SEDIMENTOLOGY, PETROGRAPHY, AND DEPOSITIONAL ENVIRONMENT OF DORE SEDIMENTS ABOVE THE HELEN-ELEANOR IRON RANGE, WAWA, ONTARIO

SEDIMENTOLOGY, PETROGRAPHY, AND DEPOSITIONAL ENVIRONMENT OF DORE SEDIMENTS ABOVE THE HELEN-ELEANOR IRON RANGE, WAWA, ONTARIO

By

KATHRYN L. NEALE

Submitted to the Department of Geology

in Partial Fulfilment of the Requirements

for the Degree

Bachelor of Science

McMaster University

April, 1981

BACHELOR OF SCIENCE (1981) McMASTER UNIVERSITY

(Geology) Hamilton, Ontario

TITLE: Sedimentology, Petrography, and Depositional Environment of Dore Sediments above the Helen-Eleanor Iron Range, Wawa, Ontario

AUTHOR: Kathryn L. Neale

SUPERVISOR: Dr. R. G. Walker

NUMBER OF PAGES: ix, 54

ABSTRACT

Archean sediments of the Dore group, located in the Wawa greenstone belt, were studied. The sediments are stratigraphically above the carbonate facies Helen-Eleanor section of the Michipicoten Iron Formation. A mafic volcanic unit, 90 m thick, lies between the iron range and the sediments.

Four main facies have been identified in the first cycle of clastic sedimentation above the mafic flow rocks. A 170 m break in stratigraphy separates the volcanics from the first facies. The basal sedimentary facies is an unstratified and poorly sorted granule-cobble conglomerate, 200 m thick, interpreted as an alluvial mass flow deposit. Above the conglomerate, there is a 20 m break in the stratigraphic column. The second facies, 220 m to 415 m thick, consists of laminated (0.1 - 2 cm) argillites and siltstones, together with massive, thick-bedded (8-10 m) greywackes. The argillites and siltstones are interpreted as interchannel deposits on an upper submarine fan, and the greywackes are explained as in-channel turbidity current deposition. The third facies, 750 m to 1300 m thick, consists of normally graded greywackes (15-20 cm thick beds) interbedded with sharp based siltstones; respective interpretations are overbank and in-channel deposition on the middle fan. Above the siltstones, there is a 100 m break in the stratigraphic sequence. The fourth facies is a subarkosic sandstone, 1400 m to 1625 m thick, which is characterized by alternating cycles of ripples, megaripples and parallel lamination--suggesting deposition

by an ephemeral or braided river. The sedimentary cycle is terminated by the intervention of a thick gabbroic sill.

The thick-bedded greywackes of the second facies contain significant amounts of authigenic talc, magnesite, ferroan dolomite and chlorite; they are not rich in detrital quartz (up to 33%) and feldspar (less than 1%). The scarcity of detrital minerals does not strictly comply with the definition of a greywacke. However, based on the Mg-Fe character of the authigenic assemblage, the original or detrital minerals are thought to have been ferromagnesian.

ACKNOWLEDGEMENTS

Above all, I wish to thank my thesis supervisor, Dr. R. G. Walker, who critically read first drafts of the text and provided many suggestions for its improvement. Dr. G. V. Middleton visited me in the field; his observations and ideas were extremely helpful.

Special thanks are extended to Ron Sage, of the Ontario Geological Survey, for suggesting the particular thesis area and providing helpful advice both in the field and throughout the year. I also wish to thank Adam Beales, Don Clement and Doug MacMillan, for their assistance in the field.

My thanks to Jack Whorwood; he was especially helpful in the preparation of the photomicrographs. I wish to thank Virginia Costley for making the acetate peels, and Dan Thompson, for his help and suggestions pertaining to the x-ray diffraction. Thanks also to my neighbour across the hall, Len Zwicker, who prepared the thin sections and provided comic relief when necessary.

Mention must also be made of Andy Fyon, Rick Kusmirski, and Patricia Pilon, for helpful discussion during the year.

Last but not least, I wish to thank my mother, whose striving for perfection in the typing of the manuscript was greatly appreciated.

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Chapter I

INTRODUCTION

Statement of Problem

In the Archean iron-formations of the Lake Superior region, James (1954) assumed generation of mineral facies to be synchronous with sedimentary deposition. Specifically, sulphides are deposited in deep, ultra-stagnant reducing waters, and carbonates, silicates and oxides deposited in progressively shallower water. On the basis of this model, Goodwin (1973) assumed that in the Michipicoten area of north-central Ontario (Fig. 1), the Dore sediments, comprised of conglomerates, graded greywackes and laminated argillites, accumulated on a shallow shelf (Goodwin 1973, Figs. 1 and 2), and that the associated oxide iron-formation also accumulated on a shallow shelf.

However, Walker (1978) points out that oxide iron-formations of Archean greenstone belts are almost invariably associated with turbidites, and that the Dore sediments, as described by Goodwin (1962), could also be turbidites. Therefore, the question arises, are features of the Dore sediments indicative of a turbidity current origin? If so, Goodwin's assumption implies a juxtaposition of depositional environments, in "that association of iron-formations with turbidites suggests deposition in the deepest parts of the basin, and not along basin margins" (Walker, 1978, p. 1214).

Clastic sedimentation in Archean Greenstone Belts

The Archean regions of the world are characterized by two types of terrain: those containing gneiss-granulite rocks of high metamorphic grade, and those preserved in a low-grade state, the granite-greenstone belts. The upper sequences of these greenstone belts consist predominantly of sedimentary rocks, commonly 1,000 to 10,000 m thick (Lowe, 1980). Detailed studies of Archean sediments in South Africa, Western Australia, and central Canada imply an association of submarine fan with shallow marine or alluvial fan deposits.

The Fig Tree Group of the Barberton Mountain Land, South Africa, is mainly a deep-water greywacke-mudstone assemblage probably deposited by turbidity currents (Anhaeusser et al. 1968; Condie et al. 1970), but the basal unit includes shales, argillites and oxide facies iron-formation with interbanded cherts. This initial pulse of sedimentation represents a period of quiescence carried over from late Onverwacht times because of the similarity of character to the underlying volcanic assemblages. The Moodies Group conformably overlies the Fig Tree Group and detailed sedimentological studies by Eriksson (1977, 1978, 1979, 1980) have shown that it is composed largely of calcareous orthoquartzite, quartzose sandstone and shale. Deposition occurred in a variety of coastal environments including deltaic plain, barrier island, and shallow marine shelf.

In Western Australia, the Cuddingwarra Formation of the Murchison Province, Yilgarn Block, consists of alternating sandstone and siltstone turbidite beds, with wash-outs, graded bedding and slump structures (Horwitz and Smith, 1978). Deep marine sequences and shallow-water to terrestrial deposits have been described by Hallberg st al. (1976) in the Meekatharra area, Murchison Province. The shallow-water deposits contain immature and mechanically derived acid flows and lithic sandstones, shed from a localized volcanic pile.

In the North Spirit Lake area of the Superior Province, Canadian

Shield, Donaldson and Jackson (1965) observed thick sequences of greywacke-argillite couplets which resemble many described deposits of the flysch facies. Most primary structures in the sequences are characteristic of sediments deposited by turbidity currents. It is important to realize that although Pettijohn wrote his summary of the Archean (Pettijohn, 1943) before advent of the turbidity current concept, he convincingly drew a parallel between sedimentary-volcanic belts of the Superior Province and classical eugeosynclines. Goodwin and Ridler (1970), Goodwin and Shklanka (1967), Teal and Walker (1977), Turner and Walker (1973), Walker (1978), and Walker and Pettijohn (1971) have demonstrated the existence of a shallow-to-deep-water clastic association with subaerial alluvial fan facies, overlain by thick turbidite submarine fan or flysch sequences (Hyde and Walker 1977, Walker 1978, Wood 1980). There appears to be a marked absence of shallow-water clastic shelf and shoreline sequences.

Location and Access

The study area is situated approximately 9 km northeast of the town of Wawa, Ontario which itself is located at the junction of Highways 17 and 101, 20 km from the northeastern shore of Lake Superior. Specifically, the field area is in the township of Chabannel, with study focusing on the sediments which border the ACR (Algoma Central Railroad) spur line from Siderite to Siderite Junction (Fig. 1).

From Wawa, the easiest means of access is to travel 8.5 km east along Highway 101. At the eastern tip of Wawa Lake, turn north onto the gravel road owned by AOP (Algoma Ore Properties) and continue to the point where the railroad intersects the road, this being the place referred to as Siderite.

Figure 1 Inset map shows the location of the Michipicoten area (hatchured rectangle). Access routes leading to the field area are depicted on the enlarged map, as are the relative locations of Siderite and Siderite Junction.


Siderite
Junction
ACR
Lena Lake
Arliss Lake
Siderite
Walbank
L.
Hwy
101
Wawa Lake
0
1 km
Oba
CPR
CNR
Franz
Port Arthur
Hawk Jct
Lake Superior
Duluth
Sault Ste Marie
Scale
0
50
100 Miles

General Geology

The consolidated rocks of the area, as described by Collins and Quirke (1926) and Goodwin (1962), comprise Archean age volcanic and sedimentary rocks of the Michipicoten group and younger intrusive rocks.

Table 1. Formations of the Michipicoten Area, Algoma District, Ontario, Canada (Goodwin, 1962)

Unit	Rock type
Precambrian	
Intrusive rocks	diabase dikes granite, granodiorite, syenite diorite, gabbro, peridotite
Michipicoten group	upper volcanic rocks--basalt, andesite, minor rhyolite Dore sedimentary rocks--conglomerate, graywacke, shale middle volcanic rocks--andesite, dacite, minor rhyolite Helen iron formation--chert, siderite, pyrite, magnetite, hematite lower volcanic rocks--andesite, dacite, rhyodacite, rhyolite, iron formation

The Michipicoten group is composed of Keewatin-type volcanic flows and pyroclastic rocks of the andesite-rhyolite association together with clastic and chemical sedimentary rocks.

The lower volcanic rocks (Table 1) comprise a lower intermediate to mafic flow section and an upper felsic pyroclastic section. The dikes and small stocks of granite, quartz porphyry, and diorite in the extrusive volcanic rocks are interpreted as ancient feeders and intrusive equivalents (Goodwin, 1962). The Helen iron-formation, a relatively thick and extensive unit, typically comprises banded chert, pyrite, and carbonate members in descending stratigraphic succession. This type of iron-formation commonly overlies felsic volcanic rocks and underlies intermediate to mafic volcanic rocks. The middle volcanic rocks, comprised of intermediate to mafic flows, are variable in thickness or locally absent. The Dore sedimentary rocks are composed of greywackes, shale, argillite, conglomerate, and quartz sandstone. Regionally, thick conglomerate-greywacke facies are common in the west, whereas thin, shaly facies prevail to the east. The upper volcanic rocks consist of intermediate to mafic flows and minor amounts of felsic pyroclastics. The Michipicoten group is surrounded by younger granitic rocks and cross-cut by diabase dikes.

Structural Geology

Goodwin (1962) notes that the folded and faulted Michipicoten rocks are relatively fresh and undisturbed compared to other Keewatin-type Shield areas. The rocks have been folded about east-west-trending cylindrical axes which have themselves been cross-folded about northwest-trending axes. Undulating, yet segmented, fold patterns have resulted. Prominent northerly striking transverse faults with left-hand horizontal offsets have sliced the area into large parallel blocks. A second fault set strikes N. 50°-80° E. with variable southerly dip. (Collins and Quirke, 1926).

In the field area, the stratigraphic units strike slightly north of east, almost paralleling the regional east-west-trending fold axes. The rocks have been subjected to greenschist facies metamorphism and in some cases, fresh surface exposure shows two directions of foliation, namely, the locally pronounced schistosity which approximately parallels the bedding has been cross-cut at a steep angle by a strong northeast fracture cleavage.

The transverse fault closest to the field area is the northwest trending Mildred Lake Fault (Fig. 2). This fault originates south of Siderite, passes slightly east of the iron range, then swings westward into Mildred Lake. The existence of the Mildred Lake Fault is substantiated, in part, by mafic volcanics dominating the east shore of Lena Lake while arkosic sandstones preside on the west.

Previous Work

The Dore sedimentary rocks represent the main clastic zone in the Michipicoten group. Greywacke, shale and argillite predominate, while conglomerate and quartz sandstone are locally abundant. Fisher (1960) and Goodwin (1962) claim that the sedimentary rocks have the essential characteristics of true volcanic sediments, in that clastic constituents have their counterparts in subjacent volcanic rocks in either extrusive or intrusive form, and appear to have been derived from them by rapid, contemporaneous erosion. Specifically, granite detritus in the Dore was derived from near-surface intrusive equivalents of the extrusive felsic volcanic rocks.

Logan (1863) assigned the name Dore to a thick boulder conglomerate at the mouth of the Dore River (west) while Coleman and Willmott (1902) (not seen; cited by Goodwin, 1962) referred to the thin, shaly facies near Mildred and Lena Lake (east) as the Eleanor slates. This represents an eastward thinning of the sedimentary belts from 925 m at Michipicoten Harbour to 770 m near Mildred Lake (distance of approximately 25 km).

Collins and Quirke (1926) considered that Dore sedimentary rocks lie within and form an integral part of complexly folded Keewatin volcanic rocks, whereas Cooke (1937) inferred a synclinal distribution with unconformable relationships to underlying volcanic rocks. However, Goodwin (1962, p. 581) notes that the Dore sedimentary rocks are conformable to enclosing volcanic rocks since the upper and lower sedimentary contacts are transitional to volcanic rocks over thicknesses of several hundred feet.

Goodwin (1973, Figs. 2 and 3) claims that the triple association of coarse-grained clastics of the Dore, oxide-sulphide iron facies transitions, and arc-type volcanics can be used as an indicator of bathymetry. In the Michipicoten area (115 km long by 50 km broad), the oxide facies of the Kabenung section (west) is enclosed by conglomerates and greywackes while the carbonate facies of the Helen-Magpie section (central, includes study area) is contained within finer grained sediments and mafic-felsic volcanics. According to Goodwin (1973), this oxide-carbonate facies transition marks the slope-edge of the shelf and the conglomerate-bearing sediments of the Dore denote the margin of the basin.

Chapter II

LITHOLOGIC DESCRIPTIONS

The field area is north-northwest of, and stratigraphically above the carbonate facies Helen-Eleanor section of the Michipicoten Iron Formation. The field map (Fig. 2, back pocket) again shows the location of Siderite, this being the termination point of the ACR spur line built to transport ore from the now abandoned Sir James' Pit.

Although the entire spur line from Siderite to Siderite Junction was mapped by the author, detailed study (i.e., stratigraphic column, lithologic and petrographic descriptions) was restricted to the section of the railroad between the points denoted as (A) and (H) in Figure 2. In general terms, the area is dominantly sedimentary with a small number of carbonated gabbroic sills and peridotite plugs invading the sequence. The upper and lower boundaries of the sedimentary sequence are marked by units of pillowed and massive mafic flows, thicknesses reaching 90 m at Siderite and 770 m north of the railroad near Mildred Lake. The pillow orientations in the rocks west of Mildred Lake plus numerous structures in the lower sediments, show direction of stratigraphic top to be north-northwest.

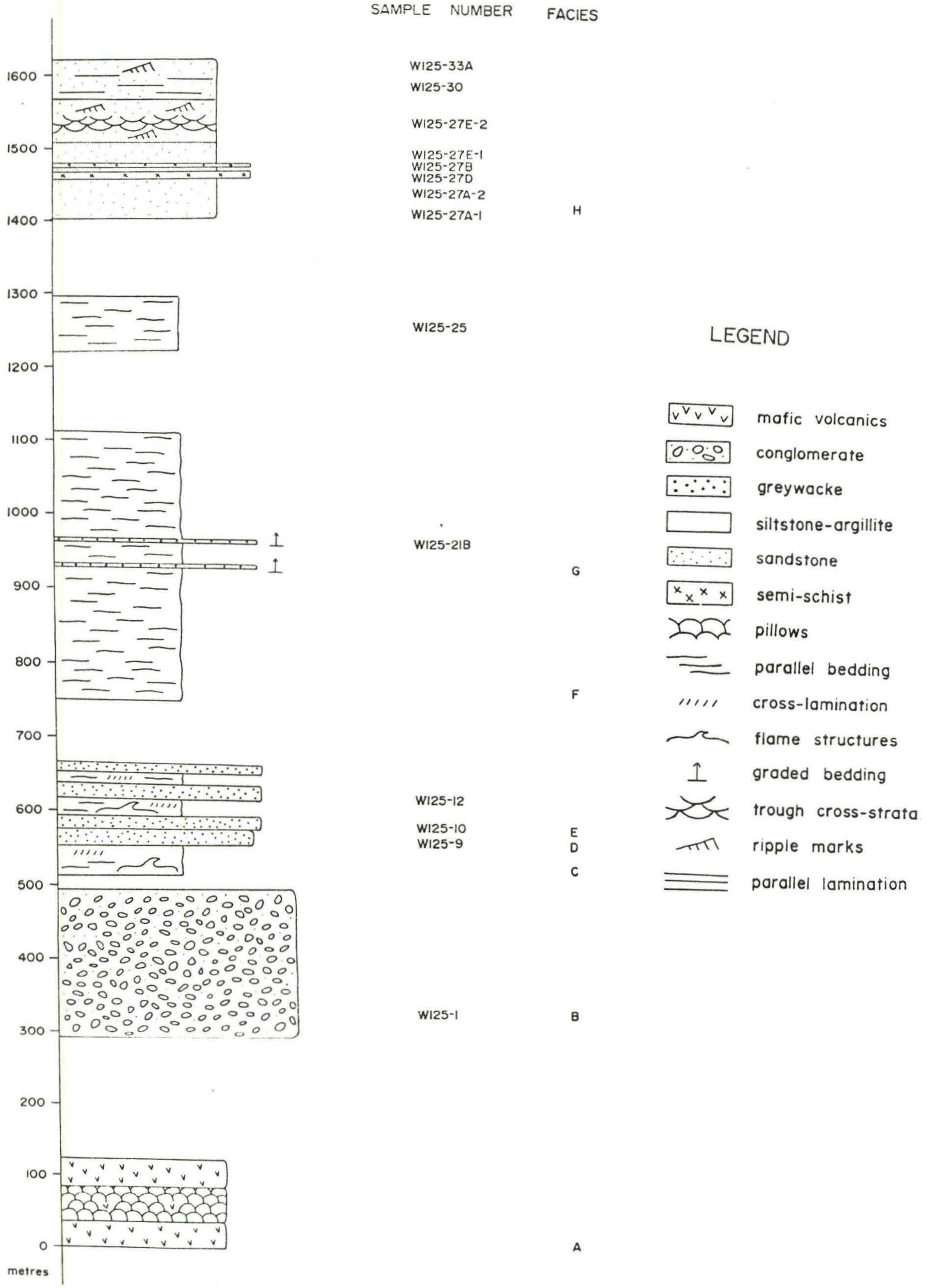
Sedimentary and Volcanic Facies

The following lithologic units are referred to in Figure 3 beginning with the mafic volcanics (A) and working up to the top of the subarkose sandstones (H).

Mafic Volcanics (A)

The basal unit consists of pillowed and massive mafic volcanics

Figure 3 Measured section illustrating Facies A through H. The numbers to the right of the column refer to the sample taken at that locality and the thin section made from it. Each facies is represented by a letter, the position of which denotes the point where the particular facies is first observed.


SAMPLE NUMBER
FACIES
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
metres
W125-33A
W125-30
W125-27E-2
W125-27E-1
W125-27B
W125-27D
W125-27A-2
W125-27A-1
H
W125-25
W125-21B
G
F
W125-12
W125-10
W125-9
E
D
C
W125-1
B
A
LEGEND
mafic volcanics
conglomerate
greywacke
siltstone-argillite
sandstone
semi-schist
pillows
parallel bedding
cross-lamination
flame structures
graded bedding
trough cross-strata
ripple marks
parallel lamination

both of which are highly carbonated, as shown by their reddish-brown colour on the weathered and fresh surfaces. Most of the fine-grained mafic volcanics are pillowed with pillow dimensions ranging from 20-25 cm (width) to 1.40 m (length). Length:width pillow ratios include values of 1.8, 1.6, 1.4 and 1.3. However, all recognizable pillow forms are stretched on a vertical face so stratigraphic top information was limited to the pillows of the upper volcanic stratigraphic unit near Mildred Lake (Fig. 2).

Conglomerate (B)

The conglomerate is polymictic, generally unstratified and poorly sorted, composed of granule to cobble size clasts in a sand-sized matrix. Size of the framework clasts ranges from 0.2 - 9 cm and the average is about 2 cm. Bedding is usually absent, only two pebble-free sandstone beds were observed. They are plane-bedded, compositionally similar to the matrix, and not greater than 10 cm thick. Variation in matrix:clast content causes the conglomerate to be matrix-supported in places and clast-supported in others, the intercalated clast-supported units are only slightly less abundant. Clasts are imbricated in the lower section of the conglomerate but the tectonic overprint makes this interpretation and any subsequent current direction deduction very equivocal.

The greyish-white matrix is felsic in composition. The granules, pebbles and cobbles consist of buff-coloured felsic volcanics (approximately 35% of total clasts), greenstones or mafic flows (30%), sandstones (15%), reddish-brown carbonate material (10%) and translucent chert (10%). Most clasts range from subangular to subrounded, however, their original shape cannot be determined because of flattening and vertical elongation. Mafic clasts have been deformed more than felsic clasts.

Argillite-Siltstone (C)

Beds of argillite (1-2 cm) and siltstone laminations (1-3 mm) are grouped together as facies C. The argillite-siltstone interbeds invariably have sharp bases, and many have sharp tops. Greyish-black argillite beds are more abundant (65% of exposed face) than those of the buff-coloured siltstones. Synsedimentary flame structures were observed in three of the argillite beds and cross-lamination was recorded in about one third of the siltstone laminations.

Talc Greywacke (D)*

The matrix of this unstratified rock is a grey-brown colour and the phaneritic minerals are talc and magnesite, both of which overprint the matrix and are therefore believed to have formed during metamorphism (thin section observation). Coarse to very coarse (0.5 - 1 mm) white talc grains are anhedral in character, recognized as talc by their softness and greasy lustre. Greyish-white magnesite forms very coarse to granule-size (1-2 mm) subhedral rhombs which comprise approximately 10% of the rock.

Quartz-Dolomite Greywacke (E)*

The essential components of this greywacke are quartz, ferroan dolomite and chlorite, all of which are visible in hand specimen. The quartz forms coarse (0.5 - 0.9 mm) anhedral grains in the matrix, while the overprinting nature of very coarse to granule-size (1-3 mm) carbonate and chlorite grains implies a metamorphic origin for these minerals (thin section observation). The rock is poorly sorted and sedimentary structures are non-existent. However, two of the three exposed outcrops are stratigraphically enclosed by argillite-dominated beds of facies C, suggesting a similar environment of deposition for the two facies.

Siltstone-Argillite (F)

This facies is similar to the previously described argillite-siltstone rocks (C) in that the fine-grained siltstones and argillites are still rhythmically interbedded. However, Plate 1 clearly shows that the siltstone beds (2-5 cm) are now thicker and more abundant than those of the argillites (0.2 - 4 cm). Furthermore, there is a marked absence of flame structures and cross-lamination, the sharp based siltstones and argillites having better defined and more regular bedding than those of facies C.

Plagioclase Greywacke (G)

The rock is composed of minerals which are essentially felsic in composition, typified by its greyish-white matrix and the very coarse to granule-size (1-3 mm) quartz and feldspar grains. The greywackes of this unit occur in sharp based, normally graded beds (15-20 cm), interlayered with the siltstones and argillites of facies F. Therefore, these greywackes are considerably different from those of facies D and E, which were both thick and unstratified. It appears that the greywackes are thinning up section.

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* I have classified both facies D and E as "greywackes", but the scarcity of detrital minerals does not comply with the definition of a greywacke. However, Mg and/or Fe form(s) an essential component of the metamorphically-derived talc, magnesite, ferroan dolomite and chlorite. Also, facies D and E are closely associated with facies C (interbedded argillite and siltstone) so I propose that these rocks are in fact sediments whose detrital grains were derived from a ferromagnesian source rock.

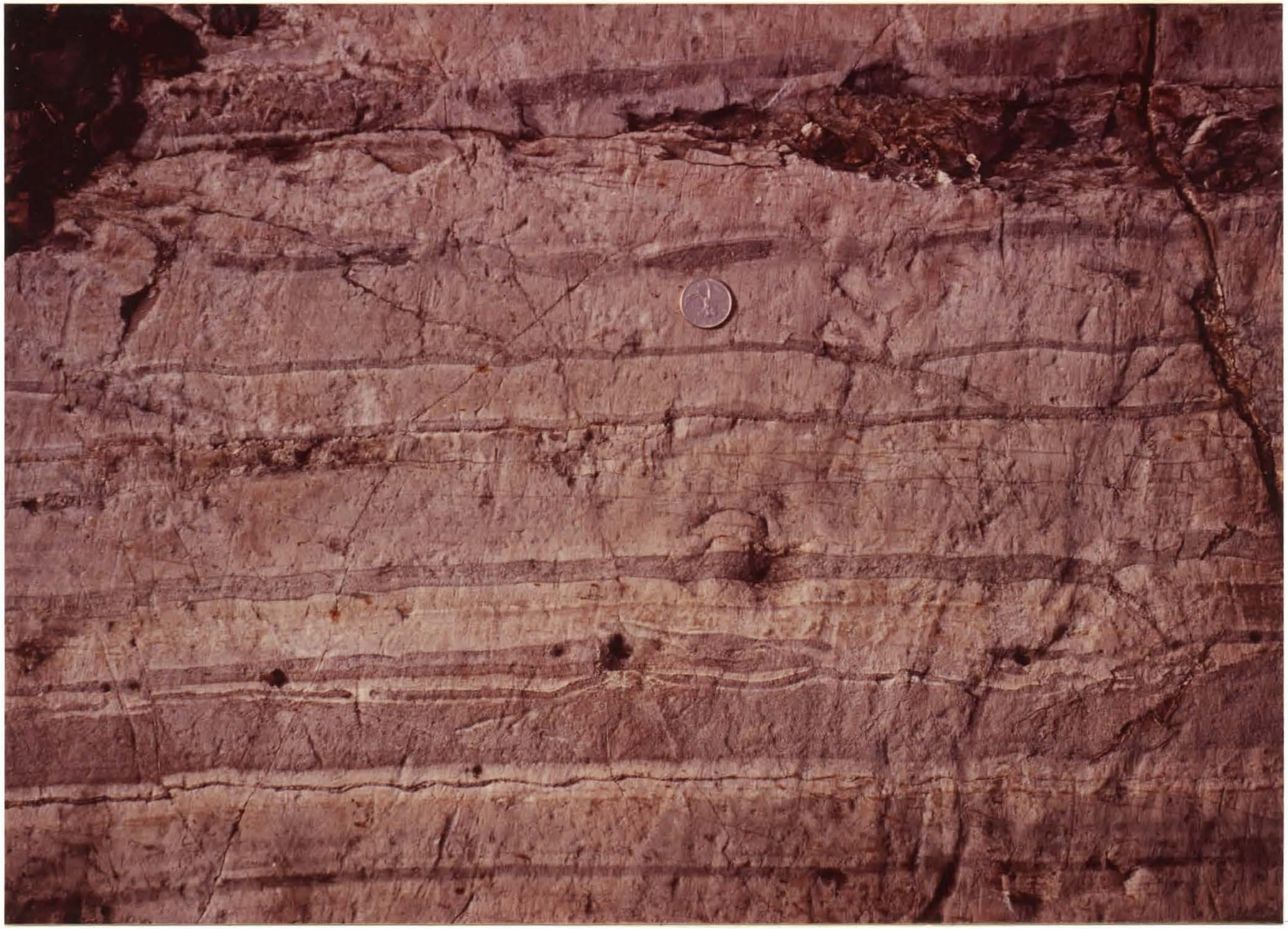


Plate 1 Interbedded siltstones (light colour) and argillites (dark colour) of facies F. Stratigraphic top towards top of photo.

Subarkose Sandstone (H)

Grey or grey-white subarkose (Fig. 3) was originally mapped as arkose, but in thin section, feldspar content is usually between 5 and 25 percent (Pettijohn, 1957). Included in the subarkose facies are deposits ranging from fine to very coarse sand (thin section observation). Sorting of the detrital quartz and feldspar grains is variable and may be in part a reflection of the grain size distribution in the source rock.

The lower section of this facies is seemingly devoid of primary lamination (suggested by acetate peels of W125: 27A-1, 27A-2, 27E-1). Stratigraphically enclosed by the massive subarkose, however, are two subunits of thick-bedded (2 and 3.5 m, respectively) chlorite-dolomite and quartz-fuchsite semi-schist, a term which means the clastic texture has been partly obliterated (Spry, 1969, p. 264). The chlorite-dolomite rock is strongly schistose and consists of coarse to very coarse (0.5 - 1 mm) chlorite flakes set in a carbonate-rich, reddish-brown matrix. The fuchsite grains (0.5 - 3 mm) are recognized as such by the bright green colour, and a similar association of fuchsite-bearing sediments with quartz sandstones has been documented by Wood (1980), in which he attributes their presence to the weathering of ultramafic rocks.

The upper limit of the massive subarkose section is marked by the appearance of primary sedimentary features, the first of which is ripple cross-lamination (Plate 2). Trough cross-beds with 40 cm mean trough thickness (Plate 3) intervene between the first and second cycles of ripple cross-lamination, and in the second cycle, asymmetrical ripples are preserved on the bedding plane surface (Plate 4). The paleo-

Plate 2 Transition from the lower unstratified section of facies H to ripple cross-laminated subarkose sandstone. Stratigraphic top is towards the right.

Plate 3   Truncation of trough cross-stratification in subarkose sandstone, facies H. Stratigraphic top towards top of photo.

Plate 4   Asymmetrical ripples exposed on bedding plane in subarkose sandstone, facies H. Stratigraphic top towards top of photo.

current direction inferred from the ripples is approximately toward 035° and stratigraphic top is towards the north. The rippled unit is capped by alternating light and dark horizontal laminations. Anhedral pyrite and limonite grains mark many of the darker horizontal laminations (thin section observation). Above the laminated rock type, ripple cross-lamination of the type photographed in Plate 2, constitutes a third cycle of ripple formation.

Chapter III

LABORATORY TECHNIQUES AND OBSERVATIONS

Petrography

The numbers of the petrographic sections and their relative positions in the stratigraphic column are outlined in Figure 3. It is important to realize that slides were not made of the argillite and siltstone rocks since their texture is too fine grained (i.e., W125-25) to show any distinctive petrographic characteristics.

Conglomerate

Microscopic examination of the basal conglomerate shows subangular to subrounded granules and pebbles of microporphyritic volcanic rock (45% of slide), mudstone (15%), and carbonate material (10%) set in a recrystallized matrix (30%) of sand-sized quartz, altered plagioclase, ferroan dolomite, sericite, and iron sulphides. Subangular volcanic pebbles (Plate 5) are most common and their chlorite-quartz-sericite mineralogy implies derivation from mafic rocks. A thinly stratified mudstone pebble (Plate 6) contains a single band of irregular pyrite veinlets and laminae of sedimentary-concentrated quartz. Minor components of the conglomerate include mosaic-textured quartz aggregates (0.3 - 0.8 mm), cross-cutting polycrystalline quartz veins (0.2 mm wide), and anhedral grains of authigenic pyrite (0.1 - 0.3 mm) which overprint both matrix and clasts.

Talc Greywacke

The bulk of the rock consists of authigenic talc and magnesite, and modal composition, determined from thin section, is outlined in Table 2.

Table 2. Modal Analyses of Talc Greywacke

Sample #	W125-10	
Grains		
	Talc	25.00
	Magnesite	17.25
	Quartz	5.50
Matrix		
	Talc	38.75
	Quartz	5.00
	Sericite	7.25
	Ferroan dolomite	0.75
	Pyrite	0.25
	Limonite	0.25

Based on count of 400 points

Talc occurs as ghost-like anhedral grains and as fibrous aggregates, the shreds of which have a subparallel arrangement. Subhedral rhombs of magnesite (Plate 7) form in a recrystallized groundmass of talc, quartz, sericite, and ferroan dolomite. Approximately 2% of the magnesite crystals are rimmed by pyrite and limonite. The matrix talc, which commonly forms small patches within the larger talc grains, is overprinted by a rust-coloured stain, possibly caused by alteration of the iron sulphides.

Quartz-Dolomite Greywacke

The abraded quartz and feldspar grains (Table 3) are detrital, but the patchy distribution of ferroan dolomite, chlorite, and white mica implies a post-depositional formation (Plate 8).

Table 3. Modal Analyses of Quartz-Dolomite Greywacke

Sample #		W125-10	W125-12
Grains			
	Quartz	5.50	4.25
	Plagioclase	0.75	
	Ferroan dolomite	21.00	33.50
	Chlorite		20.25
	White mica	12.75	
	Pyrite	0.25	1.25
	Limonite		0.25
Matrix			
	Quartz	28.00	28.75
	Sericite	18.25	11.75
	Chlorite	13.50	

Based on counts of 400 points per section

The quartz grains are angular to subrounded and show undulatory extinction. Most of the quartz is polycrystalline, and a small amount is polygonized; that is, it appears as a mosaic of smaller grains, the boundaries of which tend to be sutured (Plate 9). Such polygonal quartz is believed to be due to static annealling of weakly deformed quartz (Spry, 1969, Plate VII). Intermediate plagioclase (An_{12-17}) grains exhibit albite twinning and are usually altered to sericite along grain boundaries and cleavage planes.

Plagioclase Greywacke

Microscopic examination shows taht the rock has been partially recrystallized, in that it contains both untwinned (authigenic) and twinned (detrital) plagioclase with subordinate quartz (Plate 10), and minor to trace amounts of chlorite, ferroan dolomite and pyrite (Table 4).

Table 4. Modal Analyses of Plagioclase Greywacke

Sample #	W125-21B	
Grains		
	Plagioclase - untwinned	34.75
	- twinned	16.75
	Quartz	2.75
Matrix		
	Quartz	7.50
	Sericite	25.25
	Chlorite	9.50
	Ferroan dolomite	3.00
	Pyrite	0.50

Based on count of 400 points

The framework of the rock consists of quartz and feldspar, predominantly untwinned plagioclase. Since no K-feldspar could be detected by staining the untwinned, subhedral grains are believed to be plagioclase which has crystallized in the sedimentary environment. Intermediate to sodic plagioclase is present in subangular, twinned grains that are pervasively altered to sericite. Quartz occurs in angular to subangular grains, the majority of which exhibit strain polarization.

Subarkose Sandstone

Detrital quartz and feldspar grains, along with felsic rock fragments, are set in a partially recrystallized matrix of quartz, ferroan dolomite, sericite, chlorite and pyrite (Table 5).

Quartz occurs both as clear single unit grains, generally subangular in shape, and as polygonized aggregates. The quartz has been

Table 5. Modal Analyses of Subarkose Sandstones

Sample # W125:	27A - 1 (base of section)	27A - 2	27E - 1	27E - 2	30	33 A (top)
Framework						
Quartz	28.25	28.00	28.00	25.25	30.00	26.75
Plagioclase - untwinned	13.25	16.00	7.00	2.25	5.00	0.50
- twinned	1.25	5.80	3.25		0.88	0.25
Rock fragments		0.80		0.25		
Matrix						
Quartz	21.25	28.40	37.00	37.50	22.00	18.50
Ferroan dolomite	8.50	7.60	8.00	13.37	17.00	28.75
Sericite	13.50	8.40	16.50	16.88	17.34	20.25
Chlorite	12.30	4.00		3.00	5.33	2.00
Pyrite	1.50	0.20	0.25	1.25	2.00	3.00
Limonite	0.20	0.80		0.25	0.45	

Modal composition was determined by counts of 400 or more points per section. No K-feldspar could be detected by staining.

slightly altered by post-crystalline deformation, as shown by the suture-like penetrations along grain boundaries. Also, undulose extinction in the quartz may, in part, be attributed to post-depositional deformation.

Subhedral grains of untwinned plagioclase are more abundant than the subangular, twinned grains of acid plagioclase (An_{5-10}). The nature of the untwinned and twinned grains complies to the fact that metamorphic albite is devoid of twinning, while igneous or detrital plagioclase commonly retains its twin lamellae (Williams et al., 1954, p. 219). A triangular plot of the subarkose samples (Fig. 4) shows that percent plagioclase peaks in the two basal samples then is significantly reduced in the upper four samples.

Rock fragments and matrix make up the balance of the rock. The polycrystalline character of the matrix quartz is attributed to quartz recrystallization, while the overprinting nature of ferroan dolomite, sericite, chlorite and pyrite implies alteration of pre-existing detrital minerals.

The original dimensions of detrital quartz and feldspar grains have been slightly altered by post-depositional pressure solution. Remembering this limitation, general size of these minerals is that of very coarse sand in the two samples of the lower unstratified section (Plate 11), medium to coarse sand in the two middle samples, and fine to medium sand in the two samples from the upper subarkose facies (Plate 12). Therefore, particle size decreases with ascending stratigraphy, yet stratigraphic thickness (100 m minimum) is much greater than that recognized for a fining-upward sequence.

Within the lower section of facies H are the two subunits of

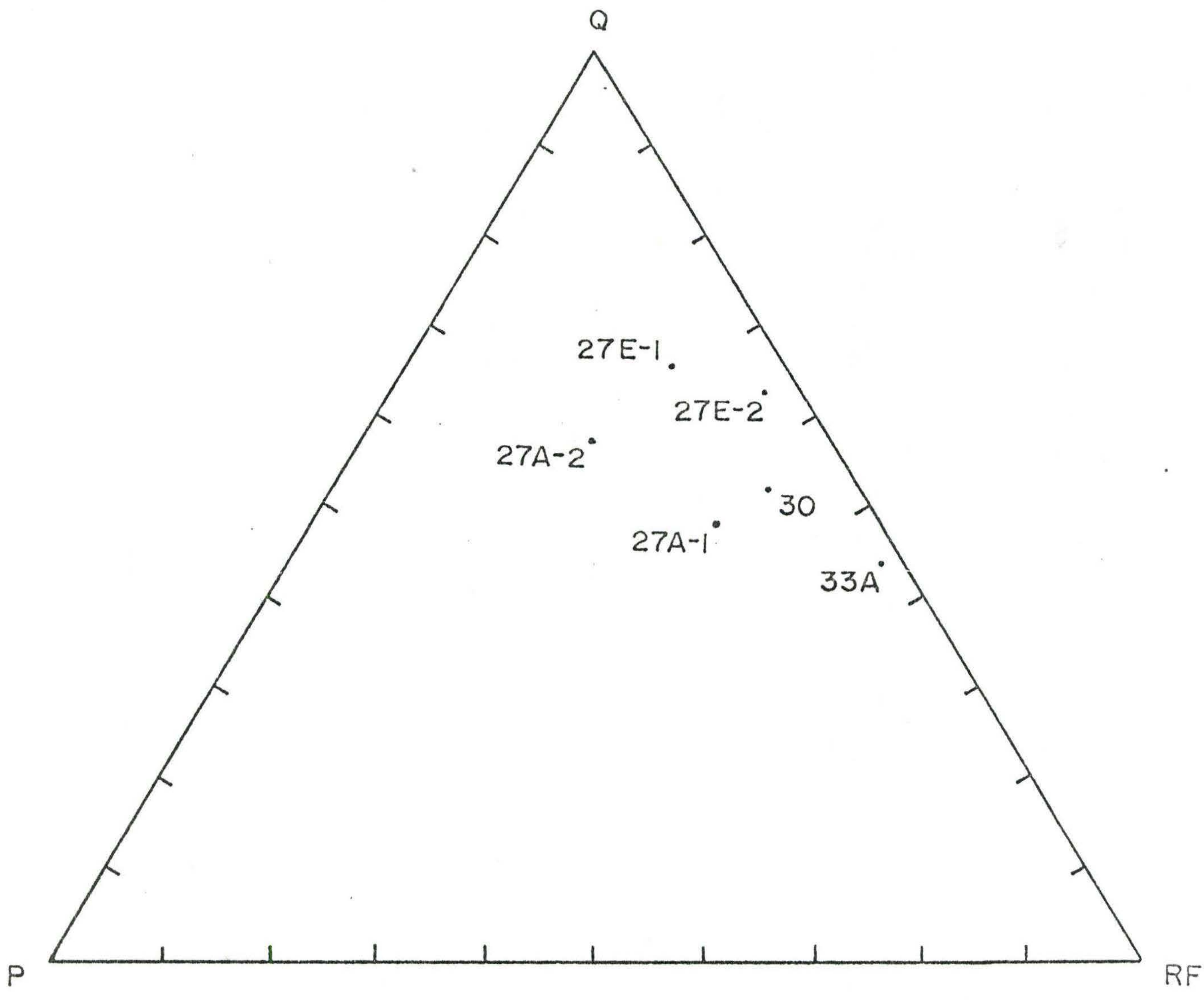


Figure 4 Percentages of Quartz (Q), Plagioclase (detrital and authigenic) (P), and Rock and authigenic mineral fragments (RF).

quartz-fuchsite and chlorite-dolomite semi-schist.

1) Quartz-Fuchsite Semi-schist

Microscopic examination shows random distribution of quartz, both as individual grains and polygonized aggregates. The fuchsite (muscovite character verified by x-ray diffraction) replaces and is contained within lenticular, microporphyritic rock fragments (Plate 13). Like the fuchsite, the ferroan dolomite, magnesite, chlorite and leucoxene grains (Table 6) are considered authigenic.

Table 6. Modal Analyses of Quartz-Fuchsite Semi-schist

Sample #	W125-27B	
Grains		
	Quartz	19.50
	Fuchsite	14.75
	Ferroan dolomite	29.00
Matrix		
	Quartz	14.50
	Ferroan dolomite, Magnesite	14.00
	Chlorite	3.00
	Leucoxene	5.25

Based on count of 400 points

2) Chlorite-Dolomite Semi-schist

Authigenic chlorite and dolomite form either dendritic bands or polycrystalline aggregates, they seldom exist as solitary grains. Much of the quartz is polycrystalline and most is contained within subangular to subrounded rock fragments. The subparallel arranged rock fragments remain as relict clasts enveloped by recrystallized chlorite and dolomite (Plate 14).

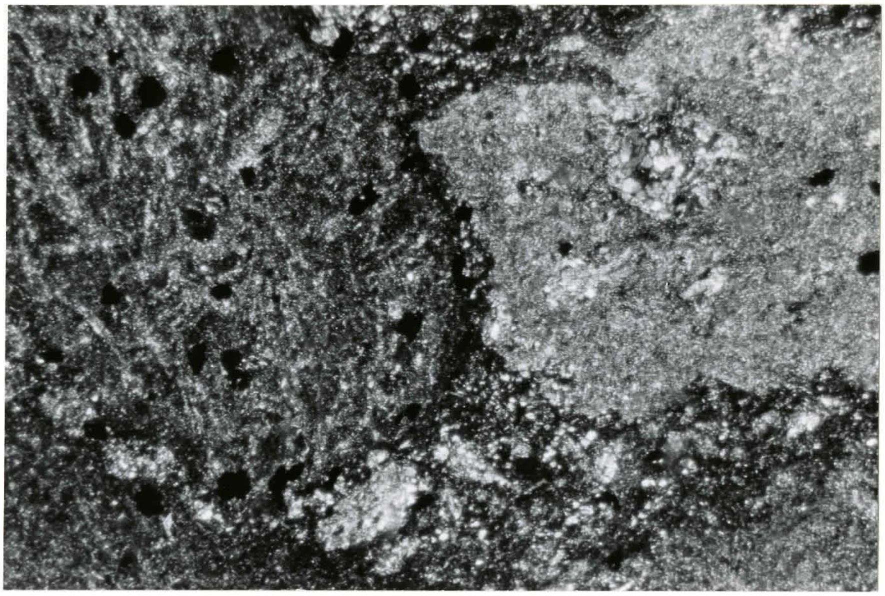
Table 7. Modal Analyses of Chlorite-Dolomite Semi-schist

Sample #	W125-27D	
Mineral		
	Chlorite	40.00
	Ferroan dolomite	33.00
	Quartz	26.00
	Pyrite	0.50
	Limonite	0.50

Based on count of 400 points

Plate 5 Dark pebble of greenstone (left) overprinted by anhedral grains of authigenic pyrite. Light-coloured carbonate granule (right) has quartz-dolomite mineralogy. Facies B. Field of view is 2.90 mm wide.

Plate 6 View of the internal structure of a mudstone pebble. The alternating light and dark laminations are rich in sedimentary-concentrated quartz. Facies B. Field of view is 2.90 mm wide.



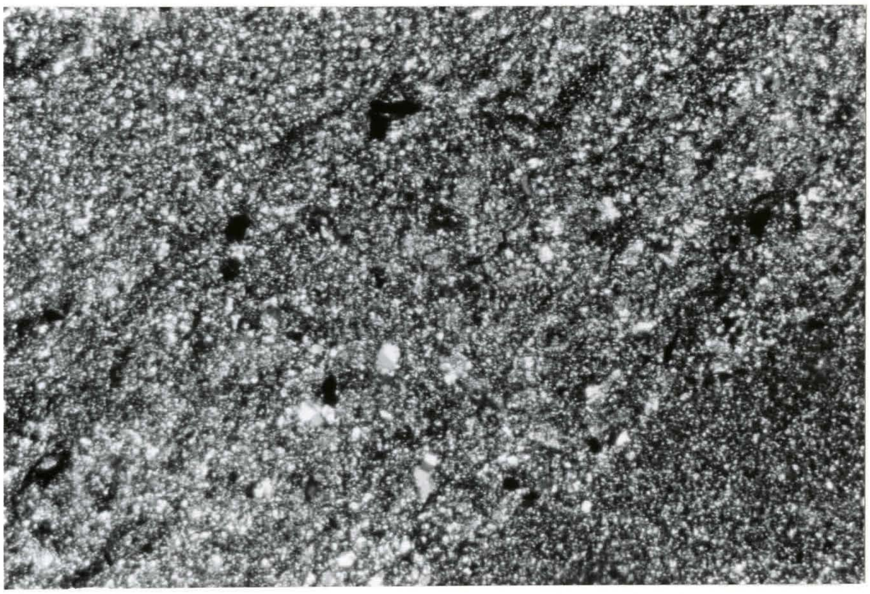


Plate 7 Subhedral grains of magnesite, rimmed by pyrite and limonite, set in matrix of recrystallized talc, quartz, sericite and ferroan dolomite. Facies D. Field of view is 1.14 mm wide.

Plate 8 White mica flake (centre) and rhombs of ferroan dolomite overprint quartz-sericite groundmass. Facies E. Field of view is 1.14 mm wide.

Plate 9 Polygonized quartz (right) - mutual grain boundaries have an irregular, interlocking form. Twinned plagioclase grain is clouded by sericite and overprinted by recrystallized quartz and dolomite. Facies E. Field of view is 1.14 mm wide.

Plate 10 Detrital grains of angular quartz (clear) and albite (twinned), together with authigenic, untwinned plagioclase, are set in a sericitic matrix. Facies G. Field of view is 1.14 mm wide.

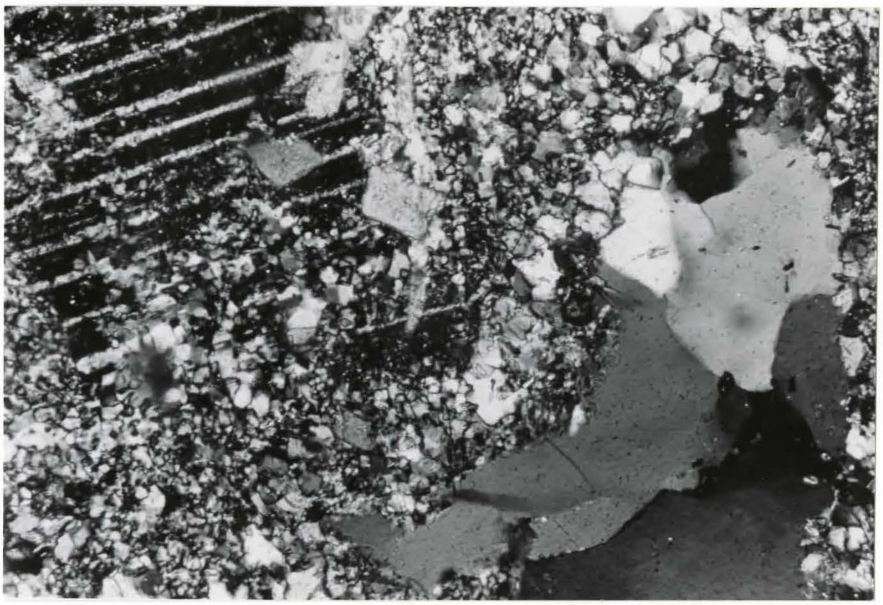


Plate 11 Polygonized quartz (clear) with sutured boundaries, subangular grain of detrital albite (twinned), and authigenic grains of untwinned plagioclase (clouded). Recrystallized quartz, ferroan dolomite and sericite are visible in the matrix. Facies H. Field of view is 1.14 mm wide.

Plate 12 Subangular quartz (clear) and feldspar (twinned) grains set in an unsorted matrix. Facies H. Field of view is 1.14 mm wide.

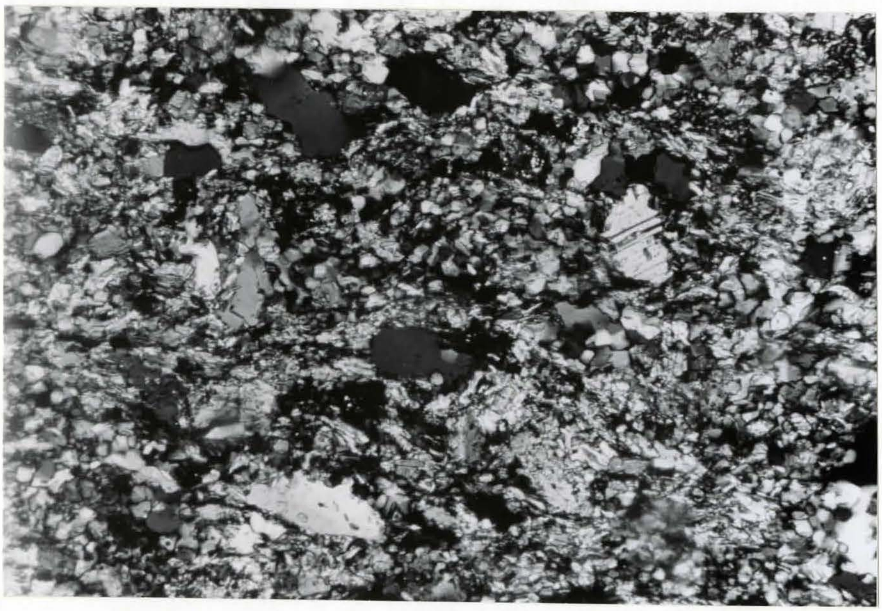
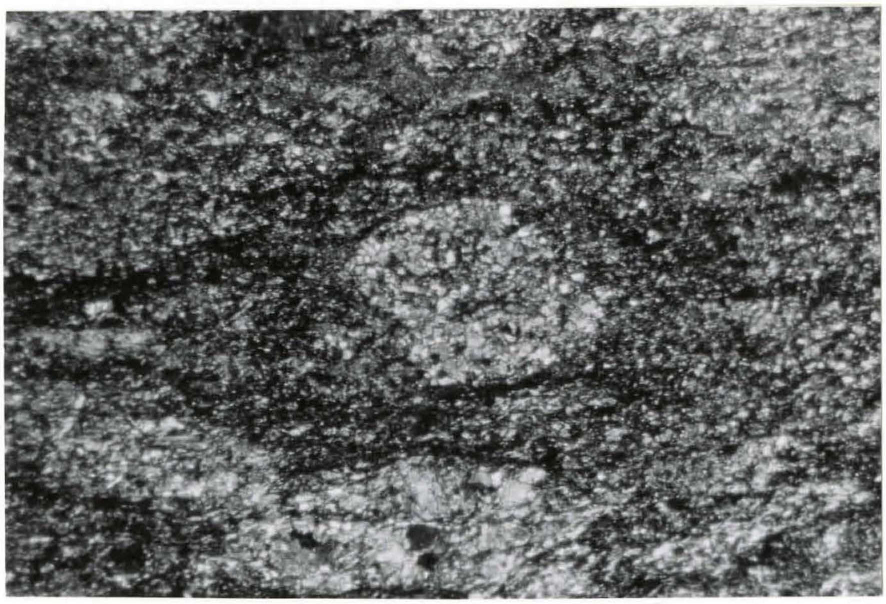


Plate 13 Fuchsite replacement of lenticular rock fragment (centre) in quartz-fuchsite semi-schist. Grey strip along upper edge of clast is chlorite. Field of view is 2.90 mm wide.

Plate 14 Subrounded quartzose rock fragments have a sub-parallel arrangement. They are enveloped by dendritic strands of chlorite and dolomite. Field of view is 2.90 mm wide.



X-ray Diffraction**

The variety of mica visible in W125-27E is too fine grained for positive microscopic identification. The results of two x-ray diffraction runs show the mica to be muscovite, while the bright green colour of the mineral indicates the mica is Cr-rich fuchsite.

The first run (Table 8) was of the whole rock, a sample which contained quartz and could therefore serve as an internal standard for both runs one and two. (Error incurred from measurements off the chart recorder was estimated at $\pm$ 0.05°.) Not only did the whole rock trace indicate the presence of quartz and muscovite, it also contained dolomite-ankerite and magnesite peaks. Although the literature (Files of the Joint Committee on Powder Diffraction Standards, 1974) assumes different, but very close, values for the two theta angle positions of dolomite and ankerite, I have combined them since their peaks were generally amalgamated and indistinct.

For the second run, bright green fuchsite grains were separated from the whole rock in order to attain a more complete sequence of two theta angle positions (Table 9). Major peaks were recorded for muscovite and chlorite. The type of chlorite, however, is not uniquely defined since the experimental peak positions resemble corresponding literature values of both corundophyllite (Cr-bearing) and prochlorite. Thin section observation shows chlorite-fuchsite replacement of rock fragments, possibly have a Cr-bearing chlorite associated with the fuchsite.

** Refer to S. L. Tihor, 1978, p. 89 for procedure.

Table 8. Run #1 Whole Rock Sample

copper K alpha radiation

Internal standard	Position (two theta) of peak in degrees (experimental)	Position (two theta) of peak in degrees (literature)	Literature minus experimental value	
Quartz	20.73	20.86	0.13	average calibration correction = 0.07
	26.53	26.64	0.11	
	50.13	50.14	0.01	
	59.91	59.96	0.05	

Mineral	Position (two theta) of peak in degrees (experimental)	Corrected position of peak in degrees	Position (two theta) of peak in degrees (literature)
Muscovite	26.53	26.60	26.70
Dolomite/Ankerite	30.85	30.92	30.98/30.95
	41.10	41.17	41.12/40.95
	50.40	50.47	50.45/50.25
	51.00	51.07	51.05/50.80
Magnesite	32.40	32.47	32.70

Table 9. Run #2 Fuchsite Sample

copper K alpha radiation

Mineral	Position (two theta) of peak in degrees (experimental)	Corrected position of peak in degrees	Position (two theta) of peak in degrees (literature)
Muscovite	8.78	8.85	8.84
	17.72	17.79	17.72
	26.55	26.62	26.70
	29.84	29.91	29.86
Chlorite			
Corundophyllite/Prochlorite			
	12.38	12.45	12.43/12.50
	18.70	18.77	18.69/18.80
	25.05	25.12	25.01/25.15
	45.40	45.47	45.03/45.27
Quartz	20.80	20.87	20.86
	26.55	26.62	26.64
Magnesite	32.50	32.57	32.70
	53.65	53.72	53.05

Acetate Peels***

With the exception of W125-33, acetate peels were made of all the subarkose sandstone samples listed in Table 5. Photographs of the peels, enlarged on a scale of 1:5.5, were then used to verify the presence or absence of internal stratification.

Examination of the lower three samples (W125: 27A-1, 27A-2, 27E-1) showed them to be convincingly devoid of any primary laminations. The ripple cross-laminated sample (W125-27E-2), however, is not only stratified, but pyrite is much more abundant than the thin section (cut parallel to bedding) indicates. The subangular pyrite cubes are interpreted as allogenic, having accumulated in the ripple-crests. The alternating light and dark bands of sample W125-30 represent primary laminations--they are not attributed to mineral alignment during metamorphism.

*** Refer to D. F. Hunter, 1980, p. 70-71 for procedure.

Chapter IV

INTERPRETATION AND DISCUSSION

Environment of Deposition and Provenance

Conglomerate (B)

The poor sorting of the matrix-supported conglomerate (Fig. 3), lack of grading, stratification, and the general absence of individual beds and associated cross-bedding, are all suggestive of an alluvial fan debris-flow mode of origin (Bull, 1972; Miall, 1978; Walker, 1975a).

Deposition by alluvial processes is partly negated by the absence of planar and trough cross-stratified sands, both of which are documented as minor facies of alluvial gravels (Rust, 1979, p. 9). Alternatively, Kurtz and Anderson (1979) have described subaqueous debris flow deposits which, like facies B, are poorly sorted and massive, but unlike facies B, are everywhere interbedded with pebbly or non-pebbly laminated muds. A deep-water turbidity current origin for facies B is unlikely because of the lack of sandy turbidites, paucity of siltstone and argillite, and an absence of primary structure sequences characterizing resedimented conglomerates (Walker, 1975b). In Archean deep-water conglomerates, graded bedding is often present (Walker and Pettijohn, 1971; Teal and Walker, 1977), however, grading of any sort was not observed in facies B. A beach or littoral environment is improbable since it is unlikely that shoreline deposition would result in a conglomerate sequence hundreds of metres thick.

The arenaceous matrix of the conglomerate argues against a true debris flow origin. Similar sand-supported conglomerates have been ascribed by Miall (1970) to "debris flood" processes which are essentially sand debris flow phenomena. The less specific term "mass flow" is preferred for this matrix-supported conglomerate since it contains no direct evidence for a viscous, matrix-strength support mechanism during transport (Middleton and Hampton, 1973). Intercalation of matrix and clast-supported units is thought to be related to separate mass flows, which were probably generated during successive floods. The absence of individual conglomeratic beds, however, disallows correlation between bed thickness and maximum clast-size (Bluck, 1967, p. 146). The minor interbedded sandstones were probably formed during waning stages of individual floods (McGowen and Groat, 1971).

The subangular to subrounded nature of the clasts could negate deposition by mass flow processes. However, Davies et al. (1978) state that rapid rates of mechanical abrasion are recorded in areas of high slope (i.e., volcanic regions). Also, the rate of rock fragment breakdown is different for different lithologies, feldspathic rock fragments being apparently the most susceptible to physical breakdown. In this case, clast lithologies closely resemble the underlying volcanics and iron formation, suggesting that deposition is proximal to the source area. Ascending order of the lower stratigraphy is felsic volcanics, siderite, graphitic chert and mafic flows, fragments of which are all present in the conglomerate (p. 11). Finally, the absence of deep-seated plutonic and granitic clasts reinstates the probability of a volcanic source terrain.

<u>Argillite - Siltstone - Greywacke</u> (C) - (G)

The interbedded argillites and siltstones, together with the generally unstratified greywacke units, are interpreted as a turbidite sequence. The massive, thick-bedded, greywackes (facies D and E) are stratigraphically enclosed by thin argillite-siltstone beds of facies C, suggesting a similar environment of deposition for the three facies.

Using the criteria outlined by Walker (1967) for distinguishing proximal (thick-bedded) from distal (thin-bedded) turbidites, facies C would be classified as a distal deposit. The argillite-siltstone beds are thin, regular and sharp based, and the rocks themselves are fine-grained and have a low sand:mud ratio. Cross-laminated siltstone, overlain by parallel laminated argillite, and capped by argillite beds containing flame structures, are interpreted as CDE Bouma divisions, indicating deposition far from their source (Walker, 1979).

However, because of the close association with thick-bedded greywackes, facies C is interpreted as deposition on levees and interchannel areas of upper submarine fans. This interpretation follows that of Walker and Mutti (1973, p. 132) and Nelson and Kulm (1973, p. 54). Deposition is caused when a turbidity current "fills up" a channel and spills out over the top. Turbidity current flow over the levee is then oblique to the channel axis, and the turbidity currents are rather weak, resulting in thin, Bouma CDE, CE, and DE sequences. Such sequences have been observed in the levee sands of the upper Astoria Fan valley (Carlson and Nelson, 1969). Relatively steep slopes on the levees and interchannel areas allow for synsedimentary deformation. Channel switching, possibly coupled with overbank deposition of thicker sands and gravels produces interbedding of thicker, coarser sandstones and conglomerates with the finer-grained sandstones, siltstones, and argillites.

In this case, facies D and E represent the thicker, coarser sandstones, while facies C is the finer-grained argillite and siltstone. According to the turbidity current model proposed by Nelson and Kulm

(1973, Fig. 18), in the uppermost fan valley, coarse-grained debris is confined to the channels while the finer-grained debris overflows the banks and spreads in a sheet-like fashion over the areas between channels.

Facies D and E are interpreted as "disorganized pebbly sandstones" of "proximal exotic" deposits (Walker and Mutti, 1973, Fig. 10). The talc and quartz-dolomite greywackes of facies D and E respectively, are comparable to the disorganized pebbly sandstones in that they are composed of very coarse sand and granule-size material, lack graded bedding, and have irregular beds which can be as thick as 10 metres. In general, proximal exotic deposits are "most prominent in the lower canyon and upper fan channels" though they may occur anywhere along fan margins that border basin slopes (Nelson and Kulm, 1973, p. 58).

The greywackes of facies G are graded, regularly bedded, and much thinner than those of facies D and E, and the siltstone-argillite rocks of facies F are devoid of synsedimentary deformation features. It is conceivable, therefore, that facies G and the siltstone-dominated beds of facies F were not deposited on the upper fan. Based on the depositional trends of the Astoria Fan (Nelson and Kulm, 1973, Fig. 20), the two facies reflect a change to overbank deposition of coarser material and in-channel deposition of finer-grained detritus. Specifically, the very coarse sand and granule-size grains of the greywackes (facies G) are deposited on the levees, while the fine-sized siltstone particles (facies F) infill the channels. Deposition of this type has been observed on the middle fan areas of Astoria.

The metamorphic talc and magnesite grains of facies D imply alteration of ferromagnesian minerals, which in turn, are commonly derived from the weathering of ultramafic rocks (i.e., peridotites). Specifically, serpentinized olivine and pyroxene grains are believed to have been mechanically deposited, and subsequent alteration has formed the mineral assemblage of the talc greywacke (Table 2). Conversion of serpentinites to rocks consisting of talc + magnesite $\pm$ dolomite necessitates access of H_2O and CO_2 to the ultramafic minerals (Winkler, 1979). In the MgO-SiO_2-H_2O-CO_2 system serpentine is stable only at very small values of X_{CO_2} (mole fraction CO_2), so at 2 kb pressure, increasing temperature and X_{CO_2} will cause serpentine to alter to: magnesite + quartz,

$$1 \text{ serpentine} + 3CO_2 = 2 \text{ quartz} + 3 \text{ magnesite} + 3H_2O \qquad (1)$$

talc,

$$1 \text{ serpentine} + 2 \text{ quartz} = 1 \text{ talc} + H_2O \qquad (2)$$

magnesite + talc,

$$2 \text{ serpentine} + 3CO_2 = 1 \text{ talc} + 3 \text{ magnesite} = 3H_2O \qquad (3)$$

However, quartz is to be expected only at a temperature lower than that of reaction (2) (approximately 320°C), and since 10.5 percent quartz (Table 2) is present in the talc greywacke, mole fraction CO_2 must have been relatively low (Winkler, 1979, Fig. 11-2).

The quartz-dolomite greywacke (Table 3) is rich in dolomite, however, it does not contain any magnesite or talc. Therefore, detrital minerals were not ultramafic in character, but if X_{CO_2} is high enough, ferroan dolomite can form from the alteration of mafic minerals--possibly derived from the lower volcanics (Fig. 3). Both actinolite and zoisite-epidote tend to break down to form calcite + chlorite + white mica. Then if CO_2 pressure is high enough, ferroan dolomite may also form. The resulting assemblage is:

calcite-ferroan dolomite-chlorite-quartz-white mica

(D. Mohr, personal communication, 1980)

Significant amounts of the above minerals, excluding calcite (probably altered to dolomite), are present in the quartz-dolomite greywacke.

The plagioclase greywacke (Table 4) is mineralogically and texturally immature. This is evident from the abundance of plagioclase relative to more stable quartz grains. Also, quartz and albite porphyroclasts are generally angular to subangular and poorly sorted, features which suggest limited mechanical transport. A probable source rock, therefore, is the porphyry which borders on Arliss Lake (Fig. 2), since it is proximal to the site of deposition and is rich in both quartz and feldspar phenocrysts (field observation). It is important to note the sodic (albite) nature of the feldspar grains because Winkler (1979, p. 45) points out that in Na_2O-bearing rocks, albite may occur only if both anorthite and plagioclase are unstable, otherwise, albite is dissolved as a component in plagioclase. Anorthite and plagioclase are unstable only at the lowest grades of metamorphism. Generalized breakdown reaction is:

$$\text{anorthite} + CO_2 + H_2O = \text{albite} + \text{Ca-bearing mineral} \qquad (4)$$

The Ca-bearing mineral may be epidote or in this case, calcite (later altered to dolomite), depending on the CO_2 pressure of the rock. However, neither epidote nor calcite are equivalent to anorthite plus water, so Ca^{2+} usually leaves the plagioclase crystal and is replaced by K^+ and OH^-. This leads to the formation of sericite within the altered clast. The Al:Si ratio of the clast remains unchanged, so that these ions do not need to travel (D. Mohr, personal communication, 1980).

Subarkose Sandstone (H)

Facies H (Fig. 3) is interpreted as a sandy braided stream deposit, a deposit which forms in a proximal environment only if a gravel supply is not available (Rust, 1978). Based on the size of detrital quartz and albite grains, facies H is fining-upward, a trend common to many braided river deposits (Miall, 1977). Documented examples of sand-dominated braided systems include the Bijou Creek, Colorado (Miall, 1977) and the Malbaie Formation, Quebec (Rust, 1977), both of which reflect the large ranges in flow conditions of ephemeral streams.

The absence of sedimentary structures in the basal sandstone unit suggests the lack of a tractional phase during deposition (Blatt et al., 1980, p. 136). A plausible mode of origin, therefore, is a sand debris flow, a mechanism which would be enhanced by the absence of vegetation. High values of plagioclase feldspar in the lower two samples (Table 5) imply that the debris is first cycle material, while the angular to subangular character of quartz and albite grains is indicative of limited transport.

Interstratified rippled and trough cross-bedded sandstone is interpreted as an upward transition to lower flow regime conditions. Grouped sets of trough cross-strata, with 40 cm mean trough thickness, are believed to have formed by migration of sinuous crested dunes (megaripples) in the deeper (at least 3 m) channels of braided streams (Walker and Cant, 1979). No evidence for linguoid or transverse bar deposition in the form of planar, tabular cross-stratification exists (Collinson, 1970; Smith, 1971, Figs. 3, 8). The increased quartz and decreased plagioclase content of the upper four samples (Table 5) reflects a change to more mature, reworked sediments.

In the horizontally laminated (verified by acetate peel of W125-30) subarkose, the framework grains of detrital quartz and plagioclase (twinned) range in size from fine to medium sand. This rock type probably records deposition from currents that were flowing only fast enough to carry fine and medium sand, but nevertheless stayed in the upper flow regime (Simons and Richardson, 1963), until velocity slowed enough to again form ripples. Dunes and bars were probably not developed because the flow was too shallow to form them. The continuous, horizontally laminated beds probably represent broad, sheet flow, less than a metre deep, that deposited the fine to medium sand as traction load deposits.

Facies H could be a coastal or shallow marine deposit, but acetate peel studies of the lower three samples (Fig. 3) show a definite absence of parallel lamination, a feature which is common in most beach settings (Hayes, 1976). The absence of argillite and siltstone detracts from a littoral or shallow marine setting, because mud is usually present in these environments forming units several metres thick interbedded with sandstones (Harms et al., 1975).

To a moderate extent, the subarkose sandstone is texturally and mineralogically immature. Subangular quartz and albite grains are only slightly altered, partly attributed to pressure solution during low-grade metamorphism, and are believed to be locally derived. The significant amount of plagioclase in the two basal samples (Table 5) suggests high level erosion with subsequent deposition of first cycle material. Plagioclase content does, however, decrease with ascending stratigraphy, a trend which may be related to increased mechanical breakdown or a change of source material.

The subarkose sandstone, composed essentially of feldspar and quartz, is thought to have been derived from coarse feldspathic rocks such as those usually comprising the crystalline basement. However, Williams et al. (1954) point out that these rocks must be exposed in the source area from which detritus is derived, otherwise, quartz-feldspar sandstones will not form. The proposed source rock, therefore, is the quartz-feldspar porphyry which surrounds Arliss Lake (Fig. 2). The porphyry correlates along strike with the subarkose, and the relative positions of the two rock types supports both high level erosion and limited grain transport.

Chapter V

CONCLUSIONS

(1) The Dore sedimentary rocks, stratigraphically above the Helen-Eleanor section of the Michipicoten Iron Formation, have a mixed provenance.

Clast lithologies of the basal conglomerate reflect volcanic derivation, and because the clasts closely resemble the underlying volcanics and iron-formation, it is probable that penecontemporaneous erosion and deposition has resulted in a conformable mafic volcanic - conglomerate relationship. In contrast, only a quartz-bearing plutonic rock would yield the high volume of quartz (averages 55 percent) present in the stratigraphically higher subarkose sandstones. The sandstones are separated from their source by an unconformity, since although quartz-feldspar porphyry has intruded the mafic volcanics, an interval of unroofing must occur before the porphyry can act as a source rock. Finally, the presence of a talc-magnesite greywacke and a fuchsite-bearing semi-schist implies erosion and weathering of ultramafic rocks.

(2) Non-marine environments are represented in the Dore by alluvial fan and braided river deposition. Alluvial fan mass-flow processes are responsible for the massive and poorly sorted character of the basal granule-cobble conglomerate. The braided river subarkose sandstone facies, however, is separated from the alluvial fan environment by an interval of marine deposition below storm wave base. This relationship

may reflect a period of rapid subsidence and uplift between the formation of the two subaerial deposits.

(3) Marine deposition below storm wave base includes thin-bedded argillite and siltstone turbidites, which are interpreted as levee and interchannel deposits on submarine fans. The associated thick beds of greywacke are regarded as in-channel deposition of coarser material.

Although the turbidites are not interbedded with any facies of iron-formation, they are stratigraphically above the carbonate facies of the Helen-Eleanor iron range. According to Goodwin's large scale model (1973, Fig. 2) of the "Michipicoten basin", Dore sediments, where associated with carbonate facies iron-formation, are deposited at an approximate depth of 600 m -- only slightly more than the total thickness of the described turbidite sequence (see Fig. 3). Preservation of such a thick turbidite deposit requires depths consistently below storm wave base, a requirement which cannot be met if water depth just equals stratigraphic thickness.

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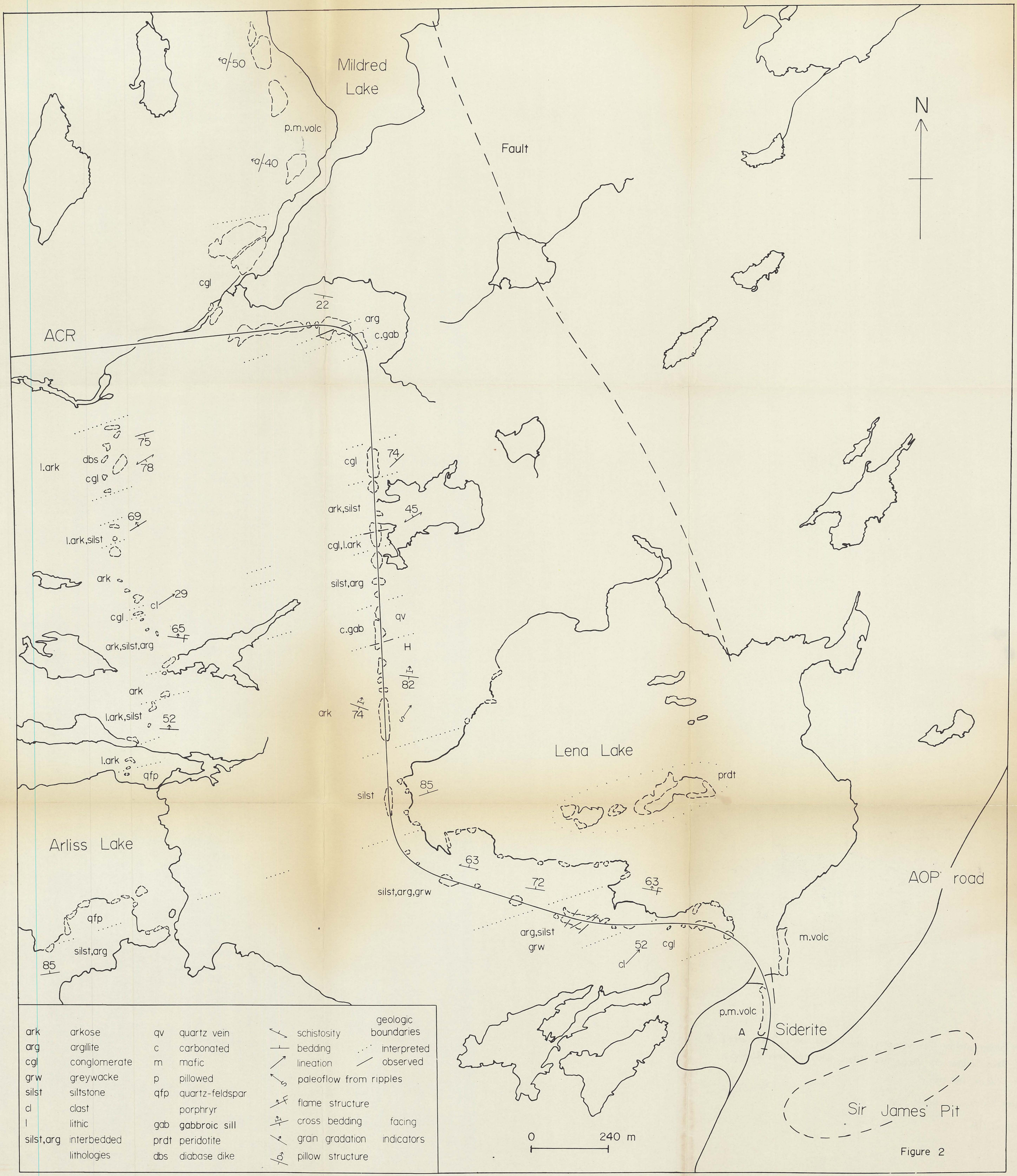
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m mafic
p pillowed
qfp quartz-feldspar porphyry
gab gabbroic sill
prdt peridotite
dbs diabase dike
schistosity
bedding
lineation
paleoflow from ripples
flame structure
cross bedding
grain gradation
pillow structure
facing indicators
geologic boundaries
interpreted
observed
Figure 2