ARCHEAN VARIOLITIC LAVAS

FROM MUNRO TOWNSHIP ONTARIO

ARCHEAN VARIOLITIC LAVAS FROM

MUNRO TOWNSHIP, ONTARIO

By

DAVID B. SAUNDERS

A Thesis

Submitted to the Department of Geology

in Partial Fulfilment of the Requirements

for the Degree

Bachelor of Science

McMaster University

May, 1982

BACHELOR OF SCIENCE (1982) McMASTER UNIVERSITY
(Geology) Hamilton, Ontario

TITLE: Archean Variolitic Lavas from Munro Township, Ontario

AUTHOR: David B. Saunders

SUPERVISOR: Dr. James H. Crocket

PAGES: iv, 74

SCOPE AND CONTENT: Chemical variations between the matrix and variole fractions of variolitic lavas are quite distinct. Analyses for major and trace elements and trace gold content was carried out on separated fractions of matrix and varioles from several handspecimens.

Discussion of the results (including the origin of variolitic textures) was aided by thin section analysis and field relationships.

ABSTRACT

The origin of varioles in mafic rocks is uncertain.
Present models of silicate liquid immiscibility cannot
explain the non-fractionation or reversal of expected
fractionation trends of certain elements, particularly
aluminum.

Field relations and microtextures suggest that
varioles were present during the emplacement of the lava and
grew to their present state during the latter stages of
cooling (quenching). Matrix-variole compositions are
occasionally unusual which suggests also that variolites
result from fractionation in the liquid state.

Metamorphic alteration indicates the enrichment of
SiO_2 and CaO (as carbonate). Trace gold concentrations show
a slight enrichment with the degree of alteration. Gold
contents fractionation is low, with the variole being
slightly higher in gold.

Comparison of matrix-variole pairs between altered
and unaltered samples of lower greenschist grade metamor-
phism, show that silicification and carbonate alteration
affect existing fractionation trends.

Major element and trace element chemistry suggests
primary liquid state segregations which may result from the
growth of globular liquid varioles by liquid immiscibility.

TABLE OF CONTENTS

LIST OF MAPS

LIST OF TABLES

LIST OF FIGURES

LIST OF PHOTOGRAPHS

CHAPTER 1

INTRODUCTION AND REGIONAL GEOLOGY

1.1 INTRODUCTION

Variolitic lavas, commonly called variolites, or
in older literature spherulitic basalts, form a very distinc-
tive rock type in the field. They are characterized by
light to buff varioles which weather out of a "typical"
brownish green weathering basalt to form a striking,
irregular weathered surface. Fresh variolites are compact
and brittle when hammered, with the difference between
matrix and variole also usually apparent on the fresh surface.

Variolites generally consist of small, 2-15 cm
diameter spherical to ellipsoidal felsic globules (varioles)
"suspended" in a matrix of fine grained chloritic material
(Gélinas et al., 1976). In Archean greenstone belts,
variolitic lavas are commonly found as distinct stratigraphic
horizons which can be traced for many kilometers, and aided
in the mapping of the Abitibi Belt (Ferguson et al., 1968).

PILLOWED FLOWS

Varioles tend to coalesce when they are present in
sufficient concentrations and commonly show a size zoning
within individual pillows (Gélinas et al., 1976). Here,
larger varioles occur in the core of the pillow where there

is a greater degree of coalescence. This type of occurrence
has also been described to the author in Ordovician pillow
lavas from Newfoundland's ophiolites (Kusmirski, 1982, pers.
comm.). Variolitic lavas have also been recorded from
samples dredged from mid-ocean ridges (eg. Cann, 1969).

MASSIVE FLOWS

Varioles generally occur as discontinuous zones
or lenses within massive flows. In some flows, the tendency
for coalescence produces large "rafts" of variolitic mater-
ial near the flow top (MacVeigh, 1978).

Within single flows, varioles can show a crude size
zonation. Typically, there is a vertical gradation with a
variole-free basal zone grading into a variolitic upper zone.
The base of the upper zone consists of large ($\sim$ 5-7 cm
diameter) atypical varioles which grades into the top of the
upper zone, characterized by an abundance of coalesced smaller
varioles.

These field occurrences lend insight to the genesis
of variolitic textures, which is discussed in detail in
Chapter 4.

1.2 LOCATION AND ACCESS

Variolitic lavas chosen for this study occur in
Munro Township, Ontario. This area offers some excellent
and unique exposures of Archean rocks of the Abitibi green-

stone belt. Munro Township is approximately 50 km west of the Ontario-Quebec border and 80 km east of Timmins (Map 1).

Access is by Highway 101 which runs east from Highway 11 at Matheson Ontario. A little-used bush road runs north from Highway 101 approximately 1 km east of the Johns-Manville Mine road. The tailings pile from this abandoned asbestos operation forms a prominent topographic feature in the area. The bush road gives access to the Croesus Gold Mine site (also abandoned), and cuts across the stratigraphy of the area.

The study area is a small section of volcanic stratigraphy adjacent to the access road (Map 2). Within this area, the main variolitic units of Munro Township are found.

1.3 REGIONAL GEOLOGY

The Abitibi belt is somewhat unique because it is the largest greenstone belt of the Canadian Shield. Goodwin and Ridler (1970) describe the belt as being an easterly trending S-shaped belt of deformed (mostly subaqueous) supracrustals bounded to the north by northwest trending granite-gneiss terrain and to the south by similar trending Grenville-aged granite-gneiss terrain (Map 1).

The belt represents a thick stratigraphic pile of. dominantly mafic volcanics (Jolly, 1980; Pyke, 1980).
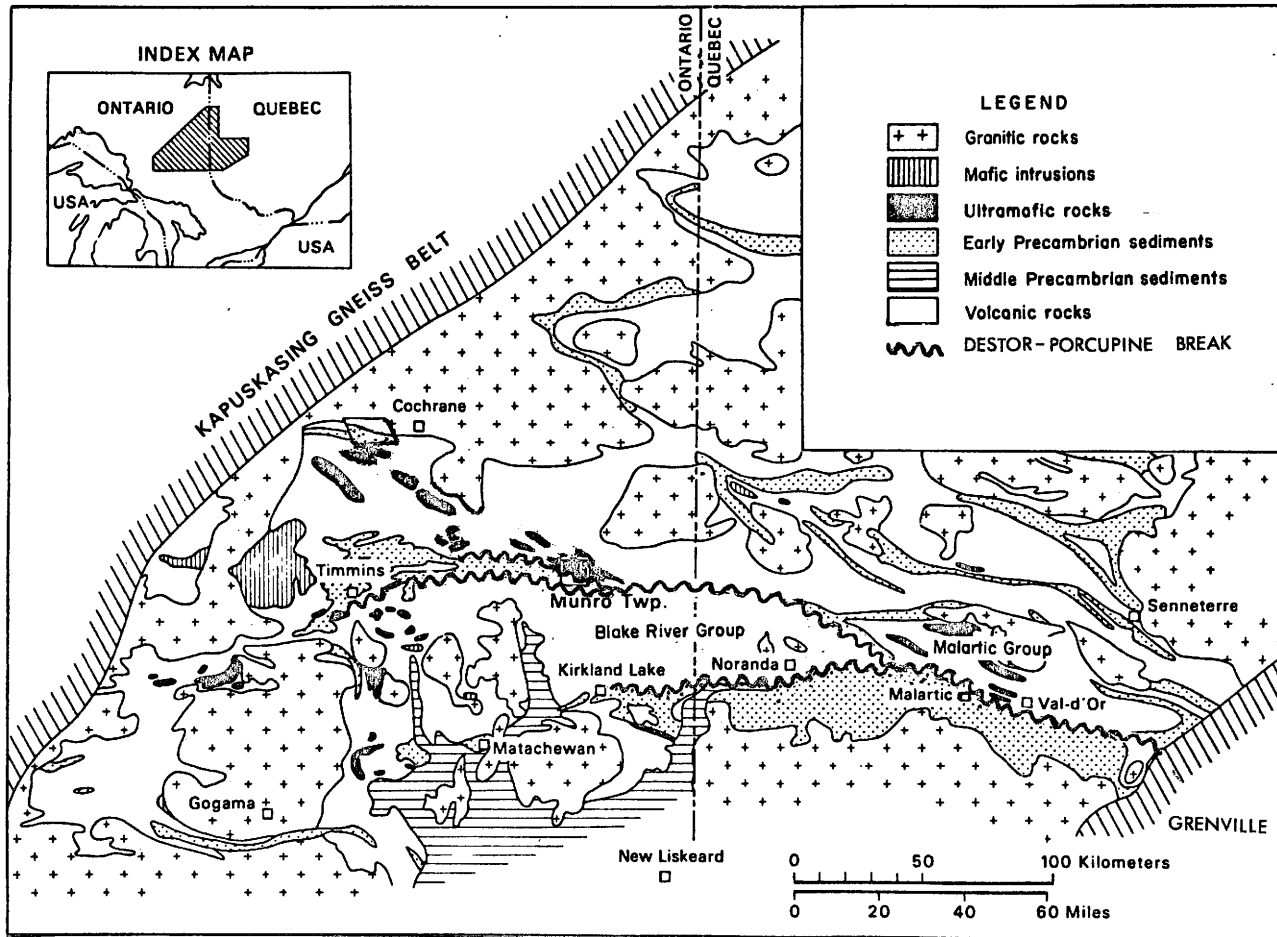
MAP 1 — PART OF THE ABITIBI BELT SHOWING THE LOCATION OF MUNRO TOWNSHIP
(after Goodwin and Ridler, 1970)

Several volcanic centers have been recognized and the strat-
igraphy is well described, although is subject to various
interpretations. For example, Pyke (1980) and Jensen (1980)
arrive at different thicknesses for the same volcanic pile
(ie. ~15 km and ~35 km respectively). Jolly (1978),
however, sets the maximum thickness at ~12 km based on
metamorphic assemblages.

1.4 TECTONIC STYLES AND METAMORPHISM

Tectonic styles, reflected in Archean greenstone
belts of the Superior Province, result in steeply dipping,
structurally complex geology (Baragar and McGlynn, 1976).
Belts are mantled and intruded by orogenic granites and over-
printed by greenschist grade metamorphism. Rocks of Munro
Township are steeply dipping but appear to have escaped
regional orogenic overprinting. On a regional scale, Munro
Township rocks are within an area of prehnite-pumpellyite
facies which has been mildly overprinted by greenschist
grade mineralogy (Jolly, 1980).

Preservation of primary textures in lower green-
schist and prehnite-pumpellyite facies mineralogies within
the Abitibi belt has been well documented (Dimroth and
Lichtblau, 1979; Jolly, 1974). Rocks of Munro Township and
the Abitibi belt are studied for this reason and also because
of many rich mines in the region.

METAMORPHISM

Prehnite-pumpellyite metamorphism is a diagenetic
or burial effect commonly found in volcanic piles (Jolly and Smith, 1972).
Hydration of primary ferromagnesium components forms chlorites
and prehnite-pumepllyite (Seki, 1961). Further metamorphism
leads to the formation of chlorites with epidote-actinolite
after prehnite-pumpellyite and marks the onset of greenschist
grade metamorphism (Jolly, 1980). It must be noted, however,
that high temperature seawater alteration of lavas can pro-
duce greenschist grade minerals (ie. spilites) and carbonate
alteration which cannot be distinguished from regionally
metamorphosed lavas (Fyon, 1980).
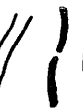
STRUCTURE

A major zone, called the Destor-Porcupine Break
(in Ontario) and Duparquet-Destor-Manneville Break (in
Quebec) trends east-west continuously across the belt (Pyke,
1980). The Destor-Porcupine Break seems to be spatially
related to many gold deposits, ie. Croesus, Hollinger, Kerr
Addison, etc.

On a regional scale, the D-P Break tends to parallel
stratigraphy, and is commonly used as a stratigraphic
division (Hogg, 1950; Dimroth et al., 1973). Munro Township
is located just to the north of the D-P Break which passes
through the next township south.
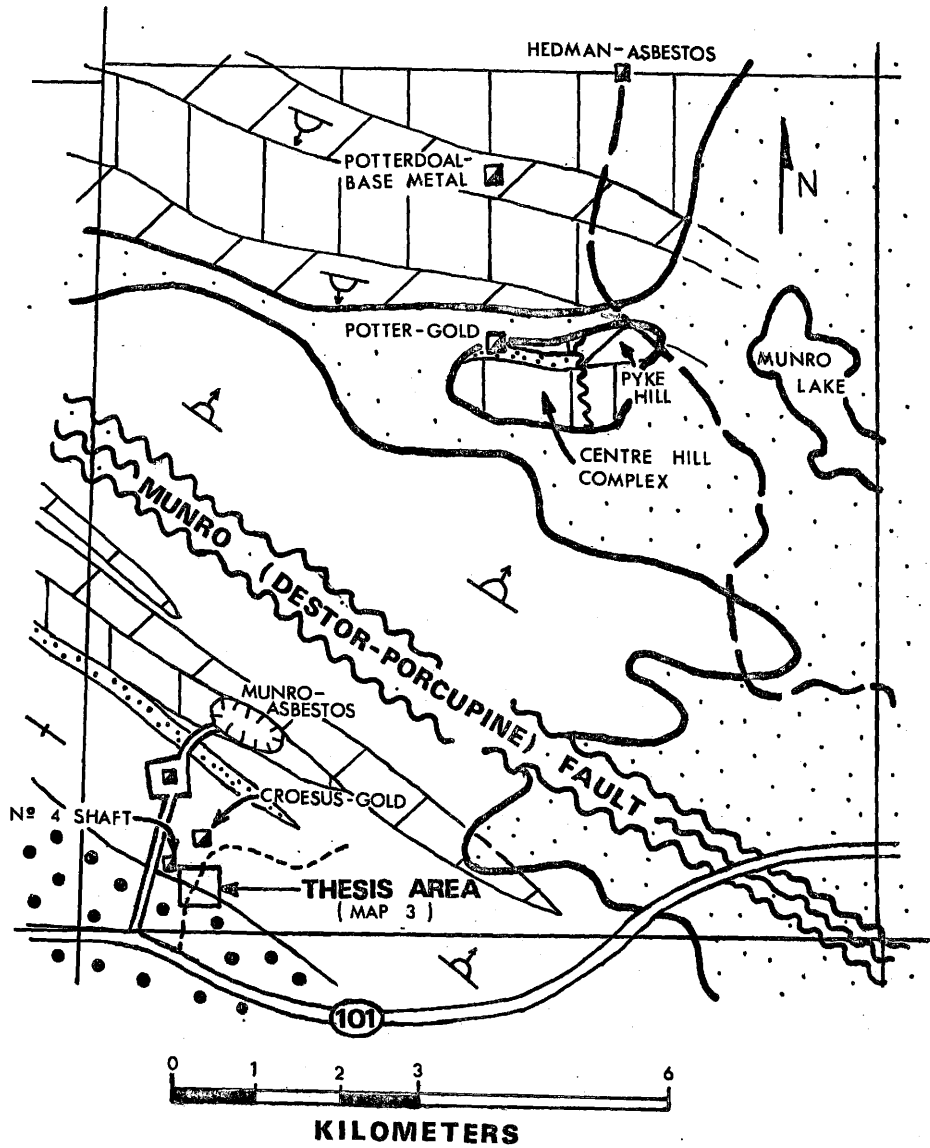
KEY

□ GLACIAL OVERBURDEN

▥ THICK (MAINLY ULTRAMAFIC) FLOWS AND SILLS

▨ THIN ULTRAMAFIC FLOWS

□ IRON-RICH THOLEIITIC FLOWS

⋰ FELSIC VOLCANICS

⦂ GREYWACKE SEDIMENTS

〰 FAULT

⊢ STRIKE OF ROCK UNITS

⚓ STRIKE OF PILLOWED FLOW INDICATING TOP

╱╲ GEOLOGIC CONTACTS

◪ MINE

◷ OPEN PIT

)//(ROADS

MAP 2 - GENERALIZED GEOLOGY OF MUNRO TOWNSHIP
       - SHOWING MAIN ACCESS ROUTES
         (after Satterly, 1951; Arndt et al., 1977)

1.5 MUNRO TOWNSHIP

Mapping of Munro Township by Satterly (1951) serves as an excellent geological description of the area, although reinterpretation of rock types has occurred in light of more recent chemical and textural evidence. Well exposed ultramafic occurrences in the northern part of the township have been the object of detailed studies in recent years (Pyke et al., 1973; Arndt et al., 1977).

Exposures are usually excellent with almost 100% outcrop in some areas. The eastern and some of the central part of the township are covered by glaciofluvial deposits and swamp (Map 2).

Rock types consist mainly of iron-rich tholeiitic volcanics overlain by ultramafic lavas and sills (Arndt et al., 1977). These rocks form part of the Blake River Group and are thought to unconformably overlie greywacke turbidites of Temiskaming sediment in the southwest portion of the township.

MINING OPERATIONS

A large ultramafic sill (the Munro-Beatty sill) has been mined on a large scale (the Johns-Manville pit) for asbestos. Thermal effects due to this intrusion may have affected rocks of the thesis area.

Gold operations include the Potter and Croesus Mines. The Potter Mine recently worked a hyaloclastite horizon over-

lying the Centre-Hill Complex. The Croesus Mine was a small high grade gold-quartz vein deposit which occurs in pillowed Fe-tholeiites stratigraphically just above the thesis area (Map 3). It appears that the control on the ore deposition at Croesus is faulting (possibly related to the activity of the Munro Fault) with precipitation of gold and arsenopyrite in quartz veins against pyritic horizons within the pillow basalts (MacVeigh, 1978). The Munro Fault (Map 2) is a subsidiary arm of the Destor-Porcupine Break which joins the main zone south and east of Munro Township (Map 1).

PREVIOUS WORK

Aside from mapping by Satterly (1951), the rocks of the thesis area were mapped in detail in 1975 for the purpose of reevaluating the Munro-Croesus property (MacVeigh, 1978). He recognized pillowed and massive variolitic flows and described these flows by their size and variolitic textures. Some of his terminology will be used in this study.

CHAPTER 2

OBSERVATIONS

2.1 FIELD METHODS

Within the area chosen for study, remapping of
variolitic units was undertaken using air-photos and Satterly's
(1951) map for outcrop control. For ease of correlation,
geology and sample locations are plotted on Satterly's 1951
map, reproduced here as Map 3.

Three days were spent mapping in the field. Two
traverse lines were flagged at 30° azimuth to run about
perpendicular to local stratigraphy. Using these lines for
reference, geology was mapped and 44 samples were collected,
along with two samples outside the main area of interest.

2.2 SAMPLING OBJECTIVES

Attempts were made to sample at regular intervals
to maximize the accuracy of the mapping. Large specimens
were collected so that where matrix-variole differentiation
is exceptional, enough material was ensured for analysis of
the fractionation trends. Large specimens also exhibit
textures that may be missed in the field, but are observ-
able upon later examination.
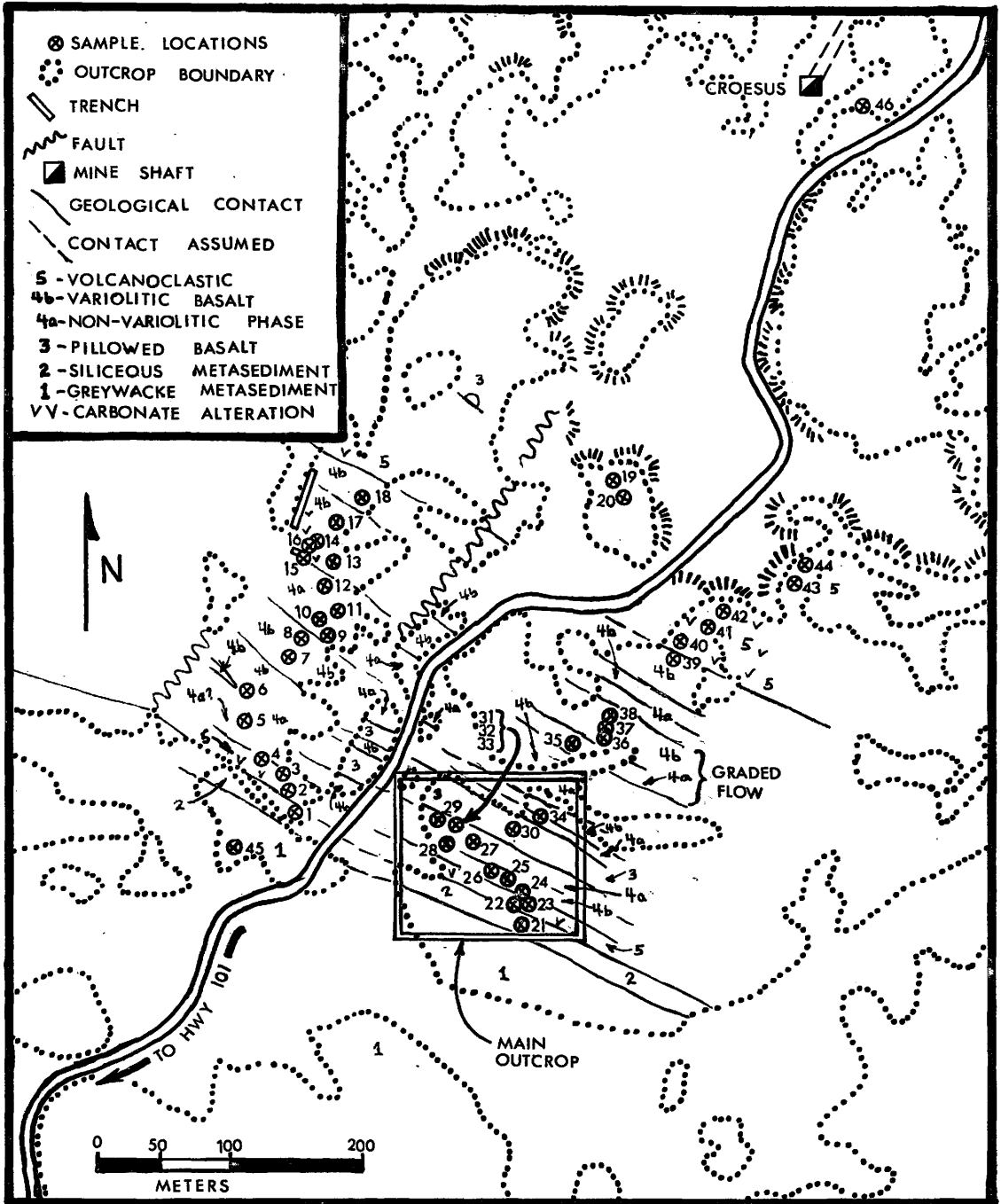
MAP 3 - GEOLOGIC MAP OF THESIS AREA - INCLUDING SAMPLE
        LOCATIONS
                REFER TO MAP 2 FOR LOCATION

2.3 MAIN OUTCROP

The outcrop shown in Map 4, was chosen for detailed study because it exposes nearly continuous outcrop along a small ridge. Easily sampled variolites are found in a horizon ~4 m from the top of the "Main Flow".

These are exceptionally striking large varioles set in a dark green (almost black) matrix and appear very well preserved (Plate 4). The Main Flow horizon was sampled along strike (DBS 27, 29, 31, 32, 33) to observe lateral variation and to ensure that well preserved specimens were obtained. Where more than one specimen was collected at the same location, a sequence number was added to the sample number (eg. 29-2).

The Main Flow is capped by a quenched mircovariolitic rock in which varioles are 2-5 mm in diameter (Plate 1). Varioles are somewhat coalesced and are set in a chloritic matrix. In Sample DBS 31, varioles are strongly sericitically altered by iron stained white mica blades. The original glassy matrix is mildly carbonate altered primarily consisting of chlorite-epidote-leucoxene, and is also sericitized by white micas.

Sample DBS 32, 1.5 m below the flow top is a vesicular, banded rock which is spherulitically devitrified (Plate 5). Banding probably results from late stage flowage which presumably destroys primary matrix-variole relationships.

N

VARIOLITIC
PILLOWS

LIMIT OF
OUTCROP

⊗34

VARIOLITIC
FLOW

29 ⊗ ·31
·32 ⊗   5

⊗30

3

33

⊗28   4   2   1

27   ⊗

LINEAMENT

PILLOWED
NON-VARIOLITIC
FLOW

⊗26

⊗25

MAIN
FLOW
(VARIOLITIC)

⊗24

⊗22 ⊗23

SILICEOUS
METASEDIMENT

VOLCANO-
CLASTIC

DISCONFORMITY

⊗21

GREYWACKE
SEDIMENTS

```
0        25       50              100
```

SCALE   IN   METERS
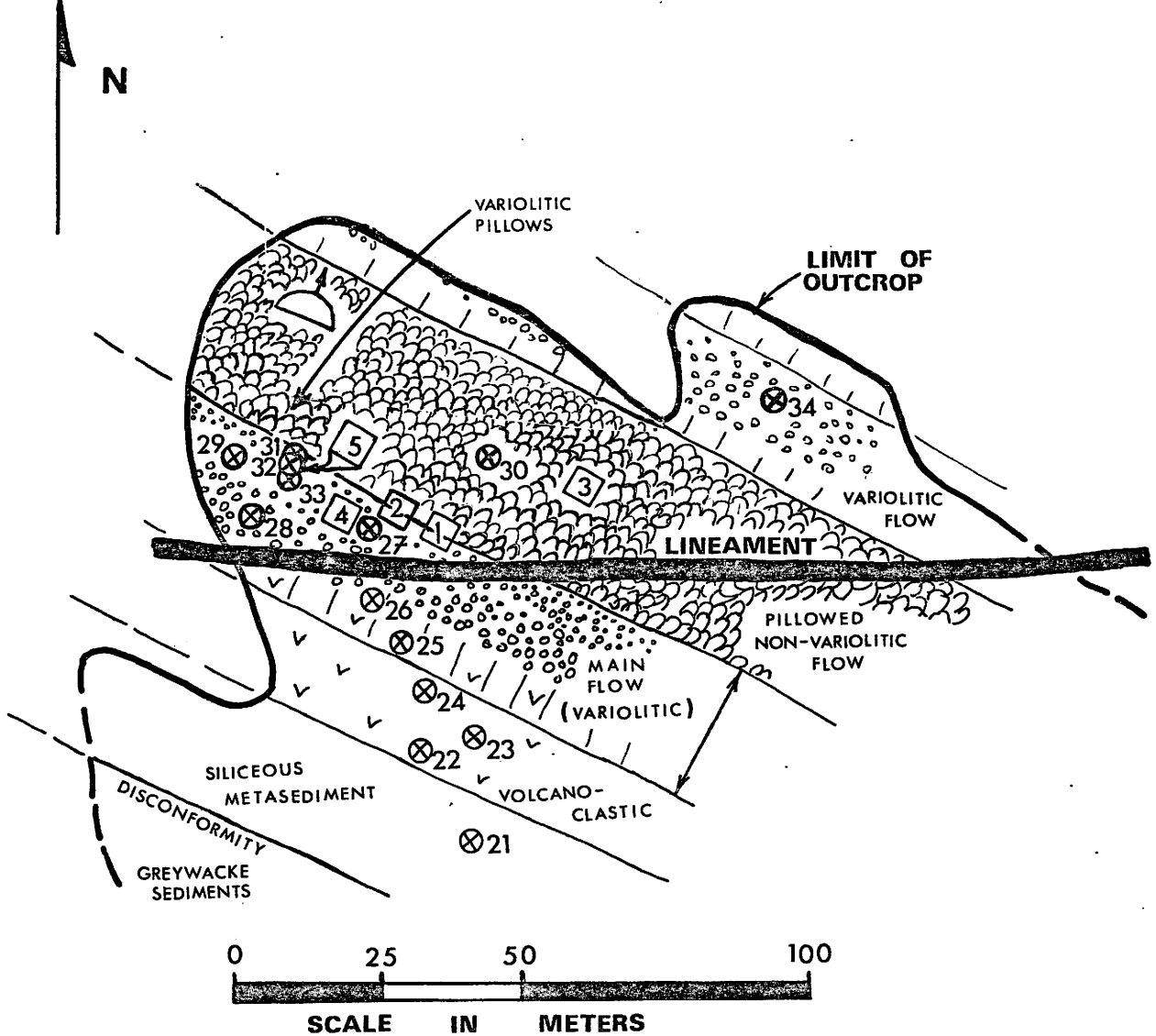
⊗ **SAMPLE   LOCATIONS**

4 **PLATES (AS LISTED IN TEXT)**

PILLOWS

VARIOLITES SHOWING SIZE GRADATION
(NOT TO SCALE)

/// **VARIOLE – FREE   BASAL   ZONE**

V
 V **CARBONATE   ALTERATION**

MAP 4 – MAIN OUTCROP SHOWING GEOLOGY AND SAMPLE LOCATIONS
REFER TO MAP 3 FOR LOCATION

14

TOPS

PLATE 1

CONTACT BETWEEN
PILLOWED FLOW
AND MICROVARIOLITIC TOP
OF MAIN FLOW

NOTE - COOLING CRACKS
(LENS CAP FOR SCALE)
REFER TO MAP 4 OR FIG. 1
FOR LOCATION

TOPS
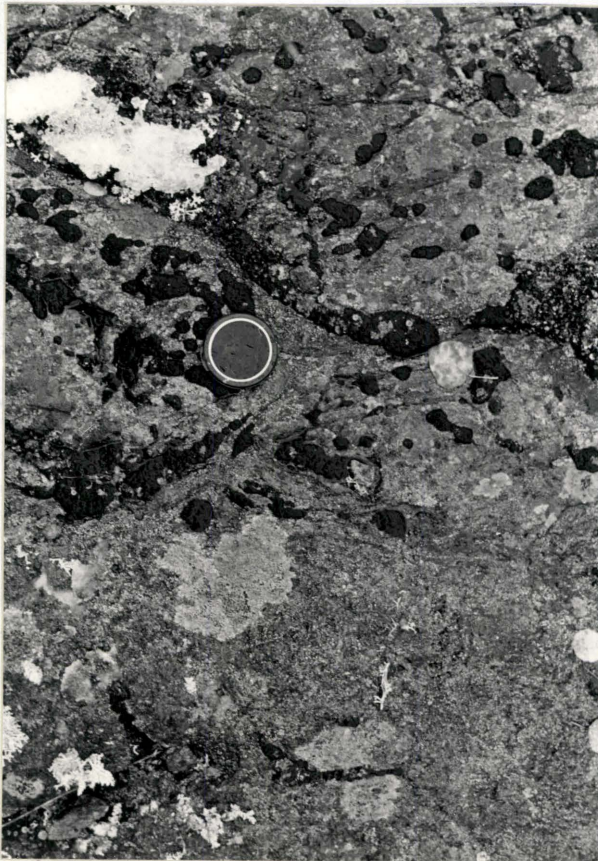
PLATE 2

CONTACT - PILLOWS
LYING DIRECTLY ON TOP
OF MAIN FLOW

(LENS CAP FOR SCALE)
REFER TO MAP 4 OR FIG. 1
FOR LOCATION

15

TOPS

↑
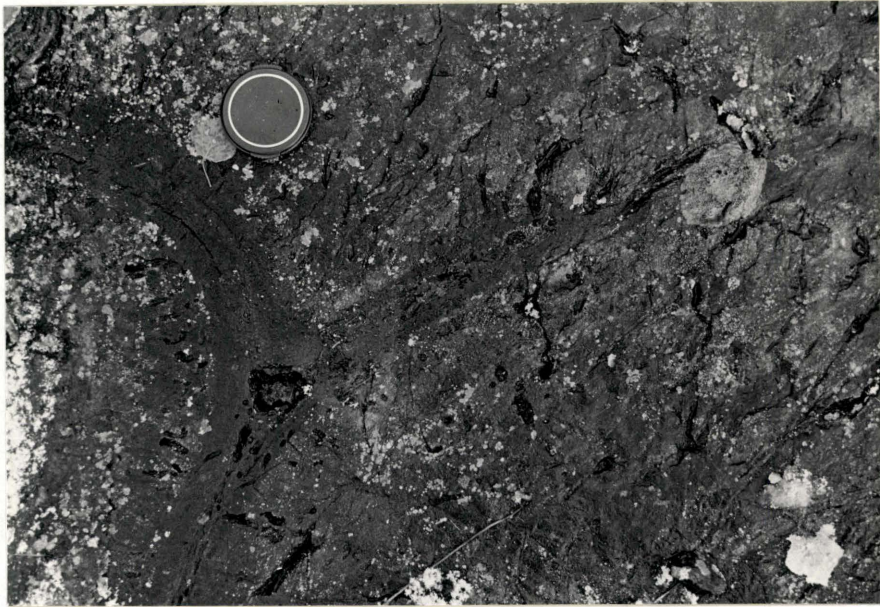
PLATE 3 - VESICULAR PILLOWS ABOVE MAIN FLOW - (DBS 30)
(LENS CAP FOR SCALE)
REFER TO FIGURE 1 FOR LOCATION

TOPS

↑
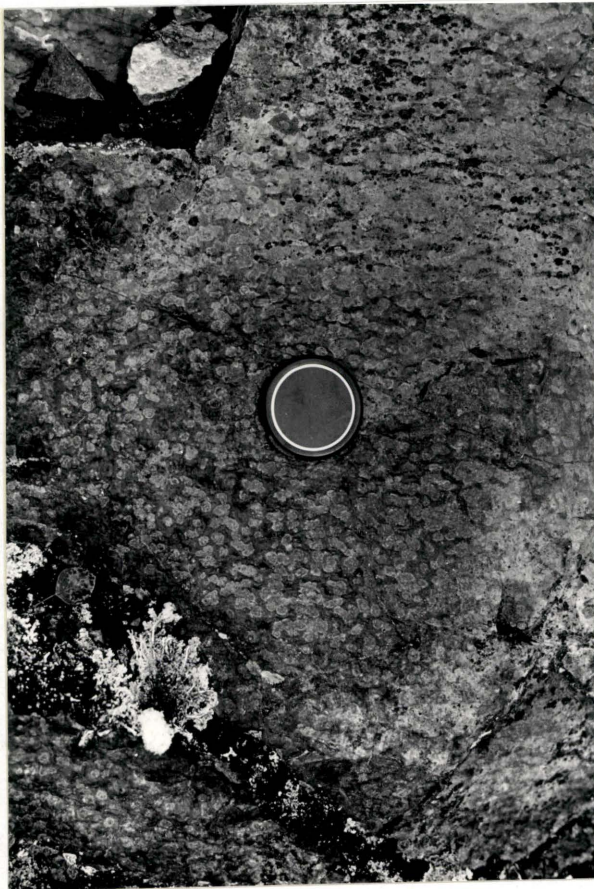
PLATE 4

VARIOLES IN GLASSY MATRIX ·
MAIN FLOW

(DBS 27) - EXFOLIATED SURFAC

(LENS CAP FOR SCALE)

REFER TO MAP 4 OR FIG. 1
FOR LOCATION
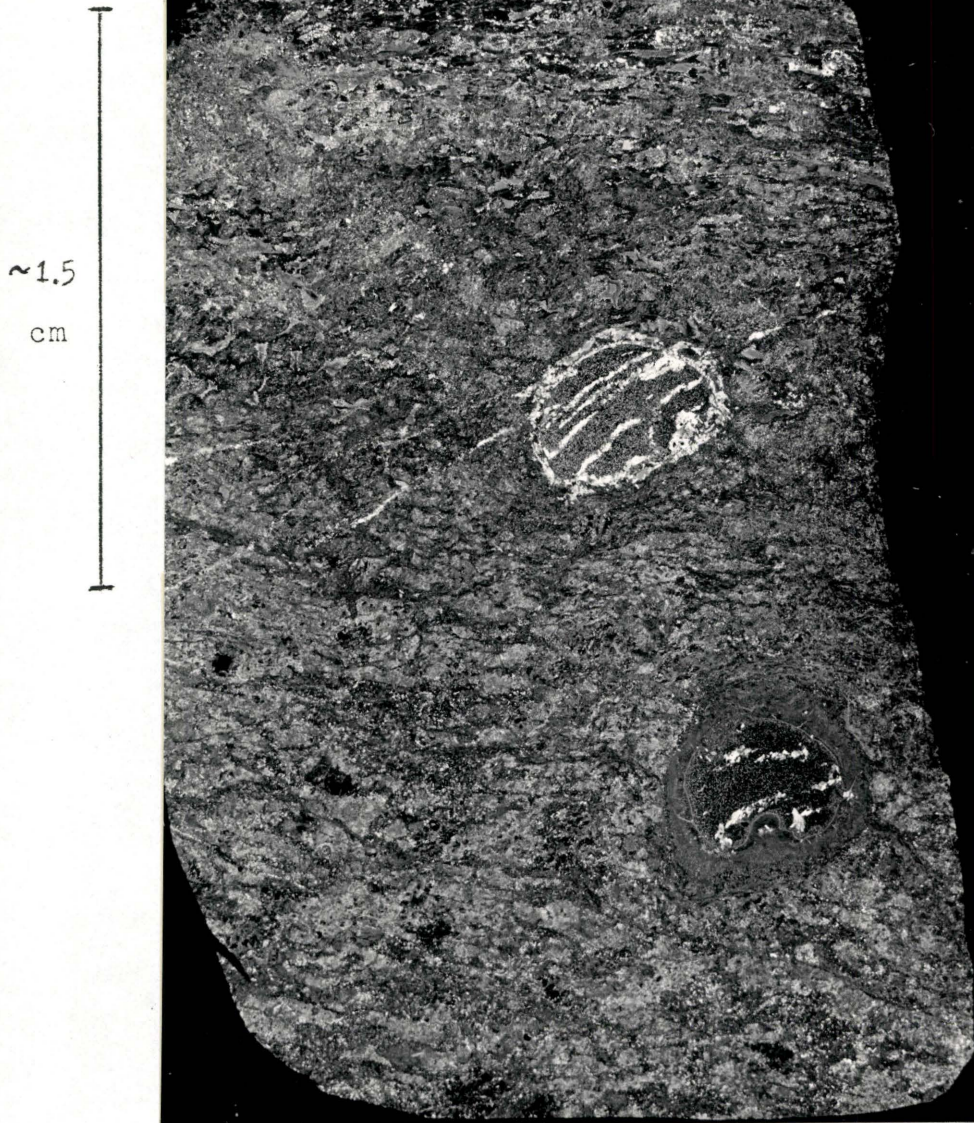
PLATE 5 - FLOW BANDED VESICULAR FLOW TOP (DBS 32) -
THIN SECTION - PLANE POLARIZED LIGHT

NOTE - CARBONATE FRACTURES IN QTZ-CHLORITE
AMYGDULES

(REFER TO FIG. 1 OR MAP 4 FOR LOCATION)

Vesicles appear as round quartz-chlorite amygdules, suggesting they probably formed after flowage had ceased. The specimen is carbonate altered and mildly sericitized. The sericitization is similar to that of DBS 31 and mica blades tend to concentrate near the amygdule edges. Also, carbonate fractures crosscut the specimen and are concentrated as parallel sets within amygdules (Plate 5).

Sample DBS 33 was collected 3 m below the flow top (Map 4). It contains a vesicular coalesced varioles. Amygdules are fillings by quartz, chlorite and sulphides. Vesicles commonly occur towards the edge of the coalesced varioles (see Plate 17, page 52). This was also observed by Gélinas et al. (1977) in pillowed variolites.

Samples DBS 27 and DBS 29 appeared to be excellent variolites to study, because of lack of alteration and the presence of large ellipsoidal varioles which were quite distinct from the glassy matrix (Plate 4). A thorough description of these samples is presented in Section 3.3 (page 24), where fractionation trends are discussed.

The ellipsoidal nature of the varioles produced a foliation parallel to bedding and is thought to represent "stretching" during latter stages of flowage, although there is some evidence of minor orogenic deformation (ie. fracturing of varioles and amygdules).

2.4 STRATIGRAPHY OF THESIS AREA

The area mapped for this study is a simple strati-
graphic section with few structural complexities. Rock
units strike at ~ 110° and are vertically dipping.

The general stratigraphy is presented in Figure 1
which is compiled from Map 3. Important sample locations
and plates are marked on this figure for reference. The
field classification of rock types was aided by chemical
analyses combined with hand specimen and thin section
observation. For clarity, most of this material is presented
separately in Appendix A.

Satterly (1951) presents the area as a series of
overturned turbidite greywacke sediments unconformably over-
lain by mafic volcanics. Regionally, these sediments form a
wedge bounded to the south by the Destor-Porcupine Fault
(Map 1).

The volcanics are all iron tholeiites according to
Jensen Classification (Appendix A). The thesis section
presents about 250 m of massive variolitic lavas, volcanic
sediments and hyaloclastites interlayered with pillowed
flows. These rocks are overlain in turn by a thick sequence
of typically pillowed non variolitic iron tholeiite flows
and associated volcanoclastics. The Croesus gold deposit
is hosted in pillowed flows approximately 400 m "up section"
from the variolitic units. Gold mineralization also occurs
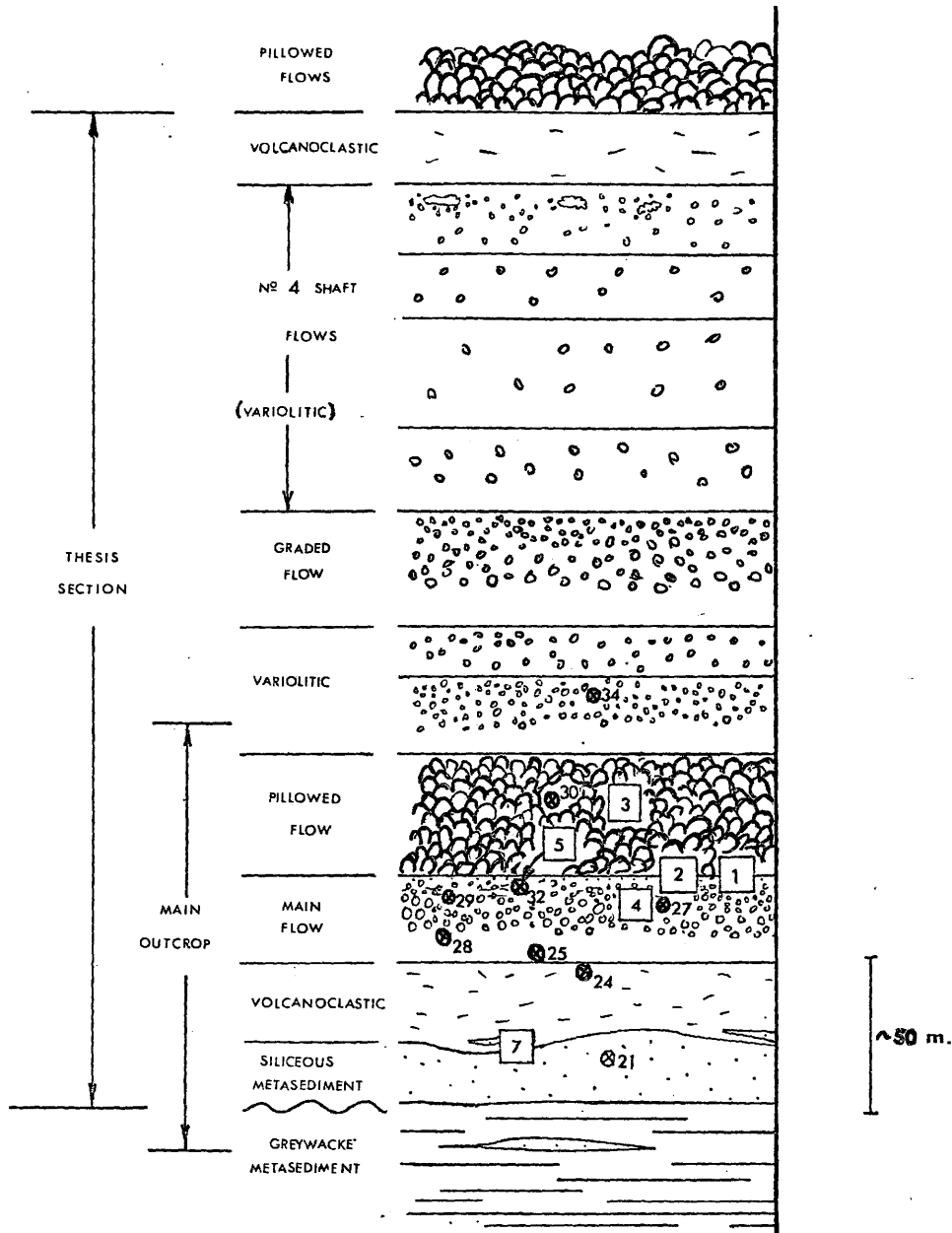
FIGURE 1 – VOLCANIC STRATIGRAPHY OF THESIS AREA – EAST TRAVERSE COMPILED FROM MAPS 3 AND 4.

TOPS ↑
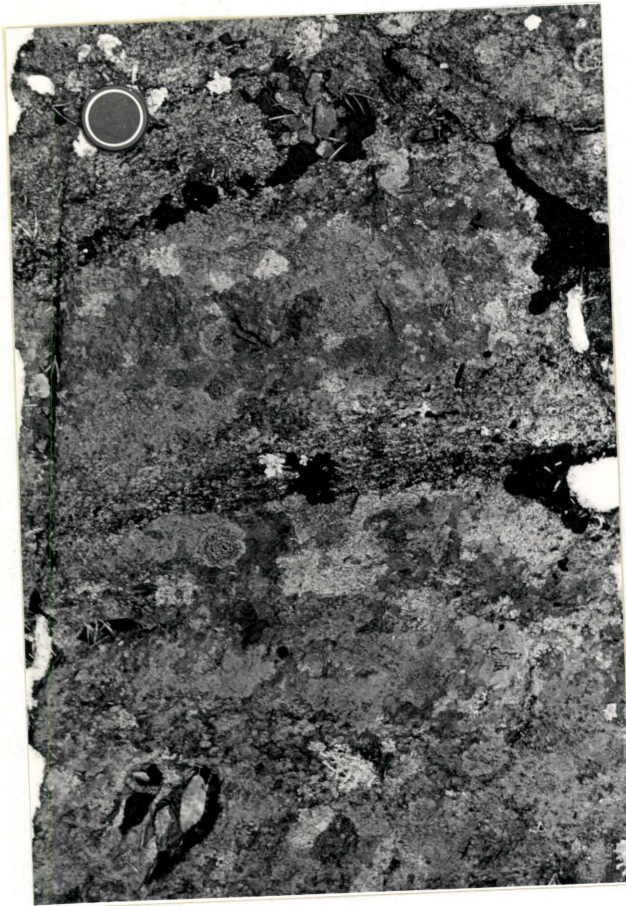
PLATE 6

TYPICAL VARIOLITIC
OCCURRENCE IN MASSIVE
FLOWS

(LENS CAP FOR SCALE)

(DBS 7) - REFER TO
MAP 3 FOR LOCATION

TOPS ↑

VOLCANO-
CLASTIC

CHERTY
META-
SEDIMENT
(DBS 1, 21)

PLATE 7 - CONTACT OF VOLCANIC UNITS AND CHERTY METASEDIMENT
NOTE - INTERCALATION

(LENS CAP FOR SCALE)

REFER TO FIGURE 1 FOR LOCATION

in fractures among the coalesced variolites near the Croesus
No. 4 shaft west of the thesis section (MacVeigh, 1978).

Field relations presented in Satterly's 1951 map
are considered accurate. Several minor "faults" were omitted,
because no displacement was observed across the observed
lineament. Also, little evidence was seen to confirm an
angular unconformity between the sedimentary and volcanic
units.

The unconformity is marked in places by a thin
($\sim$5 m) siliceous metasediment rock and is commonly obscured
by carbonate alteration. The volcanics are intercalated
with the siliceous unit (Plate 7). Also, thin lenticular
base of the siliceous unit were seen totally within the
greywackes near the contact, suggesting that the volcanics
conformably overlie the sediments at least within the thesis
area. However, Satterly (1951) and MacVeigh (1978) have
concluded, based upon regional orientations, that the
volcanics disconformably overlie the greywacke sediment.
The author chooses to follow this line of argument.

VARIOLITIC UNITS

Flow units, averaging about 20 m thickness con-
stitute the thesis section. The flows are generally
massive, but vague pillowed structures (commonly variolitic)
are sometimes seen. These structures constitute lenses and
patches of variolitic material (Plate 6).

MacVeigh (1978) recognizes a flow sequence and divides it into two parts. The upper part he calls the No. 4 Shaft Flows. Just below these flow units, is a distinctive graded variolitic flow which MacVeigh traced for 800 m along strike. This flow will be called the "Graded" Flow for purposes of this study. Below the Graded Flow are other graded variolitic flows (including the Main Flow) and pillowed flows (In the thesis section, the pillowed flows are essentially non variolitic).

To the west, MacVeigh describes large pillows in a porphyritic variolitic flow, which may represent the same pillowed horizon found in the thesis area.

CHAPTER 3

DATA PRESENTATION

3.1 SAMPLE PREPARATION

In all, 46 samples were collected. Each was cut
with a diamond saw and 26 were selected and slabbed for thin
section, 14 for chemical analysis and 12 for gold analysis.

Fresh rock chips were crushed by hand with a soft
iron mortar and pestle. The chips were reduced to a powder
in a ceramic ball mill, or if only small amounts of material
was available, the chips were reduced to a powder using the
mortar and pestle. A detailed description of preparation
methods is presented in Appendix B.

The analysis of matrix-variole pairs involved cut-
ting the rock into thin slabs and hand picking matrix and
variole fragments. Care was taken to avoid contamination
(especially by gold). A detailed outline of these methods
is presented in Appendices C and D.

3.2 ANALYTICAL METHODS

GOLD ANALYSIS

Trace gold content was determined by carrier based
radiochemical neutron activation methods (RNAA). Four
experiments (involving 8 samples and two chemical standards

each) were performed following procedures outlined by
Crocket et al.(1968). These methods are very sensitive and
0.5 ppb of Au is considered accurate to within ±5% (Kwong
and Crocket, 1978).

MAJOR AND TRACE ELEMENTS

Major elements were determined by analysis of fused
sample pellets by a Phillips Model 1450 AHP automatic XRF
spectrometer, according to method of Hutchinson (1974).
Trace elements determined using powder pellets are listed in
Tables 4 and 5.

VOLATILE COMPONENTS

Volatiles were determined only for samples of
particular interest. Total volatiles were determined by
loss on ignition (H_2O, S, CO_2) by heating sample powders at
$1000^{o}C$ in a furnace for approximately one hour. Mass dif-
ferences before and after heating determine LOI. Weight
percent of water can be determined by subtracting CO_2 from
LOI (assuming sulphur to be negligible).

Results for volatiles are presented along with
other data in Tables 4 and 5. In general, the amount of
volatiles is an indication of the degree of alteration in the
sample.

3.3 MATRIX-VARIOLE RELATIONSHIPS

In the field, DBS 27 and DBS 29 were collected as

the freshest variolitic samples. After sawing, DBS 27 was
observed to be somewhat altered and carbonate veined (compare
Plates 10 and 11). Matrix-variole relationships in these
specimens are similar to those described by Gélinas et al.
(1976).

VARIOLES

Varioles tend to show a moderate degree of coales-
cence and are commonly fractured. Each variole is ellip-
soidal and has a concentric zonation with a radial fabric.

The core zone contains coarse relict dendritic
textures with occasional chloritic blebs. Gélinas et al.
(1976), describe partially resorbed quartz or plagioclase
grains, or a carbonate amygdule at the core of some varioles.

Dendritic textures defined by relict skeletal mafic
minerals and albite, form the inner zone, which occupies
most of the variole (Plate 8). In the inner zone, branching
arrays of skeletal crystals form a generally radial orient-
ation and are finer grained towards the edge of the variole.

The border zone is in sharp contact with the matrix
and varies to 2-3 mm into the variole. This zone consists
of quartz and albite with concentric patches of leucoxene
(Plate 8). Where varioles have coalesced, the border zone
is not present, suggesting that the zone is a metamorphic
reaction rim between the matrix and the variole and that
coalescence is a result of primary (ie. magmatic) processes.

2.0 mm
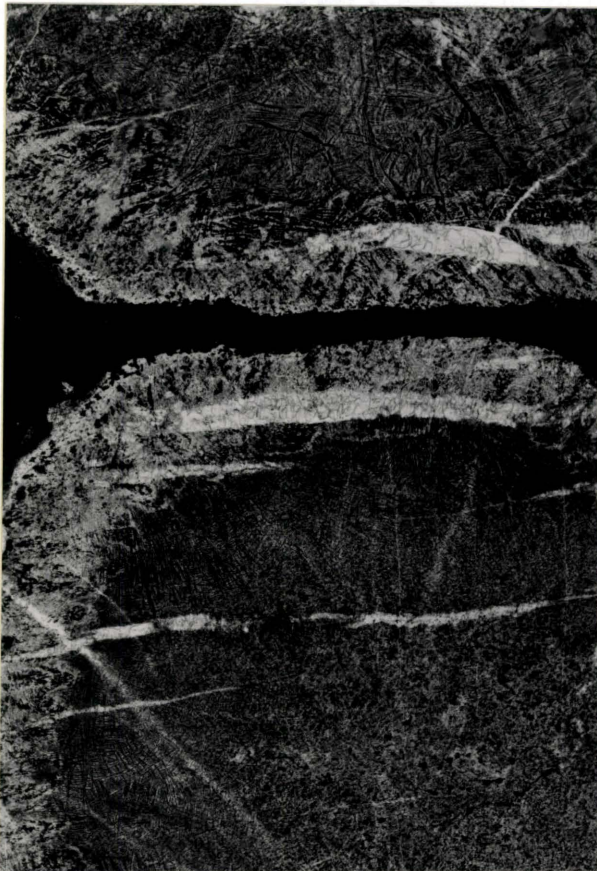
MATRIX

BORDER ZONE WITH LEUCOXENE

INNER ZONE

CORE ZONE

PLATE 8 - MATRIX-VARIOLE CONTACT SHOWING BORDER ZONE
            (DBS 27)
         NOTE - DENDRITIC TEXTURES, LEUCOXENE

0.5 cm

PLATE 9 - MATRIX-VARIOLE RELATIONSHIPS
         DBS 29
         NOTE - PATCHY MATRIX
             - COALESCED VARIOLES
             - CARBONATE VEINING IN VARIOLES

The border zone, where it contacts the matrix, is optically sharp to 10 μm (Gélinas et al., 1976). The presence of leucoxene which is a common alteration product of basalts (Fyon, 1980) also suggests that the border zone results from metamorphic alteration.

Contacts between coalesced varioles are straight lines and processes which suggest this is a (semi)liquid feature is discussed in Chapter 4 (Section 4.2).

MATRIX

The matrix consists dominantly of massive chlorite with irregular patches of albite and quartz generally found near varioles (Plate 9). Chloritic matrix appears as uniform aggregates of chlorite with small dispersed grains of epidote and opaques (rutile?). Leucoxene was observed replacing the opaque mineral (rutile) of matrix. These mineral assemblages are typical of devitrified Archean basaltic glasses (Dimroth and Lichtblau, 1979).

Gélinas et al. (1976) and Pugin and Khitarov (1980) describe primary skeletal mafic minerals and perlitic textures in the matrix. This also suggests that the matrix was a quenched basaltic liquid.

SUMMARY

Textures demonstrated by matrix and varioles, are preserved in metamorphic mineral assemblages. Primary relationships suggest that varioles are discrete globules of felsic liquid set in a rapidly cooled mafic liquid.

3.4 GOLD FRACTIONATION IN MATRIX-VARIOLE PAIRS

SAMPLE DBS 29

Sample DBS 29, the least altered available, was extensively analysed to determine fractionation trends (particularly gold).

Problems arose because even this specimen was mildly deformed and altered (Plate 9). Varioles are commonly riddled with parallel carbonate-filled microfractures occasionally containing pyrite. This effect is due to minor deformation of the rocks, and because of competence differences, varioles fracture and fill with carbonate material. The matrix, being "softer" accommodates the stress by more ductile behavior.

Due to the common association of gold with carbonate and sulphides (Kwong and Crocket, 1978), these carbonate veinlets and authigenic pyrite will probably affect the gold values.

Results obtained by RNAA for gold fractionation are presented in Table 1. A detailed account of the experiments performed on DBS 29 is presented in Appendix D. Samples contaminated by experimental procedure will be ignored.

Gold fractionation in DBS 29 is represented by averaging gold values for 6 matrix-variole pairs (ie. 12 samples). Samples DBS 29-2 and 29-3 were included in the average because they are very similar in appearance to

TABLE 1 - GOLD DISTRIBUTION OF MATRIX-VARIOLE SEPARATES

FOR SAMPLE DBS 29

*See Appendix D for sampling rationale	DBS 29-1	GOLD CONC. (ppb)	
	*SLAB	MATRIX	VARIOLE
	B	1.22	1.55
	B	0.53	1.48
	C	1.66	1.05
	G	0.60	0.98
Contaminated Samples (preparation methods OR authigenic pyrite or gold)	F_1	11.84	23.06
	F_2	9.01	18.53
	F_2	9.45	6.37
Variole sample known to contain authigenic pyrite	B_{py}	—/—	6.20

TABLE 2 - GOLD DISTRIBUTION OF OTHER MATRIX-VARIOLE PAIRS
(FOR LOCATIONS, SEE MAP 3 OR FIG. 1)

SAMPLE DBS	GOLD CONC. (ppb)	
	MATRIX	VARIOLE
29-2	0.99	1.55
29-3	0.49	2.00
27	4.43	4.17
34	3.5	3.9
36	1.03	2.40
38	1.51	1.23

DBS 29. (These samples were collected near location DBS 29).

Gold content of the matrix is ∿ 0.91 ppb and the variole is ∿ 1.43 ppb. Gold levels in the matrix are, in general, slightly lower than in the variole. Gold values seem to correlate with the percent CO_2 and sulphur contents (ppm) presented for DBS 29 in Table 4. The presence of carbonate in veinlets of the variole probably cause the slight elevation in gold in the variole (as the matrix has very little carbonate) and this suggests that primary gold fractionation was negligable.

SAMPLE DBS 27

This specimen, being carbonate altered and slightly silicified (Table 4), gave gold values of 4.43 and 4.17 for matrix and variole respectively. Comparison with percent CO_2 again shows that gold values are probably related to carbonate content. Here, gold values are elevated and "homogenized" by pervasive alteration and veining during deformation. Veins in DBS 27 form in two roughly perpendicular sets which are thought to result from stress deformation (Plate 11).

OTHER MATRIX-VARIOLE PAIRS

Gold values for DBS 34, 36 and 38 are presented in Table 2. These samples represent variolites which have

coalesced and "resorbed" to such a degree that there is very little matrix relative to the amount of variole material. Colour differences between matrix and variole are not as marked as in DBS 29 and this is reflected in compositional fractionation presented in Table 5 (Section 3.7). Carbonate alteration typical of most samples from the study area was present in these samples.

DBS 34 shows gold concentrations of 3.5 and 3.9 for matrix and variole respectively. This sample shows no obvious alteration (as in DBS 27) but ~15 modal percent carbonate was estimated in thin section. Gold values are higher than for DBS 29, but DBS 34 is from a different flow which may have a higher initial background of gold. The most probable reason is carbonate alteration.

DBS 36 and 38 come from the Graded Flow. These gold values are lower and are within 1-2 ppb (as in DBS 29). Gold contents of samples from this flow will be included with the discussion of the Graded Flow (Section 3.7, page 37).

3.5 OTHER GOLD VALUES

This data, presented as Table 3, includes samples considered as pertaining to the distribution of gold in the thesis area.

DBS 30 and DBS 46 are samples from pillowed, non-variolitic flows. Material from these samples were

TABLE 3 - OTHER GOLD VALUES-See Map 3 for Locations

Croesus Flow

SAMPLE DESCRIPTION	SAMPLE DBS	GOLD CONC. (ppb)
Pillowed Fe-thol. (Non variolitic)	30	4.9
Pillowed Fe-thol. (Non variolitic)	46	4.6
ALTERED VARIOLITE (PROXIMAL TO VEIN)	15	9.3
Variole free basal zone-Graded Flow	35	3.15
Middle of Graded Flow-large varioles	37	1.32

TABLE 4   VARIATION IN VARIOLE-MATRIX FRACTIONATION DUE TO
METAMORPHIC ALTERATION - MAIN FLOW

PLATES 10, 11
CUT SURFACES
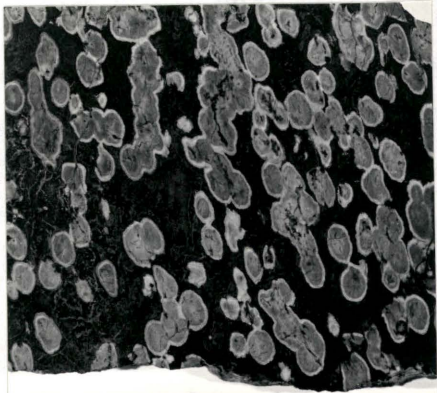
	RELATIVELY FRESH		ALTERED	
	DBS 29		DBS 27	
(wt%)	MATRIX	VARIOLE	MATRIX	VARIOLE
SiO_2	49.23	82.59	52.20	87.3
Al_2O_3	18.67	7.88	18.43	3.11
Fe_3O_3	20.03	1.83	12.49	1.81
MgO	3.18	0.74	2.62	0.77
CaO	2.12	3.30	7.86	5.24
Na_2O	3.73	2.68	0.74	0.61
K_2O	1.54	0.03	4.62	0.24
TiO_2	0.92	0.71	0.66	0.68
MnO	0.42	0.09	0.22	0.07
P_2O_5	0.16	0.15	0.17	0.15
LOI(wt%)	3.75	1.97	6.96	3.51
$\%CO_2$	0.48	2.07	4.60	3.53
S(ppm)	0	181.3	31.5	571
Au(ppb)	average of 6		1 sample	
	0.91	1.43	4.43	4.17

MAJOR ELEMENT (rows SiO_2 through P_2O_5)

VOLATILES (rows LOI, $\%CO_2$, S(ppm))

TABLE 4 - VARIATION WITH ALTERATION (Cont...)

		DBS 29 RELATIVELY FRESH		DBS 27 (ALTERED)	
		MATRIX	VARIOLE	MATRIX	VARIOLE
	Rb	39.8	0.4	155.4	5.6
	Sr	107.5	46.6	97.9	47.6
	Y	188	109	146	92
	Zr	422	405	335	419
TRACE	Nb	16	26	19	28
ELEMENTS	Cr	48	93	4	34
(ppm)	Co	75	0	27	1
	Pb	9	0	11	0
	Cu	5	7	6	14
	Zn	357	44	243	139
	As	0	0	0	0
	V	84	24	45	28
	Ni	17	95	2	53

Alteration is marked by an increase in volatiles content (mostly as CO_2 from carbonate), in both the matrix and the variole. Silicification correlates with the loss of volatiles Na_2O and potassium metasomatism (addition of K_2O) in the varioles.

The water content of the matrix of both samples is 2-3 wt% (subtract CO_2 from LOI). Hydration of the original mafic glass forms the chlorite-leucoxene-epidote matrix observed in thin section. Notice that LOI for the varioles is accounted for by carbonate (as CO_2) which is found in microfractures (eg. Plate 8). This follows, because the varioles are made up of essentially nonhydrated mineral assemblages (ie. albite-quartz-oxide).

For both samples, SiO_2, Al_2O_3, Fe_2O_3, MgO and Mn show distinct fractionation. Si is enriched in the variole whereas Al, Fe, Mg and Mn are enriched in the matrix. Trends for TiO_2 and P_2O_5 do not correlate with fractionation, nor do they appear to be significantly affected by alteration. CaO tends to associate with observed trends in carbonate addition. Sulphur content also appears to correlate with carbonate addition and is especially apparent in varioles.

3.7 MATRIX VARIOLE TRENDS IN THE GRADED FLOW

The Graded Flow is a distinct, approximately 30 m thick flow which demonstrates flow differentiation by the

rise of varioles which coalesce towards the upper part of the flow. This flow which underlies the No. 4 Shaft flows, in continuous along strike for 800 m (MacVeigh, 1978).

Figure 2 represents a cross section of this flow and the textures it exhibits. Table 4 presents data for samples taken across strike of this flow.

The flow consists of a carbonate altered variole-free basal zone (DBS 35), which grades into an upper variolitic zone. The variolitic zone is marked by a gradation from large (5-7 cm) diameter varioles with a peculiar weathered surface (DBS 36), which grades into large (3-5 cm) coalesced "mega" varioles (DBS 37), and finally into more typical coalesced varioles (DBS 38). The upper contact with the next flow is a slightly foliated variolitic rock which was not sampled. The base of the next flow is non-variolitic.

A thin diabase intrusion occurs near the base of the Graded Flow in the thesis area.

DBS 35

This sample is somewhat highly carbonate altered. In thin section it appears as a medium grained, mottled-looking rock with slightly sericitized plagioclase laths (now albite). Carbonate grains produce the mottled texture. Some plagioclase show myrmekitic alteration to quartz and albite. These are secondary effects altering a fine-medium grained basaltic-textured volcanic.

FLOW TOP

COALESCED
VARIOLITE

UPPER VARIOLITIC
ZONE
∼ 20 m

EVEN - COLOURED
"MEGA" VARIOLITE

LARGE , ATYPICAL
VARIOLES

BASAL ZONE
∼ 15 m

CARBONATE ALTERED ,
VARIOLE—FREE
BASAL ZONE
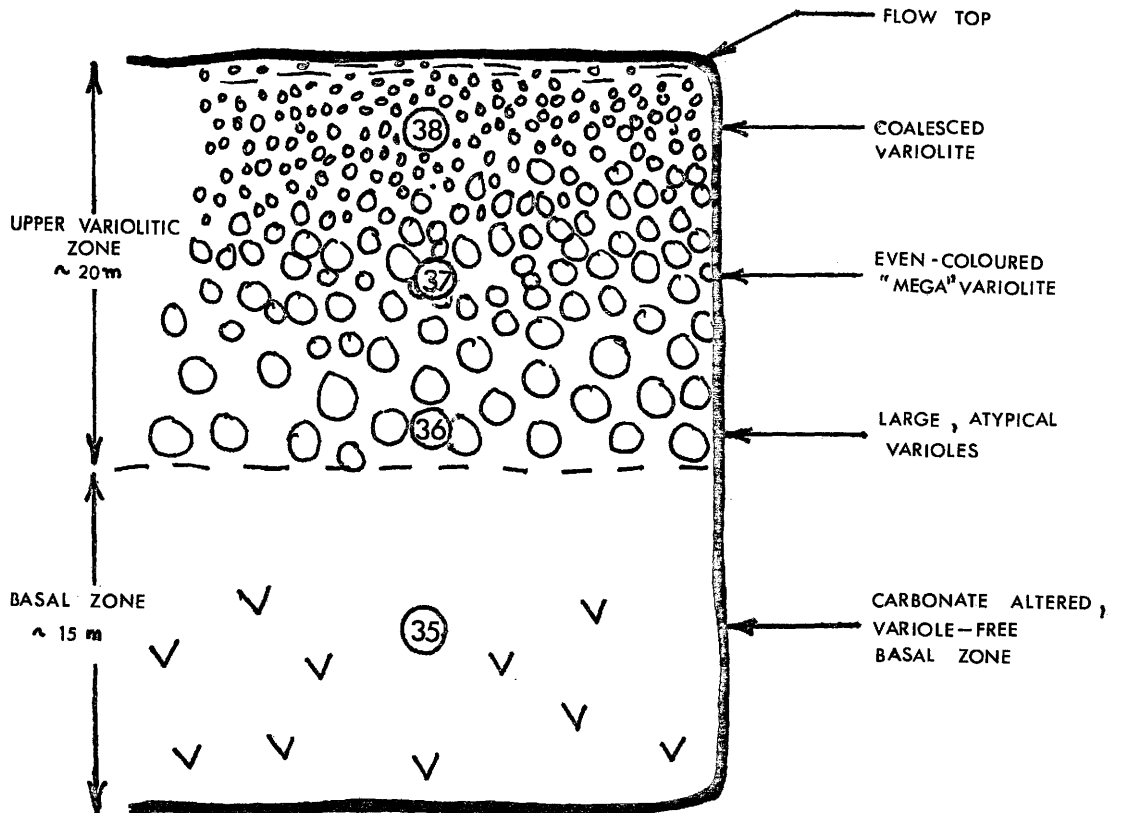
FIGURE 2   PROFILE SKETCH OF GRADED FLOW WITH SAMPLE LOCATIONS
(APPROXIMATE SCALE)
FOR LOCATIONS SEE MAP 3

PLATE 14 "MEGA" VARIOLES - MIDDLE OF VARIOLITIC ZONE
(DBS 10)
(LENS CAP FOR SCALE)

PLATE 15 LARGE ATYPICAL VARIOLES FROM THE BASE OF VARIOLITIC
ZONE - MAIN FLOW (DBS 28)
(LENS CAP FOR SCALE)
COMPARE TO SAMPLE 36 (PLATE 12)

DBS 36

This sample, pictured in Plate 12 is similar on weathered surface to Plate 15 (DBS 28 from the Main Flow). Large chloritic varioles are set in chloritic matrix. The difference between matrix and variole is hardly apparent in thin section, and chlorite is intermixed with fine grained albitized plagioclase.

DBS 37

This sample represented is by large coalesced "mega" varioles. The degree of coalescence was so great, that matrix and varioles could not be visually distinguished on a fresh surface. Megavarioles, set in a glassy matrix are pictured in Plate 14. This is from a different location and is not representative of DBS 37.

DBS 38

This sample pictured in Plate 13 is similar to DBS 33 from the Main Flow. Varioles are highly coalesced and show coarse dendritic crystallites in the varioles (See Plate 17, page 53). Contacts between adjacent varioles in thin section are poorly defined and irregular as opposed to linear boundaries of varioles from DBS 29. These samples also lack the border zone characterized by varioles of DBS 29.

TABLE 5 VERTICAL VARIATION OF MATRIX-VARIOLE FRACTIONATION WITHIN GRADED FLOW (SEE FIGURE 2)

PLATES 12, 13
CUT SURFACES
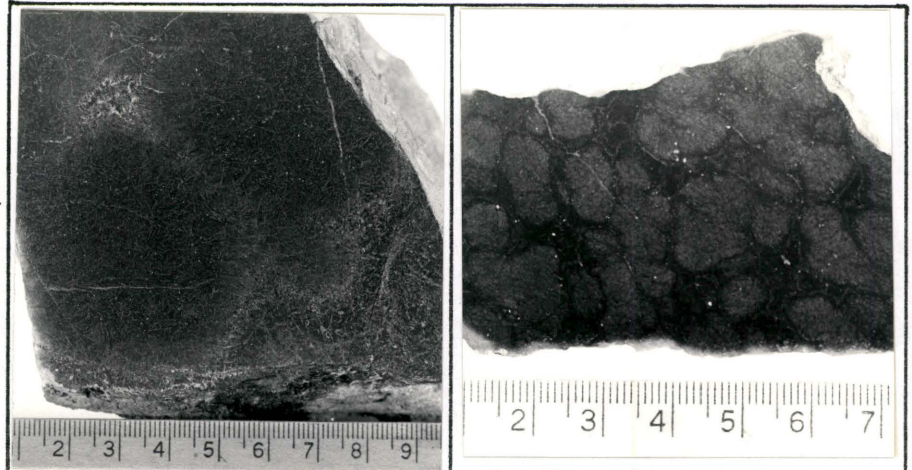
wt%	DBS 35	DBS 36		DBS 38	
		MATRIX	VARIOLE	MATRIX	VARIOLE
SiO_2	54.70	60.85	60.20	40.96	59.52
Al_2O_3	12.94	12.16	13.13	15.40	11.83
Fe_2O_3	17.89	14.49	12.46	26.45	10.39
MgO	3.91	3.78	3.62	7.30	3.03
CaO	4.86	3.59	2.98	1.49	4.93
Na_2O	2.67	2.76	4.83	1.42	3.76
K_2O	0.28	0.09	0.50	0.70	0.38
TiO_2	2.31	1.75	1.56	2.13	1.31
MnO_2	0.22	0.20	0.13	0.30	0.21
P_2O_5	0.22	0.26	0.24	0.19	0.23
LOI(wt%)	4.6	5.4	2.6	5.6	5.1
Au(ppb)	3.15	1.03	2.40	1.51	1.23

FLOW BASE ⟶ FLOW TOP

TABLE 5 - VERTICAL VARIATION (Cont...)

(ppm)		DBS 36		DBS 38	
		MATRIX	VARIOLE	MATRIX	VARIOLE
	Rb	3.1	8.8	7.8	5.1
	Sr	53.4	79.5	33.3	147.3
	Y	98	72	154	387
	Zr	253	219	387	277
	Nb	15	14	12	18
	Cr	0	0	0	0
	Co	54	43	122	36
	Pb	11	12	6	14
	Cu	17	1	50	16
	Zn	245	113	263	135
	As	0	0	0	0
	V	182	149	484	171
	Ni	47	58	163	62

FRACTIONATION TRENDS

Variolites DBS 36 and 38 were analysed for fractionation trends. It was impossible to separate varioles from matrix for DBS 37 because of the degree of coalescence.

DBS 38, has smaller varioles than DBS 37 or 38 and shows a fair degree of matrix-variole fractionation. The matrix shows higher Al_2O_3 and MgO than the variole and is a high iron tholeiite. The variole is higher in SiO_2 and CaO.

Sample DBS 36 with large atypical varioles shows less marked fractionation. In fact, matrix and variole compositions are quite similar, suggesting that the degree of fractionation is less marked in the larger "resorbed" varioles towards the middle of the flow. This is probably a result of "homogenization" between matrix and variole and probably reflects the mechanisms by which they formed.

GOLD FRACTIONATION

Gold contents for samples from the Graded Flow presented in Tables 2 and 3 are summarized here. The variole-free basal zone (DBS 35) yields 3.15 ppb gold. This value is higher than the rest from the same flow and is almost certainly related to carbonate alteration (because this specimen observed as being highly altered in thin section). Sample DBS 37,(consisting mostly of varioles) yield a gold level of 1.32 ppb. Matrix variole separates for

DBS 36 and 38 (stratigraphically above and below DBS 36) also yield low gold values. DBS 36 shows slight gold enrichment in the variole and DBS 38 has matrix gold levels slightly higher than the varioles. The gold values here are low and similar to values yielded for DBS 22.

3.8 SUMMARY OF FRACTIONATION TRENDS

By plotting matrix and varioles on a Jensen plot (Jensen, 1976), fractionation trends become immediately obvious (figure 3). Tie lines can be drawn between the matrix and variole points. Longer tie lines indicate greater fractionation.

DBS 29 shows the most marked fractionation and DBS 36 shows the least. These trends are also noticed in the colour differences between matrix and variole (ie. DBS 29 is marked and DBS 36 is slight).

Sample DBS 27, considered an altered equivalent of DBS 29 shows a shift in fractionation trends due to alteration effects.

Matrix samples plot in the tholeiitic andesite and iron tholeiitic fields. Varioles vary from rhyodacite to tholeiitic andesite.to iron tholeiite. This trend reflects the tendancy towards homogeneous composition in highly coalesced and resorbed varioles.

Sample DBS 35, representing the non-variolitic
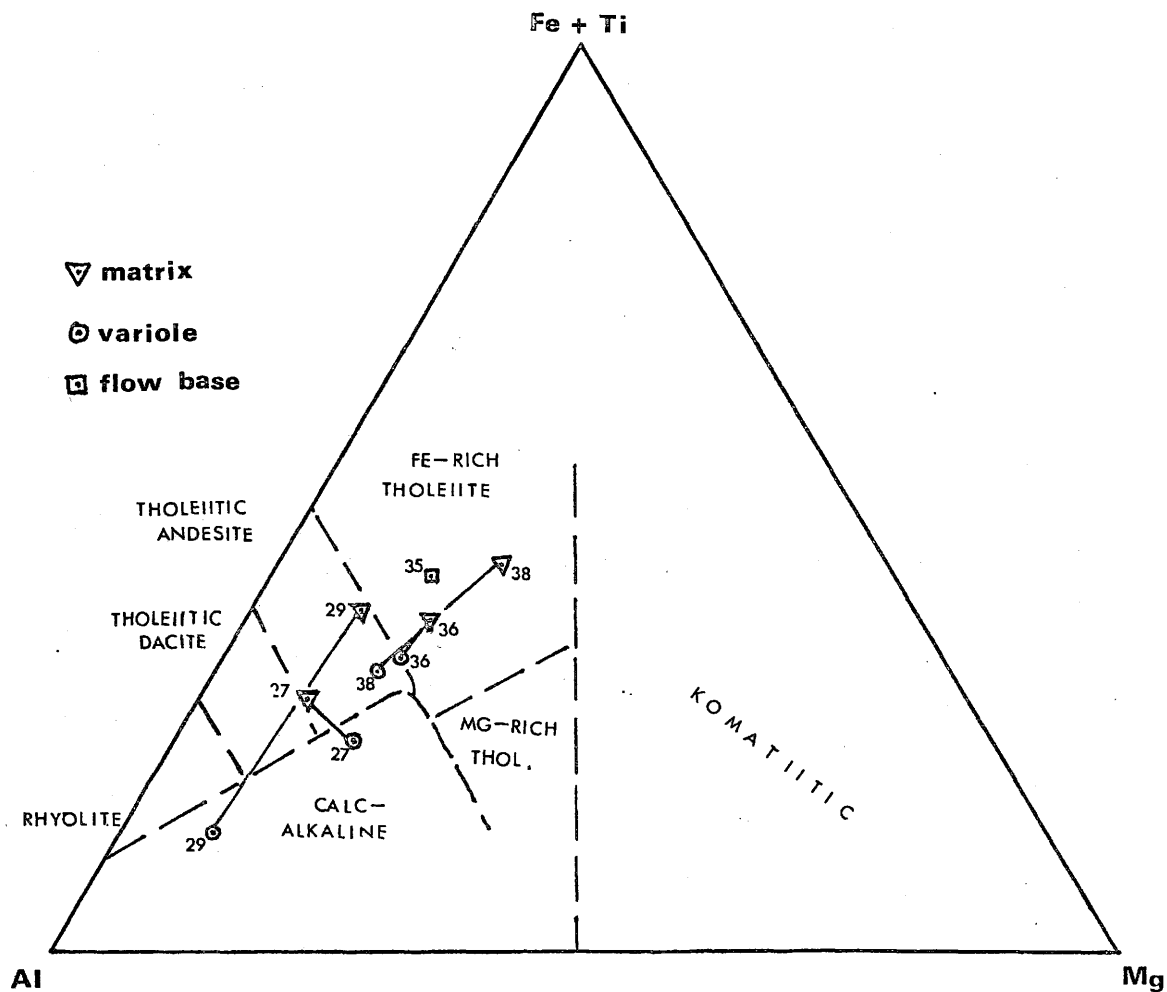
FIGURE 3 - JENSEN PLOT OF MATRIX-VARIOLE PAIRS

base of the Graded Flow plots in the iron tholeiite field. This position may reflect a composition similar to the initial one-liquid source of variolites.

GOLD FRACTIONATION

Gold values of matrix and variole tend to be low and the trends of enrichment can always be correlated to carbonate alteration. It is probable that gold values were initially low and that fractionation did not affect gold concentrations.

Gold concentrations of both rhyolites and basalts are typically low (0.2-3.5 ppb) and gold does not seem to higher background levels in either (Crocket, 1974). Gold tends to behave as an inert element and does not form chemical bonds with silicates (Crocket, 1974). Thus it is equally likely to diffuse through a rhyolite or iron tholeiite, even when in contact as immiscible liquids.

CHAPTER 4

DISCUSSION AND CONCLUSIONS

4.1 THE ORIGIN OF VARIOLITES

Several models have been proposed for the origin of
variolitic textures. Each model (presented below) is subject
to inconsistencies, but textural evidence and field relations
lend support to an origin involving primary magmatic segre-
gation of matrix and variole before rapid cooling (ie. liquid
immiscibility).

DIAGENETIC ORIGIN

This model, supported by Dimroth and Lichtblau
(1979) and Hughes (1977), suggests that varioles form during
spherulitic devitrification related to spillitic alteration.
Varioles here are thought to be abnormally large spherulites
in basaltic glass which nucleated and "coalesce" to form
typical variolites. This model tends to ignore textural
evidence and chemical fractionation trends, especially
between major elements considered to be relatively immobile -
ie. Al, Mn and to some extent Fe, Mg (Smith, 1968; Davies
et al., 1979).

CONTEMPORANEOUS MAGMAS

Experimentally, and in relatively rare field examples, two different magmas can coexist; at least for a limited time (Yoder, 1973). Models to explain field occurrences involve rapid partial melting of at least one source rock, or two distinct magma sources which mix before emplacement. Philpotts (1971) considers it unlikely to produce regionally distributed amounts of magma by this model. Variolitic lavas in the Abitibi belt form thick horizons many kilometers long (Ferguson, 1968) and the author favours a model which involves immiscible liquids.

LIQUID IMMISCIBILITY

The presence of immicible tholeiitic melts has been well documented in recent years (eg. De, 1974; Philpotts, 1978). This came after the discovery of immiscible glasses in lunar basalts (Roedder and Weiblen, 1970). Prior to this, liquid immiscibility was widely held as being geologically unfeasable (eg. Bowen, 1928), although field occurrences of some rocks were suspect to this model (eg. Drever, 1960).

Liquid immiscibility has been suggested as the origin of several rock types, including variolitic lavas and anorthosites (eg. Gélinas et al., 1976; Weibe, 1979).

Philpotts (1971) describes abundant "feldspathic ocelli" from regional Lower Cretaceous dikes in Quebec. He attributes the textures of these rocks to liquid immiscibility.

Ocelli are similar to varioles and show some evidence of
coalescence, flow deformation and differentiation (including
flotation).

Other examples of variolitic or ocellar textures
have been described by Ferguson and Currie (1972) from
Transvaal, and Pugin and Khitarov (1980) from Russia and are
quite similar to those of the Abitibi belt (Gélinas et al.,
1976, and this study).

IMMISCIBILITY THEORY

The formation of two melts, in equilibrium as
separate immiscible phases is presumably in response to a
particular component of the flow (perhaps alkali content) and
the drop in temperature and pressure upon extrusion. The new
phase, nucleating as droplets, grow and coalesce until surface
tension requirements are satisfied (Philpotts, 1977). Being
in a liquid state, the droplets would grow extremely quickly
because diffusion kinetics are very favourable in liquids.

The droplet, usually having a lower density will
rise as they coalesce (Philpotts, 1971). When coalescence
occurs, "floating" rates will increase dramatically (relative
to the rate of increase of the droplet's radius). When matrix
viscosities are lowered by quench cooling, the rising droplets
are commonly "frozen" showing various degrees of coalescence.
This has been confirmed experimentally (Philpotts, 1977).

The above argument explains the textures and size

zonations seen in the Main and Graded Flows, and in variolitic pillows. The microvariolitic flow top (Plate 1) is a quenched capping representing the initial state of the rapidly cooling liquid. As flowage continued, varioles grew, coalesced and rose towards the top, until the decreasing viscosity of the cooling flow top trapped them in a glassy or dendritic textured matrix

The base of the variolitic zone displays large individual or slightly coalesced atypical varioles which have compositionally resorbed back into the matrix (DBS 36 Plate 12) Presumably this is because they did not rise rapidly enough to quench, and is a result of slower cooling and changing conditions, became miscible with the melt. The variole-free base of the flow shows plagioclase crystals typical of a medium grained basalt indicating there was enough thermal insulation by the variolitic upper zone for these textures to develop.

In a pillow or lava tube, the varioles "float" to the center because of flow mechanics so that the larger more coalesced varioles are found in the core of the pillow. Smaller varioles are found in a glassy matrix towards the rim of the pillow, suggesting that they were quenched before they could coalesce.

Stretched or flow banded variolites result in elliptical variolites (DBS 29) or in a rock similar to DBS 32 (Plate 5) where flowage has destroyed primary relationships.

ZONED VARIOLES

Dendritic crystallization of the varioles with two main primary zones, the core and the inner zone (Plate 8 , page 26) suggests that the variole was not homogeneous before it began to quench. This does not fit the theory because an immiscible droplet should be homogeneous, unless:
1) the core zone represents the nucleation site as Gélinas et al. (1976) do suggest. The inner zone then represents a rapid late stage growth and some coalescence results from this rapid growth.
2) Varioles began crystallizing from the rim to the core, due to thermal insulation by the variole's own mass, allowing for the core zone to be slightly coarser.

The border zone is a metasomatic alteration product. There is a possibility that in part, this zone may have existed before alteration because continued alteration would certainly obscure the matrix variole contact.

COALESCENCE

In rapidly quenched variolites, this is probably the most distinctive feature demonstrating that varioles are semi-liquid droplets prior to complete quenching. Where two varioles have coalesced, contacts are roughly straight lines (Plate 9, page 27). Where three varioles are in contact, straight lines intersect at 120° at the common point of contact (Plate 16).

52
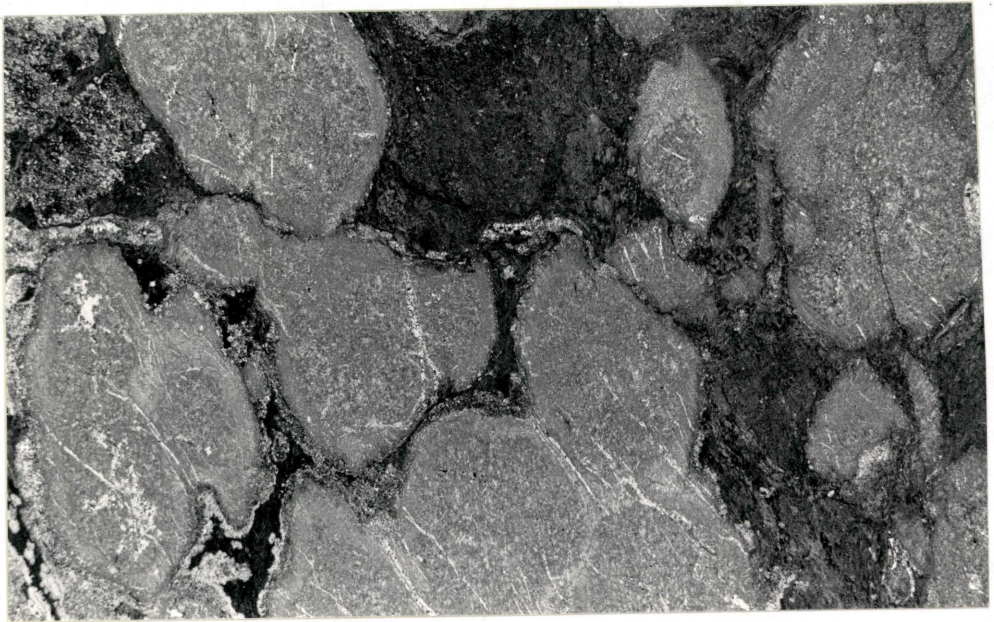
PLATE 16   COALESCED AND MICROFRACTURED VARIOLES - DBS 29
NOTE - BORDER ZONE, COALESCED CONTACTS

1.5
cm
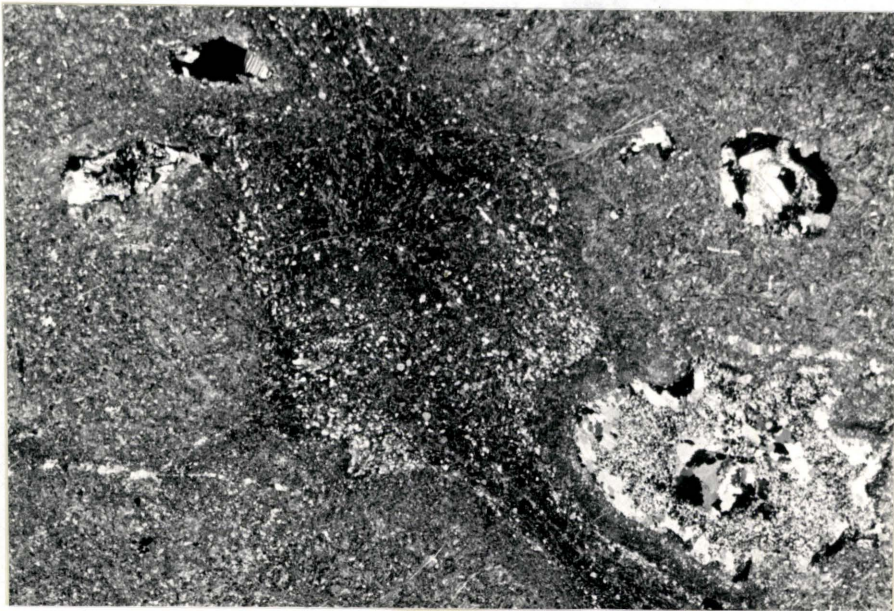
PLATE 17 VESICLES IN COALESCED VARIOLES - DBS 33
NOTE - COARSE TEXTURES

0.8
cm

Coalescence can progress to such a degree that large (1-3 m thick) rhyolitic zones form at the upper part of some massive flows (ie. No. 4 Shaft flows). MacVeigh (1978) cites evidence for coalesced "rafts" by observation that at the margins of the "rafts", individual varioles show typical matrix-variole relationships.

Where two quenched varioles are in close contact, but coalescence has not occurred, a thin band of mafic matrix separates the two varioles. The border zone persists around the whole variole, and where the varioles come close together, the contact is a straight line in thin section. There is no observable deformation of dendritic textures, suggesting that quench crystallization occurred after the varioles came together. Plate 8 on page 26 shows these relationships.

OTHER TEXTURES

Gélinas et al. (1976) describe tension cracks and microfractured dendritic textures attributed to late stage cooling and flowage. A variole, shown in plate 9 (page 27 of this study) shows an angular gash which may be a cooling crack. Flow brecciated varioles set in a glassy matrix of variolitic pillows has been observed by the author at other locations close to Timmins.

A microfaulted variolite (DBS 29), shown in plate 16 probably results from minor orogenic deformation which occurred

after border zones had formed on the varioles. Thin alter-
ation rims are observed where minor displacement brings
the core of the variole into contact with the matrix.

Plate 16 also demonstrates the ductile behaviour
of the matrix, probably a result of recrystallization of
chlorite. Varioles fracture leaving irregularities (note
the displaced border zone), and the matrix or carbonate
material occupies pore spaces.

VESICLES IN COALESCED VARIOLES

Plate 17 shows quartz-chlorite amygdules within
highly coalesced varioles of the Main Flow (DBS 33).
Vesicles tend to occur towards the edge of the variole.

Gélinas et al. (1976) also describe vesicles which
occur near the edges of coalesced varioles. A possible
explanation as to why vesicular outgassing occurs in the
variole only, may be related to higher volatile pressures in
the more felsic matrix.

Dendritic textures observed in this type of coalesced
variolite(Plate 13, page 42) do not show fine skeletal
structures typical of quenched variolites of the Main Flow
(ie. DBS 27, 29). Coarse dendritic textures persist and
coalescing margins are indistinct, suggesting that these
variolites had more time to cool than those samples set in
a glassy matrix.

4.2 PROBLEMS WITH LIQUID IMMISCIBILITY MODELS

Models of silicate melts should predict fractionation trends, if the matrix and varioles are immiscible from one liquid source. Data presented by Philpotts (1971, 1977) suggests that immiscible fractionation should enrich ocelli (varioles) in Si, Al and K. The matrix should be enriched in Fe, Mn, Mg and Ca. Analysis of immiscible glasses summarized by Philpotts (1981), shows the Si-rich phase should be high in Si, Al, Na, K whereas the Fe-rich phase should be high in Fe, Ti, Mg, Mn, Ca, P, Zr.

Fractionation observed in this study (Tables 4 and 5) show a marked depletion of Al in the matrix, whereas Si, Al, Fe, Mn, and Mg show "expected" trends. Ti, Ca, P do not seem to correlate. Ca, Na and K, being strongly susceptable to remobilization, especially in Archean aged rocks, should be used cautiously where any evidence of alteration is found.

Quench variolites studied by Gélinas et al. (1976) show a slight depletion of Al in the matrix. Studies by Pugin and Khitarov (1981) and Ferguson and Currie (1972) show little fractionation of Al between matrix and variole.

Silicate melts are thought to consist of configurations of polymerized SiO_4 molecules (Hess, 1981). The degree of polymerization is dependant upon concentrations of metallic cations such as Fe^{+3}, Ti^{+4}, Ca^{+2}, Na^+, etc. These tend to break up polymerized chains to balance charge

deficiencies. The addition of metallic ions will reduce the viscosity of the melt by breaking up polymerized SiO_4 chains into more isolated SiO_4 groups. Varioles would thus have a higher viscosity than the matrix and would tend to be "coherent" relative to the matrix. Coalescence and the size of the immiscible droplets depends upon the surface energies of the liquids involved (Philpotts, 1977).

Al will substitute for Si, so that it is likely to be associated with the Si-rich fraction. This is not the case for variolites of the study area. Thus, silicate liquid immiscibility by present models of silicate melts cannot explain the origin of these variolites.

Simple polymerization models are sufficient to explain immiscibility in binary systems. However, due to the complexity of natural silicate melts, and the inability to experimentally reproduce the state of the original melt in the laboratory, a great deal of knowledge is missing in this field. Abnormal concentrations of ions such as Na, K and Ca and certain other trace elements may be the cause of immiscibility associated with the emplacement of the lavas, and primary relationships are lost during metamorphic recrystallization.

Philpotts (1977), proposes a "late spherulitic crystal- lization phenomenon" to explain Archean variolites. This does not consider highly coalesced varioles and other tex- tural evidence which suggests liquid flowage before final crystallization. This model may explain the border zone of

varioles as being a primary structure due to spherulitic growth, as opposed to being diagenetic alteration. To initiate this type of spherulitic growth, would require unusual compositions or conditions, otherwise they would be more common rock types. This is a requirement common to explanation using liquid immiscibility models.

4.3 CONCLUSIONS

Massive variolitic flows of Munro Township exhibit relationships which suggest they result from liquid segregation of matrix and variole during the emplacement of each flow. Micro-textures exhibited by variolites also demonstrate fluidal origins. Liquid immiscibility or a similar process is considered likely to produce these features.

Contrasting chemical compositions between matrix and variole also suggests the presence of immiscible liquids. The growth of immiscible droplets and subsequent cooling demonstrated by quench crystallites is considered an extremely rapid process which begins before the flow has stopped moving.

Diagenetic alteration obscures some matrix-variole relationships. Carbonate alteration enhances gold values locally, but economic mineralization requires special circumstances not present in rocks of the thesis area.

Gold fractionation between matrix and variole is minimal, suggesting that gold behaves as an inert element

during liquid segregation. Slightly higher gold values in the varioles is probably a result of the addition of carbonate material in microfractures.

4.4 SUGGESTIONS FOR FURTHER WORK

To determine more about variolitic rocks, several ideas should be tested:

1) Similar studies of variolitic rocks from locations where alteration and deformation are minimal. The study and comparison of pristine variolites from ocean floors or ophiolite suites should be warranted. The location chosen for this study is probably one of the best that will be found in Archean rocks.

2) Observation of coalesced variolites to determine the exact nature of internal variole zonation, and dendritic crystallization. Particular attention should be given to the border zone to determine its exact nature.

3) Careful study of preserved phenocrysts with particular attention to inclusions and compositions to observe any unusual trends. These trends should reflect the original composition of the source magma.

REFERENCES

Arndt, N.T., Naldrett, A.J., and Pyke, D.R. (1977). Komatiitic and iron rich tholeiitic lavas of Munro Township, northeast Ontario. Jour. of Petrology vol. 18; p.319-369.

Baragar, W.R., and McGlynn, J.C. (1976). Early Archean basement in the Canadian Shield: A review of the evidence. GSC Paper 76-14.

Bowen, N.S. (1928). The evolution of igneous rocks. Princeton University Press, pp.332.

Cann, J.R. (1969). Spillites from the Carlsberg Ridge. Journal of Petrology vol. 10; p.1-19.

Condie, K.C. (1976). Trace element geochemistry of Archean greenstone belts. Earth Sci. Review vol. 12; p.393-417.

Crocket, J.H. (1974). Gold - Handbook of Geochemistry. vol 11-4; Springer-Verlag, Berlin.

--------, Keays, R.R., Hsieh, S. (1968). Determination of some precious metals by neutron activation analysis. Jour. Radioanal. Chem. vol. 1; p.487-507.

Davies, J.F., Grant, W.E., and Whitehead, R.E.S. (1979). Immobile trace elements and Archean volcanic stratigraphy in the Timmins mining area, Ontario. Can. Jour. Earth Sci. vol. 16; p.305-311.

De, A., (1974). Silicate liquid immiscibility in the Deccan Traps and its petrological significance. Geol. Soc. Amer. Bull. 85; p.471-474.

Dimroth, E. and Lichtblau, A.P. (1979). Metamorphic evolution of Archean hyaloclastites, Noranda area, Quebec, Canada. Part 1: Comparison of Archean and Cenozoic sea floor metamorphism. Canadian Jour. Earth Sci. vol. 16-7; p.1315-1340.

--------, Boivin, P., Goulet, N., and Larouche, M. (1973). Tectonic and volcanological studies in the Rouyn-Noranda area. Open File Manuscript, Que. Dept. Nat. Resour.; pp.1-60.

60

Drever, H.I. (1960). Immiscibility in the picritic intrusion
        at lg'dlorsuitt, West Greenland. 21st Int. Geol.
        Cong. Copen. 1960, Proc., Sec. 13, part 13, p.47.

Ferguson, J., and Currie, K.L. (1972). Silicate immiscibility
        in the ancient "basalts" of the Barberton Mountain
        land, Transvaal. Nat. Phys. Sci., vol. 235; p.86-
        89.

Ferguson, S.A., Buffam, B.S.W., Carter, O.F., Griffis, A.T.,
        Holmes, T.C., Hurst, M.E., Lones, W.A., Lane, H.C.,
        and Longley, C.S. (1968). Geology and ore deposits
        of Tisdale Township, District of Cochrane. Ontario
        Dept. Mines, GR 58, 177p.

Fyon, J.A. (1980). Seawater alteration of early Precambrian
        (Archean) volcanic rock and exploration criteria
        for stratiform gold deposits, Porcupine Camp,
        Abitibi belt, NE Ontario. Unpublished MSc. Thesis,
        McMaster University.

Gelinas, L., Brooks, C., Trzcienski, Jr., W.E. (1976).
        Archean variolites - quenched immiscible liquids.
        Can. Jour. Earth Sci. vol. 13; p.210-230.

Goodwin, A.M., and Ridler, R.H. (1970). The Abitibi orogenic
        belt, In: Symposium on basins and geosynclines of
        the Canadian Shield, Geol. Surv. of Canada Paper
        52-28; p.7-18.

Hess, P.C. (1981). Structure of silicate melts. Can.
        Mineralogist vol. 15; p.162-178.

Hogg, N. (1950). The Porcupine area - Can. Mining Journal
        vol. 71; p.102-106.

Hughes, C.J. (1977). Archean variolites - quenched immiscible
        liquids: Discussion. Can. Jour. Earth Sci. vol. 14;
        p.137-139.

Hutchinson, C.S. (1974). Laboratory handbook of petrographic
        techniques. John Wiley and Sons, New York; p.264-332.

Jensen, L.S. (1976). A new cation plot for classifying sub-
        alkaline volcanic rocks. Ont. Min. Nat. Res., Misc.
        Paper 66.

→ Jolly, W.T. (1974). Regional metamorphic zonation as an
        aid in the study of Archean terrain, Abitibi
        region, Ontario. Can. Mineralogist vol. 12;
        p.499

→ --------, (1978). Metamorphic history of the Archean Abitibi
        belt. In: Metamorphism in the Canadian Shield.
        GSC Paper 78-10; p.63.

→ -------- (1980). Development and degredation of Archean
        lavas, Abitibi belt, Ontario; In light of major
        element chemistry. Jour. of Petrology vol.21-2;
        p.323.

-------- and Smith, R.E. (1972). Metamorphic differentiation
        and degradation of Keeweenawan lavas of northern
        Michigan. Jour. of Petrology vol.21-2; p.323.

Kwong, Y.T.J. and Crocket, J.H. (1978). Background and
        anomolous gold in rocks of an Archean greenstone
        assemblage, Kakagi Lake area, northwestern Ontario.
        Economic Geology vol. 73; p.50-63.

✓ MacVeigh, J.G. (1978). in Toronto '78 Field Trip Guidebook
        (Currie, A.L. and MacKasey, W.O., eds.) G.A.C.
        361p. (Stop 15, p. 180).

Philpotts, A.R. (1971). Immiscibility between feldspathic
        and gabbroic magmas. Nature Physical Science
        vol. 229; p.107-109.

→ -------- (1977). Archean variolites - quenched immiscible
        liquids: Discussion. Can. Jour. Earth Sci. vol. 14;
        p.139-144.

→ -------- (1978). Textural evidence for liquid immiscibility
        in tholeiites. Min. Mag. vol. 42, no. 324; p.417-
        425.

-------- (1981). A model for the generation of Massif-
        type anorthosites. Can. Min., Vol. 19; p.233-253.

→ Pugin, V.A. and Khitarov, N.I. (1980). Variolites as an
        example of liquid immiscibility in magmas. Geo-
        chemistry International, 1980; p.102-117.

→ Pyke, D.R. (1980). Relationship of gold mineralization to
        stratigraphy and structure in Timmins and surround-
        ing area. In: Genesis of Archean volcanic-hosted
        gold deposits, OGS MP 97; p.1-15.

Pyke, D.R. Naldrett, A.J., and Eckstrand, O.R. (1973).
    Archean ultramafic flows in Munro township, Ontario
    Geol. Soc. Amer. Bull. 84; p.995-998.

Roedder, E. and Weiblen, P.W. (1970). Silicate liquid
    immiscibility in lunar magmas, evidenced by melt
    inclusions in lunar rocks. Science, vol. 167;
    p.641-644.

Satterly, J. (1951). Geology of Munro Township. Ont. Dept.
    Mines vol. 60, pt 8.

Seki, J. (1961). Pumpellyite in low grade metamorphism.
    Jour. of Petrology vol. 2; p.407.

Smith, R.E. (1968). Redistribution of major elements in the
    alteration of some basic lavas during burial meta-
    morphism. Jour. of Petrology vol. 9, pt. 2; p.191-
    219.

Stockwell, C.H. et al. (1976). Geology of the Canadian
    Shield. In: Geology and Economic Minerals of
    Canada, Part A, Chapter 4.

Weibe, R.A. (1979). Fractionation and liquid immiscibility
    in an anorthositic pluton of the Nain Complex,
    Labrador. Jour. of Petrology vol. 20, pt. 2; p.239-
    269.

Yoder, H.S., Jr. (1973). Contemporaneous basaltic and
    rhyolitic magmas. Am. Min. vol. 58; p.153-171.

APPENDIX A

SAMPLES DEFINING THESIS LITHOLOGIES

The lithologic sequence presented in Figure 1
is a result, mainly of observations of field relationships.
Thin sections, hand specimens and chemical analysis were
used to further refine the rock divisions. For example
samples DBS 22, 23, 24 were originally mapped as carbonate
altered "volcanics". After thin section observation, DBS 22
was reclassified as a carbonate altered volcanoclastic.
Observation of DBS 24 in hand specimen showed hyaloclastic
textures and lesser degrees of carbonate alteration.

The thesis samples chosen for analysis were plotted
on a Jensen Plot (Fig. 5), and listed in stratigraphic order
with rock names as Table 6. For convenience these are
presented on opposite pages. Classification shows that the
volcanics of the thesis area are iron tholeiites, save for
DBS 39 which is from a highly coalesced "raft"of varioles.
(The trend seen here is close that of varioles for DBS 29,
plotted in Fig. 4).

The siliceous metasediment DBS 21, plots also in
a position indicative of the low mafic contents.

Samples DBS 30, 44 and 46 represent fresh volcanics.
DBS 30 and 46 are pillowed flows. DBS 44 is a massive flow

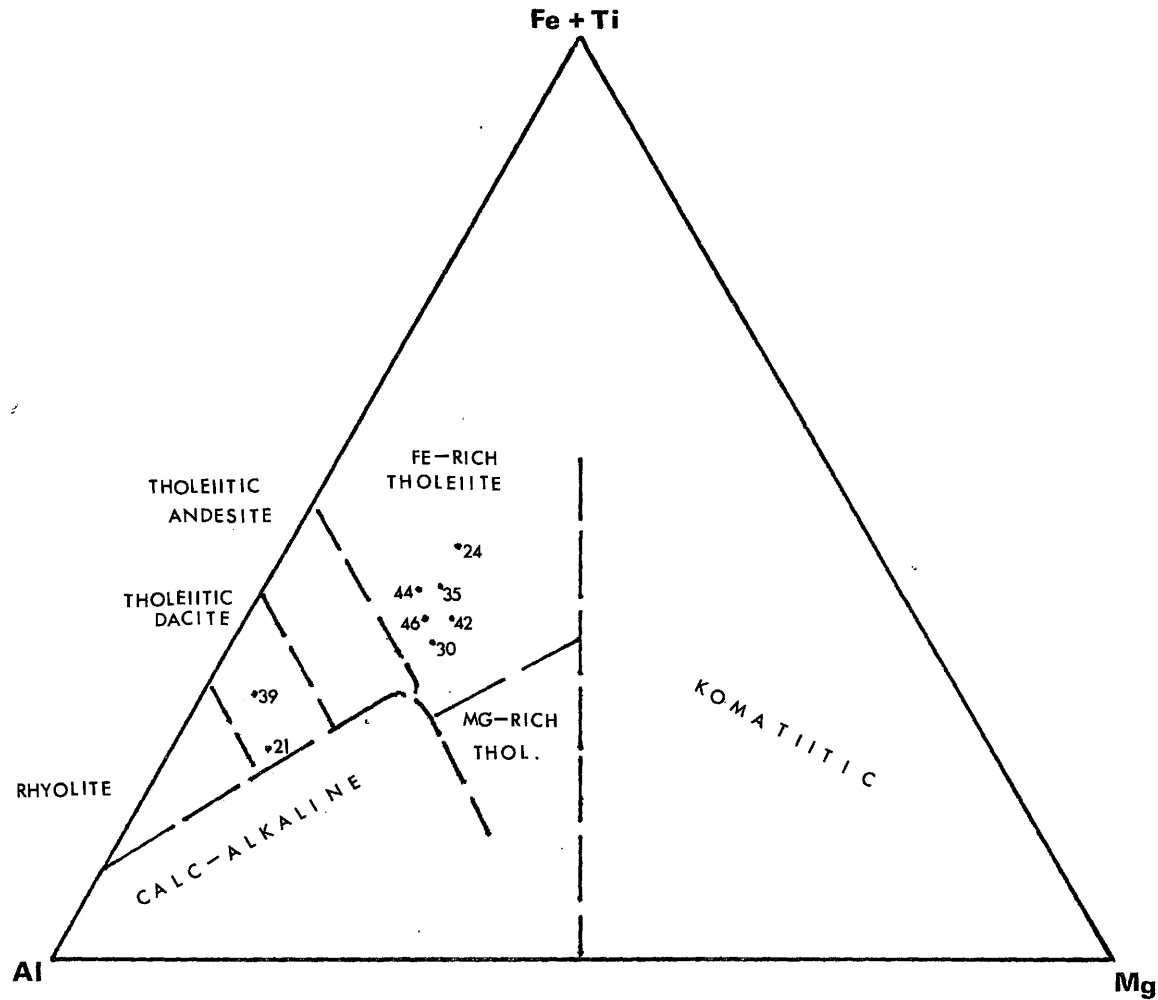Fe + Ti

FE–RICH
THOLEIITE

THOLEIITIC
ANDESITE

•24

44• •35

THOLEIITIC
DACITE

46• •42

•30

•39

K O M A T I I T I C

RHYOLITE

•21

MG–RICH
THOL.

C A L C – A L K A L I N E

Al

Mg

FIGURE 4 - JENSEN CATION PLOT FOR SAMPLES FROM THESIS SECTION

STRATIGRAPHIC TOP	SAMPLE	DESCRIPTION	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	P_2O_5
	46	CROESUS FLOW ("fresh")	50.36	14.84	16.64	4.44	8.77	2.39	0.20	1.82	0.38	0.17
	44	MASSIVE FLOW ("fresh")	48.08	13.51	18.49	3.93	10.80	1.92	0.10	2.41	0.51	0.24
	42	VOLCANOCLASTIC (carbonate altered)	54.12	12.77	17.66	4.67	5.32	4.16	0.65	0.52	0.14	0.09
	39	VARIOLITIC FLOW TOP (altered)	72.14	12.76	7.64	0.94	0.95	2.96	0.47	2.35	0.27	0.22
	35	BASE OF "GRADED FLOW"(Carbonate altered)	54.70	12.94	17.89	3.91	4.86	2.67	0.28	2.31	0.22	0.22
	30	PILLOWED FLOW	50.28	14.71	15.58	4.47	7.85	3.80	0.42	2.43	0.28	0.18
	24	VOLCANOCLASTIC	42.53	15.29	26.14	5.24	6.43	1.47	0.03	2.23	0.41	0.22
STRATIGRAPHIC BASE	21	SILICEOUS META-SEDIMENT (carbonate altered)	77.25	10.14	4.85	1.14	3.54	0.89	1.76	0.26	0.14	0.04

TABLE 6 – MAJOR ELEMENT DETERMINATION FOR SAMPLES FROM THESIS CROSS SECTION (NORMALIZED TO 100%)

REFER TO FIG. 1 FOR LOCATION

with anomalously high iron content (MacVeigh, 1978). This flow forms a magnetic marker above the variolitic section, and could reflect part of an unusual magma pulse which may have been responsible for the variolitic flow.

APPENDIX B

PREPARATION OF ROCK POWDERS

Fresh rock chips obtained by hammering hand specimens, were first ground to a fine grit in a soft iron mortar and pestle. The grit was then transferred to a ceramic ball mill and reduced to a fine powder (by automatic shaking) for approximately 30 minutes.

Matrix and variole pairs were sometimes of such small volume, that they could be reduced to a fine powder in the mortar and pestle. This was typically done for samples prepared for gold analysis alone.

DECONTAMINATION

Decontamination steps were performed during and after the preparation of each sample. This involved cleaning the mortar and pestle and ball mill by abrasion with refined quartz sand, followed by disassembly and wiping with dry paper towels. This decontamination step was performed twice, after each specimen passed through the mortar or ball mill. Also, preliminary sample material was processed and discarded when there was enough sample available. The mortar and pestle, and ball mill were disassembled and wiped with dry paper towels after each step.

DISCUSSION

These methods were used, as opposed to more auto-
mated methods because gold contamination is a serious problem
when concentrations in the rock are in the ppb range. By
using equipment which has never processed rocks with high
gold levels (eg. sulphides) and regularly decontaminating
with sand abrasive, the possibility of gold contamination
is reduced or standardized.

Most gold values obtained are low enough ($\sim$ 1-4 ppb),
to suggest that contamination was successfully eliminated.
See Appendix D (Discussion) for an example of contamination.

APPENDIX C

SEPARATION OF MATRIX AND VARIOLES

Samples chosen for matrix-variole analysis were first thinly slabbed with a diamond saw. Slabs varied in thickness from 2 to 10 mm. Separation of matrix-variole fractions was easiest from the thinnest slabs although they gave smaller sample volumes.

Each slab was roughly polished with coarse silicon carbide powder on an iron grinding disc to remove saw deposits and marks. Before separating matrix from variole, each slab was rinsed in distilled water and air dried. This was done to remove possible contaminants such as sulphide dusts. Matrix and variole were then physically broken apart with steel pliers and visually separated.

For most samples (eg. DBS 27, 29) matrix-variole colour difference is sufficient to readily distinguished between matrix and variole material. For some samples (eg DBS 36, 38) matrix-variole separation is difficult because the colour difference is small. Here also, the tendancy for coalesced varioles reduces the amount of matrix material that is available and it became difficult to collect more than 3 or 4 grams of material.

The rock separates were then bottled and prepared using methods in Appendix B.

APPENDIX D

EXPERIMENTAL GOLD ANALYSIS - SAMPLE DBS 29

Results obtained during experimentation were initially confusing, but continued analysis confirmed that some samples had been significantly contaminated during preparation.

An arbitrary lettering system was assigned to each slab of the hand specimen (Fig. 6). Portions of these slabs were selected and separated for analysis.

EXPT 1

DBS $29F_1$ (M-V) and $29F_2$ (M-V) showed very high gold values (9-23 ppb) with a matrix: variole ratio of 1:2. These numbers were initially thought to reflect high primary gold values (relative to typical basalts at 2-5 ppb (Crocket and Kwong, 1978)).
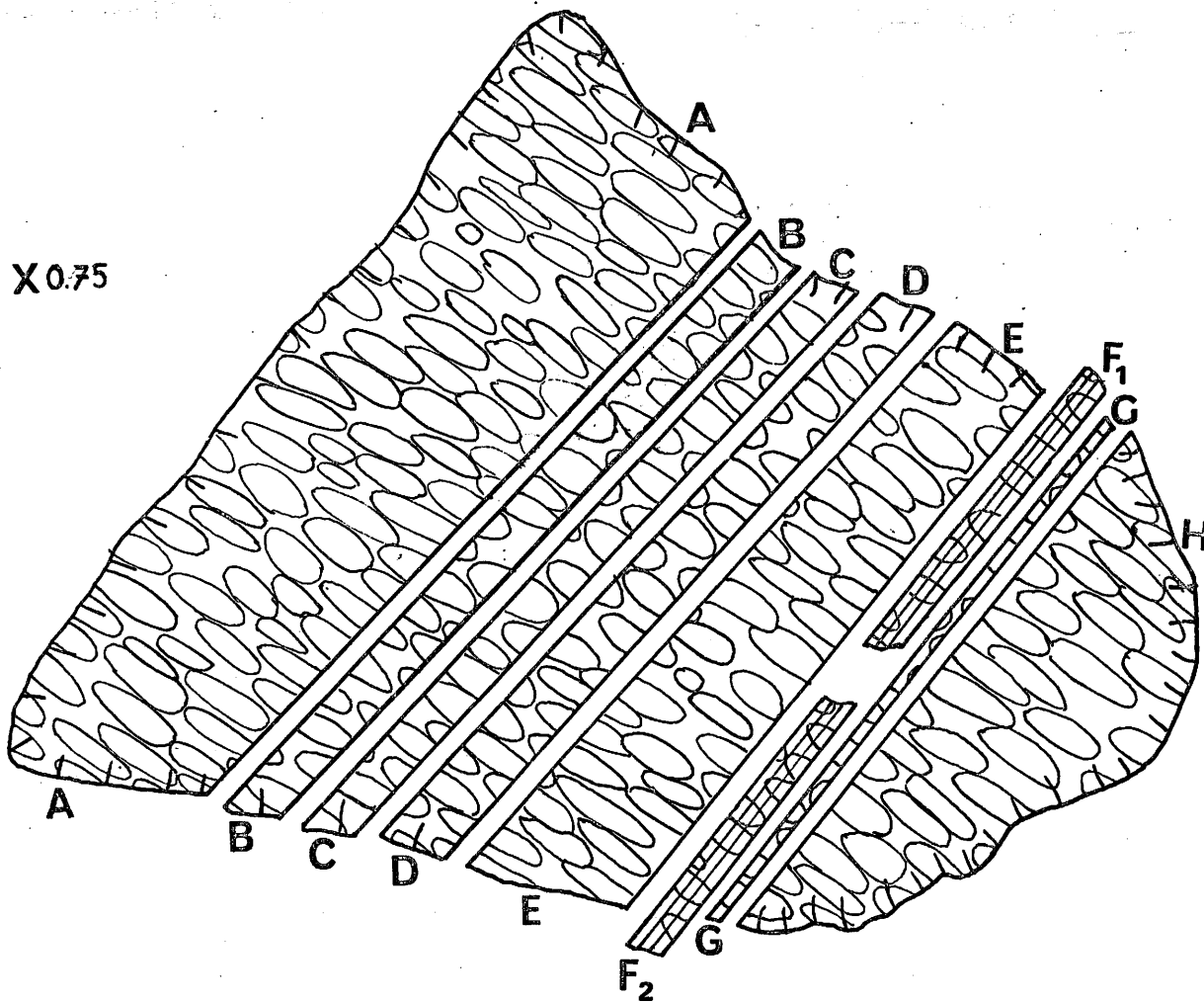
EXPT 2

DBS 29B(M-V) tested a different part of the sample and very low values were obtained for matrix and variole compared with analyses from EXPT 1.
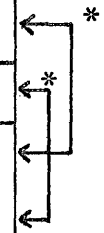
Three explanations are suggested:
1) Primary gold distribution is very irregular and an order of magnitude different across the hand specimen.

FIG. 5 SAMPLE DBS 29

X 0.75

EXPERIMENT	SAMPLE NUMBER	(ppm) MATRIX-VARIOLE	
		(M)	(V)
1	$29-F_1$	11.84	23.06
	$29-F_2$	9.01	18.53
2	29B	0.53	1.48
3	*$29F_2$	9.45	6.37
	*29B	1.22	1.55
	29C	1.66	1.05
	29G	0.60	0.98
4	29B pyrite		6.1

*INDICATES SPECIMEN ANALYSED WAS FROM THE SAME
BOTTLE USED IN A PREVIOUS EXPERIMENT

TABLE 7 - GOLD CONTENTS IN EXPERIMENTAL SEQUENCE FOR SAMPLE 29
        (COMPARE TO FIG. 2)

2) Samples used in EXPT 1 contain authigenic pyrite with high gold contents.

3) Samples used in EXPT 1 were contaminated by gold during preparation.

EXPT 3

Sampling was devised to solve these problems and give an accurate measure of the gold content. This experiment was run with all specimens taken from DBS 29. Two matrix-variole pairs were retested from previous experiments ($29F_2$ and 29B) and two new samples were prepared in the usual fashion (29C and 29G).

The results showed that there was some sort of contamination present in EXPT 1. The newly prepared samples yielded low gold values, even though one was adjacent to samples which yielded high values in EXPT 1 (DBS 29G). The contamination is irregular (compare $29F_2$-V between EXPT 3 and 4) and is probably due to the addition of grains of sulphide dust from contaminated steel wool used in the preparation of $29F_1$ and F_2.

EXPT 4

A sample, $29B_{py}$ was taken from varioles which were seen to contain pyrite in small fractures. The analysis of this specimen shows high gold and suggest that the values of EXPT 1 may (in part) have been due to gold in authigenic

pyrite.

DISCUSSION

It is probable that contamination of samples used in EXPT 1 is a result of preparation methods. This concurs with the fact that samples from EXPT 1 ($29F_1$, F_2) were the very first samples prepared in the mortar and pestle. Variole samples were crushed first and matrix samples second. This may cause the apparent systematic variation between those samples.

The actual source of contamination was traced to contaminated steel wool which was used to brush (and clean) the motar and pestle, as a decontamination step. This step was eliminated from the procedure after the preparation of $29F_1$, F_2 because of the extra time to perform it, and because decontamination by sand was deemed sufficient.