillows that are completely surrounded by selvage. The viscosity of these pillows must have been low because the pillows conform to the shape of the cracks (Fig. 8). These pillows are probably related to the overlying pillowed flow but could also represent a type of squeeze-up in the massive flow. The fact that some of the cooling fractures developed into wide cracks indicates that some flow movement occurred after the fractures first developed. Similar cracks were not

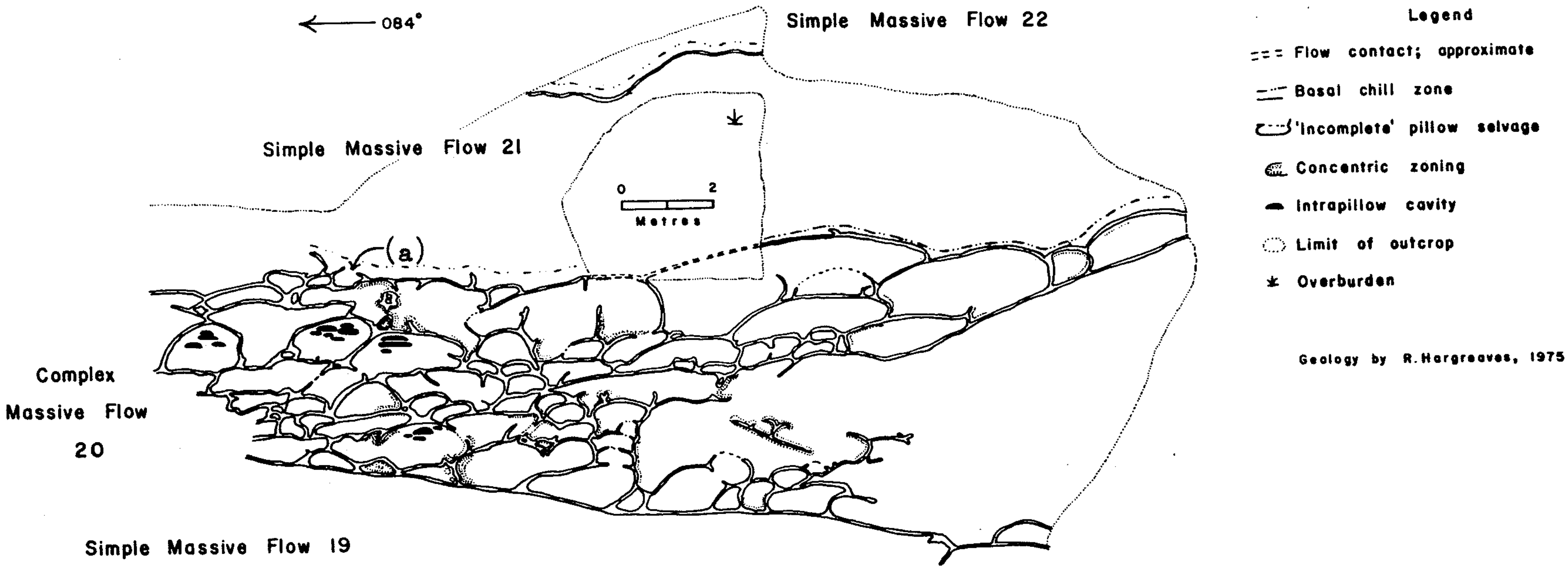

Figure 5. Outcrop diagram showing massive flow 20 underlain and overlain by simple massive flows. Flow 20 consists of a massive flow that grades laterally into interconnected pillows. Note the flat-based pillows at the bottom of the pillowed unit and the slight inclination of the pillows. The flow surface of flow 19 is flat whereas flow 21 has an undulating surface. Note the incipient pillow at the base of flow 21 (a).

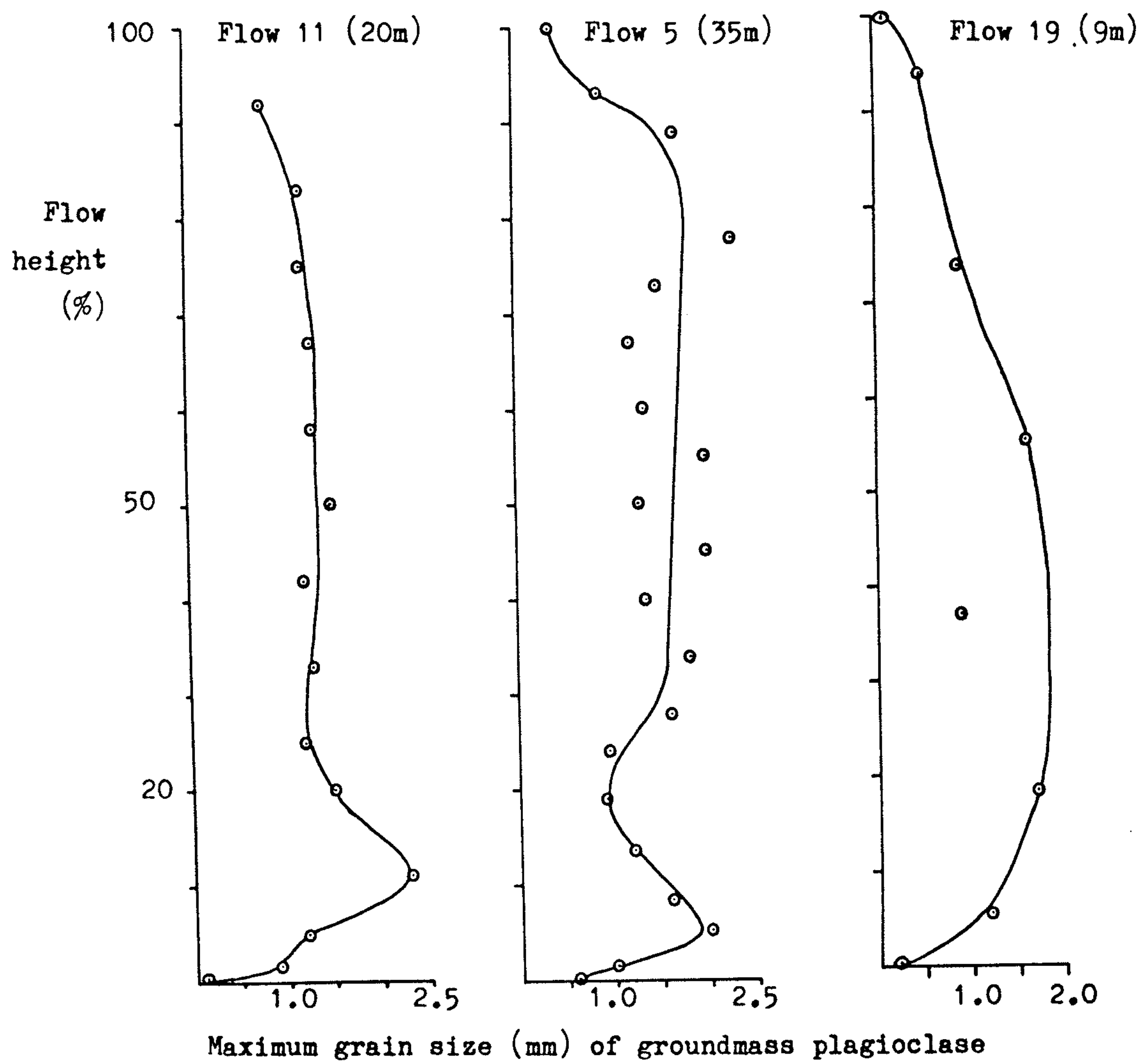

Figure 6. Graph of maximum groundmass plagioclase size plotted against flow height.