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STRATIGRAPHY AND FACIES AT THE SOUTH MARGIN OF THE ARCHEAN NORANDA CALDERA

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RESUME

La région de Rouyn-Noranda se trouve a la limite de la zone archéenne d'Abitibi, dans la province Supérieure du Bouclier Canadien. Les formations comprennent une partie du groupe supérieur de Blake River laquelle est caractérisée, à Rouyn-Noranda, par des volcans calc-alcalins recouvrant une plaine de basalte tholéitique. Les plutons granitoïdes Flavrian et Lac Dufault occupent maintenant l'axe d'un synclinorium le long duquel une éruption de rhyolite à eu lieu progressivement vers l'est, a partir de centres d'éruption au-dessus d'une chambre commune de magma.

La région étudiée couvre une superficie d'approximativement 5km^2, autour des dykes de Quémont, situes à la marge sud-est de la caldeira archéenne de Noranda. Les dykes de Quémont ont nourri la coulée Quémont, qui se trouve restreinte au bloc de soulèvement. Les andesites de la formation de Powell remplissent la zone d'effondrement au nord-ouest des dykes de Quémont. L'ensemble volcanique est recouvert de la formation de rhyolite Héré.

Deux coulées pyroclastiques, interlitées avec les coulées de l'andesite Powell, démontrent une evolution de textures sédimentaires proximale à distale. La coulée inférieure présente une séquence de granoclassement inverse à normale et enfin stratifié sur une longeur de 1.1km; son origine provient de la retombée rapide des débris d'une éruption phréatique sub-acqueuse sur la crête de la caldeira. Autour de la cheminée on retrouve des débris pyroclastiques grossiers (la Brèche de Quémont) ayant été abandonnés lors du passage de la coulée pyroclastique. La coulée pyroclastique supérieure est enracinée dans une brèche in-situ a l'intérieur d'un des dykes de Quémont et à été initiée par une éruption phréatique. La séquence latérale primaire présente des caractéristiques de coulée de débris typiques d'un courant de haute densité, évoluant dans un courant de faible densité avec dépôt de turbidites.

Dans la formation Powell, le membre rhyolitique à été mis en place peu après le commencement de l'activité pyroclastique ce qui a donné naissance au membre tufacé

de la formation. Ce tuf comprend des cendres, des cendres grossières, des tufs à lapillis, des tufs rémobilisés et des turbidites grossières. Excepté quand le tuf est directement recouvert par la rhyolite Héré, les fragments sont typiques de la formation Powell, c'est-à-dire, des fragments rhyolitiques à porphyres de quartz. Les fragments sont angulaires, sans vésicularité, ce qui suggère un processus phréatique avec peu de composante magmatique.

La déformation syn-sédimentaire et l'interlitage des coussins indiquent que les tufs se sont déposés en milieu sub-acqueux. Les évidences de remobilisation (rides, dunes, lits-entrecroisés, chenaux) indiquent un courant unidirectionnel ("vague de fond"?) provenant du sud-est, c'est-à-dire, la crête de la caldeira.

Le sommet de la formation Powell est caractérisé par un assemblage de lits granoclassés, composés de fragments de rhyolite Powell et de rhyolite Héré. Le début de l'activité Héré met fin à la caldeira: Les coulées rhyolite Héré couvrent la formation Powell, située dans l'ancien bassin, ainsi que les formations sur la crête de la caldeira.

ABSTRACT

The Rouyn-Noranda area is located at the south central margin of the Archean Abitibi Belt, in the Superior Province of the Canadian Shield. The formations comprise part of the upper Blake River Group, characterised in Rouyn-Noranda by calc-alkaline shield volcanoes overlying a tholeiitic basalt plain. The Flavrian and Lake Dufault granitoid plutons now occupy the axis of a synclinorium along which eruption of rhyolites occurred progressively eastwards from centres of extrusion above a common magma chamber.

The study area encompasses approximately $5km^2$ straddling the northernmost Quemont Dyke, one of three dykes feeding a major rhyolite flow. The dyke separates the basin of a proposed caldera from its rim. Stratigraphy SE of the Quemont Dyke comprises rhyolite flows and breccias localised on the rim of the basinal depression. The Powell Formation is found NW of the Quemont Dyke and comprises andesitic flows and minor rhyolite volcaniclastics filling the basin.

On the rim of the caldera, the Quemont Breccia Pile comprises two distinct facies (I and II) overlying Brownlee and Joliet Rhyolites. The Breccia is cut by the Quemont Feeder Dykes and is overlain by the Quemont Rhyolite flow. Quemont Breccia I was erupted subaqueously by a series of phreatic explosions at the site of the present middle Quemont Feeder Dyke. Overlying Quemont Breccia II is a chaotic, unsorted tuff-breccia at least in part formed as a flow-foot breccia of the Quemont Rhyolite Flow.

Northwest of the Quemont Dykes the basinal depression is filled-in by Powell Formation, built upon a substrate of Brownlee Rhyolite, and capped by Héré Rhyolite flows. The Powell is predominantly composed of andesitic flows. Near the southeastern limit of the formation, abutting the Caldera rim at the Quemont Dykes, varying thicknesses of massive and brecciated Powell Rhyolite, Tuff and pyroclastics are interbedded with pillowed andesite flows.

Vertical and lateral sedimentary texture sequences and clast lithology indicate the Lower Marker Horizon (a convenient reference unit within the andesitic caldera-fill) is the distal facies equivalent of Quemont Breccia I. Similarly, the Upper Marker Horizon is the distal, basinward equivalent of the Joliet Breccia. The latter is the product of a steam explosion rooted in the northernmost

Quemont Feeder Dyke, forming the caldera wall.

The short, stubby Powell Rhyolite Flow was immediately preceeded and followed by phreatic eruptions forming the Powell Tuff sequence. The presence of interbedded pillowed flows, coarseness of clasts, ubiquitous parallel statification and small scale scouring indicates the tuffs were deposited subaqueously from settling-out of lapilli to fine ash-sized ejecta. Reworking by unidirectional (rip-?) currents from the caldera rim formed scours, small ripples and micro-dune bedforms.

The gradual disappearance of Powell Rhyolite clasts in the top few metres of Powell Tuff and the concomitant increase in frequency of Héré Rhyolite clasts indicates the commencement of Héré Rhyolite activity, which marks the end of the caldera basin. The first Héré flows were ponded in the last vestiges of the basin. The Héré is not faulted above the Quemont Dykes.

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Für Erich

I

INTRODUCTION

The Rouyn-Noranda area of Northwestern Québec is ideally suited for detailed study of Archean volcanic terrains. Outcrop is extensive due to early stripping and burning by prospectors; in addition, regrowth of moss and lichen is inhibited by sulfur dioxide effluent from the nearby Noranda Mines smelter.

The area is underlain by relatively undeformed intermediate and acid volcanic and shallow subvolcanic intrusive rocks. Regional metamorphism has left an overprint through which coarse microscopic textures may still be recognised.

The Rouyn-Noranda region has been the focus of geologic attention since the discoveries of gold and massive sulfides in the 1920's. In recent years, the importance of determining the paleogeography of volcanic piles has been recognised as a valuable exploration tool in the search for eruptive centres and possible spatially and temporally associated mineralising paleofumaroles.

This study is a description of the stratigraphy and sedimentology of the volcanic and related intrusive rocks in an area north of the town of Noranda, Québec. This area, comprising a rectangular block of roughly 5 km² straddling Highway 101 between Noranda and Noranda-North (see end-piece map), has not been previously studied in detail.

Four months of field work were done in the summer of 1977 and three weeks in the spring and autumn of 1978. Detailed outcrop mapping at scales of 1:480 and 1:1200 was carried out; stratigraphic sections were measured where-ever possible.

Laboratory work consisted of thin section examination of selected rock types; the most useful technique however, was found to be examination of cut and polished slabs of samples showing undeformed primary mesoscopic textures.

The author is deeply indebted to the late Dr. Erich Dimroth, UQAC, whose help in the field and laboratory proved quite invaluable. Through my association with him I had the opportunity to discuss my ideas and problems with other eminent volcanologists.

I thank C.D.A. Comba, Falconbridge Ltd., and David Watkins, Minnova Inc.; the former forbeing the first to realize the the intrinsic importance of the study area; the latter for allowing me to continue my stratigraphic correlations while employed by Minnova Inc. (formerly Falconbridge Copper).

My thanks also go to Jim McIntosh, Resident Geologist, and Marc van de Walle, Geologist in the Resident Geologist's Office, Rouyn, for their keen interest and material assistance.

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II
METHOD OF STUDY

Tuff and other pyroclastic beds were described and plotted on stratigraphic sections using techniques and terminology developed by BOUMA (1962) for turbidites. Although there are textural similarities between turbidites and the fragmental rocks of the study area, the features described here do not generally occur in the typical sequences described by Bouma for turbidity deposits.

Metamorphic recrystallisation, especially near major rhyolite dykes, has rendered it impossible to determine fragment size smaller than 1/4mm. This is also at the limit of resolution of the unaided eye. Hence, thin section examination did not greatly enhance grain size determinations. Neither did it aid in the determination of clast composition beyond the mafic/intermediate and rhyolite/dacite divisions. Unaltered feldspar phenocrysts and some quench crystal textures are present in select samples, however. Primary sedimentary textures (ripples, graded bedding, etc.) were recognizable only with difficulty in thin section. Detailed outcrop and polished slab examination were, therefore the principal means of rock description and identification.

To determine grain size variations in coarse-grained beds more than 50cm thick, the five largest clasts in $1/4m^2$ (for beds up to 2m thick) or $1m^2$ (for beds greater than 2m thick) were taken as representative of the vertical variation in grain size, when measured in successive squares, from bottom to top. For beds thinner than 50cm a qualitative of grain size variation was used, for example "bed grades from coarse to fine ash over 10cm".

The technique of measuring only the largest clasts in sedimentary mass flow and turbidite beds was deemed by ALLEN (1968), ROCHELEAU and LAJOIE (1974) and LAJOIE (1977) to be an adequate indicator of flow conditions. If flow power was such that the coarse fraction was transported, then the flow should also have had the competancy to transport the finer material. This technique was effectively used for the analysis of lateral facies variations of pyroclastic flows by WALKER and CROASDALE (1971) and TASSE, LAJOIE and DIMROTH (1978).

Grain size classification for this study was adapted from FISHER (1961):

Grain Size	Fragment	Rock Name
64mm	block or bomb	breccia
64-4mm	lapilli	lapilli-tuff
4-1/4mm	coarse ash	coarse ash tuff
1/4mm	fine ash	fine ash tuff

Stratigraphic sections referred to in the text are presented in Appendix I. "Sectors" refer to locations on the end-piece map.

III
PREVIOUS WORK

The following is a partial list of early work covering the Rouyn-Noranda area, consisting mainly of large-scale geological surveys be governmental agencies (in chronological order):

WILSON, M.E.

1913: Kewagema Lake Map Area, Québec; Geol. Surv. Can., Memoir 39.

1918: Timiskaming County, Québec; Geol. Surv. Can., Memoir 103.

JAMES, W.F.

1925: Rouyn Map Area, Timiskaming County, Québec; Geol. Surv. Can., Sum. Rpt. 1923, pt. C, p. 99-125.

COOKE, H.C., JAMES, W.F. and MAWDSLEY, J.B.

1931: Geology and Ore Deposits of the Rouyn-Harricanawa Region, Québec; Geol. Surv. Can., Memoir 166.

WILSON, M.E.

1941: Noranda District, Québec; Geol. Surv. Can., Memoir 229.

1962: Rouyn-Beauchastel Map Areas, Québec; Geol. Surv. Can., Memoir 315.

More recently, BARAGAR (1968) and GELINAS et al (1977) subdivided the Abitibi Greenstone Belt into various chemo-stratigraphic units; JOLLY (1974) applied regional metamorphic zonations in Rouyn-Noranda to Archean terrains in general; DIMROTH and LICHTBLAU (1979) found identical seafloor metamorphic effects in comparing Archean volcanics from Rouyn-Noranda with Cenozoic volcanics from New Zealand.

Numerous papers by Dimroth and co-workers dealing with the volcanolgy and sedimentology of the area are given in the bibliography.

Recent theses on specific rock units of Rouyn-Noranda include GORMAN (1975) and PROVOST (1978) on one side of the current debate over the formation of the Don Rhyolites, and BOUCHARD (1978) and SIMARD (1978) on the other. COUSINEAU (1979) studied the stratigraphy and facies relationships within the Amulet Andesite Formation in the Norbec Mine area. Reworked tuffs in the Amulet Andesite were described by COMBA (1975).

Unpublished company maps (at 1":200') and report by MORRIS (1959), for Anglo-Rouyn, Powell-Rouyn and Joliet-Québec Mines, are on file at the Resident Geologist's Office, Rouyn, and include the area of the present study, as does the thesis of de ROSEN-SPENCE (1976) (at 1":1000'), but no formal or detailed examination has ever been made.

IV
REGIONAL GEOLOGY

The Rouyn-Noranda area is located at the southern central margin of the Archean Abitibi Greenstone Belt (GOODWIN and RIDLER, 1970), in the Superior Province of the Canadian Shield (Fig. 1). The area is underlain by rocks of the upper part of the Blake River Group (DIMROTH, 1975), characterised in the central Rouyn-Noranda area by calc-alkaline shield volcanoes (Dufault Calc-alkaline Units of GELINAS et al, 1977) overlying a basal subdivision of tholeiitic basalt.

A succinct résumé of the development of the Blake River Group, contemporaneous and overlying sediments is given by DIMROTH and ROCHELEAU (1979, p. 14-18). The following summary is taken primarily from their paper.

Volcanic activity commenced south of the Duparquet-Destor-Manneville Break (Fig. 1) with the emplacement of a plain of tholeiitic basalt, comprising the lowermost unit of the Blake River Group. Upon this substrate grew the central volcanic complexes of Cléricy, Renault and Dufault (or Noranda).

Sedimentation was active during and continued after the cessation of volcanism. A sedimentary basin was situated south of the present-day Cadillac Break. Basal turbidite fans (Lower Cadillac Group) were both coeval with and continued after the cessation of volcanism, and grade upward into fluvial fans (Timiskaming Group) deposited during emergence and erosion of the volcanic edifices.

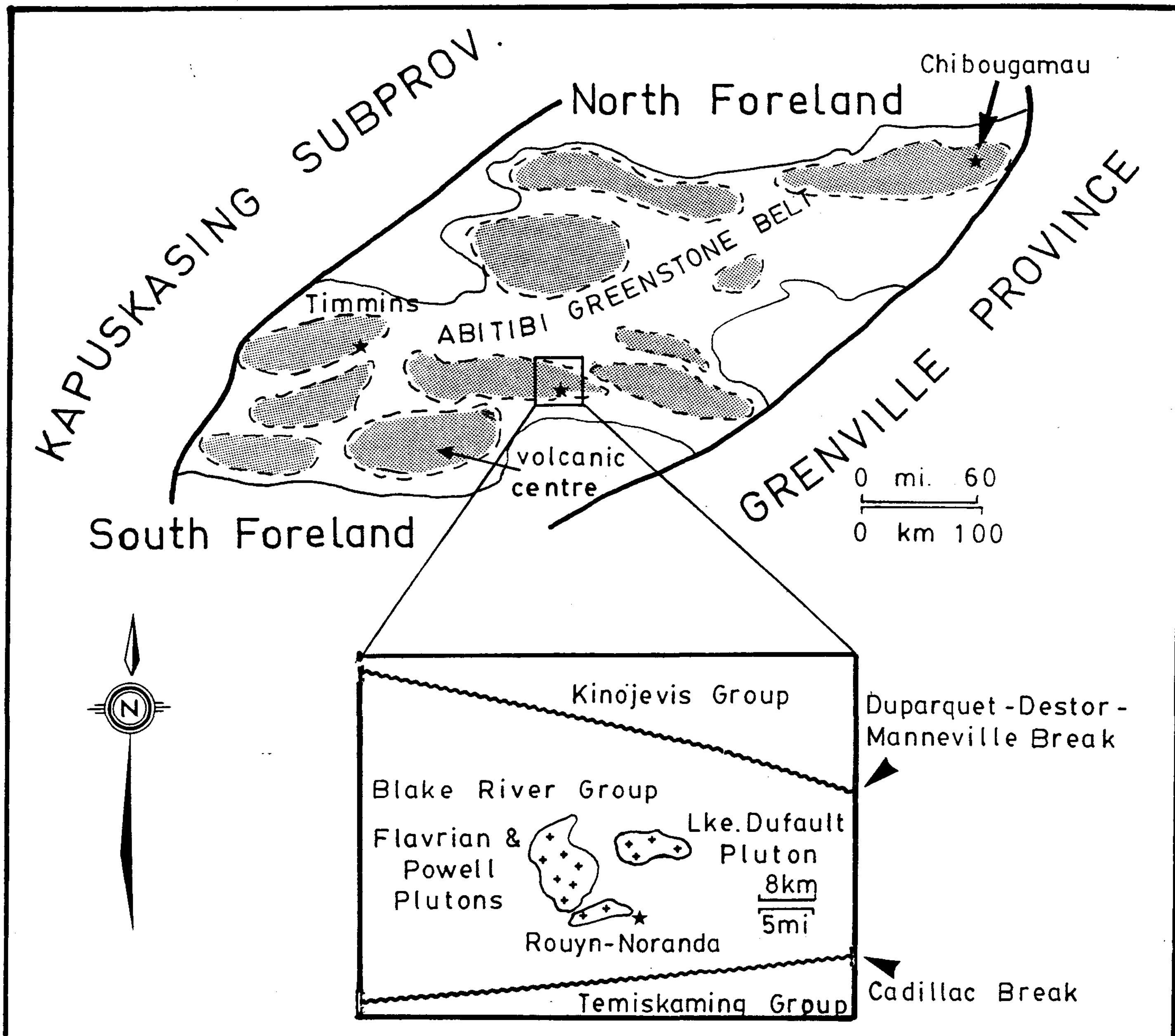


FIGURE 1 **INDEX MAP**

Rouyn-Noranda is underlain by Blake River volcanics of the Abitibi Greenstone Belt, lying within the Superior Province of the Canadian Shield

(after GOODWIN and RIDLER, 1970)

Diorite dykes and sills, and granitoid plutons may represent late, shallow cogenetic intrusions beneath the volcanic complexes. After the Kenoran Orogeny, NNW trending Proterozoic diabase dykes cut all the rocks of the region and may represent feeder dykes to plateau volcanism (BARAGAR, 1977).

A comprehensive synthesis of the geological development of the immediate Rouyn-Noranda area was made by de ROSEN-SPENCE (1976) and SPENCE and de ROSEN-SPENCE (1975). They postulated that the central Noranda sequence of Formations comprise the upper, central part of what they term the Noranda Volcanic Complex (Fig. 2). The Flavrian and Lake Dufault Plutons now occupy the axis of a synclinorium along which eruption of rhyolites occurred progressively eastwards from centres of extrusion subsidiary to one postulated magma chamber at depth.

These granitoid plutons may be shallow, synvolcanic intrusives (GOLDIE, 1976) possibly related to cauldron subsidence (de ROSEN-SPENCE, 1976). The Flavrian Pluton hosts a disseminated copper ore body (the Don Rouyn Mine) with characteristics similar to porphyry copper type mineralisation (GOLDIE and KOTILA, 1979).

This study has determined that facies changes in volcaniclastic units and detailed stratigraphic correlations across synvolcanic faults are consistent with the interpretation that a volcano-tectonic depression existed for a discrete period of time in the central Noranda area. In-filling of the basin predominantly by andesitic flows more or less kept up with subsidence. After the faults became inactive the basin

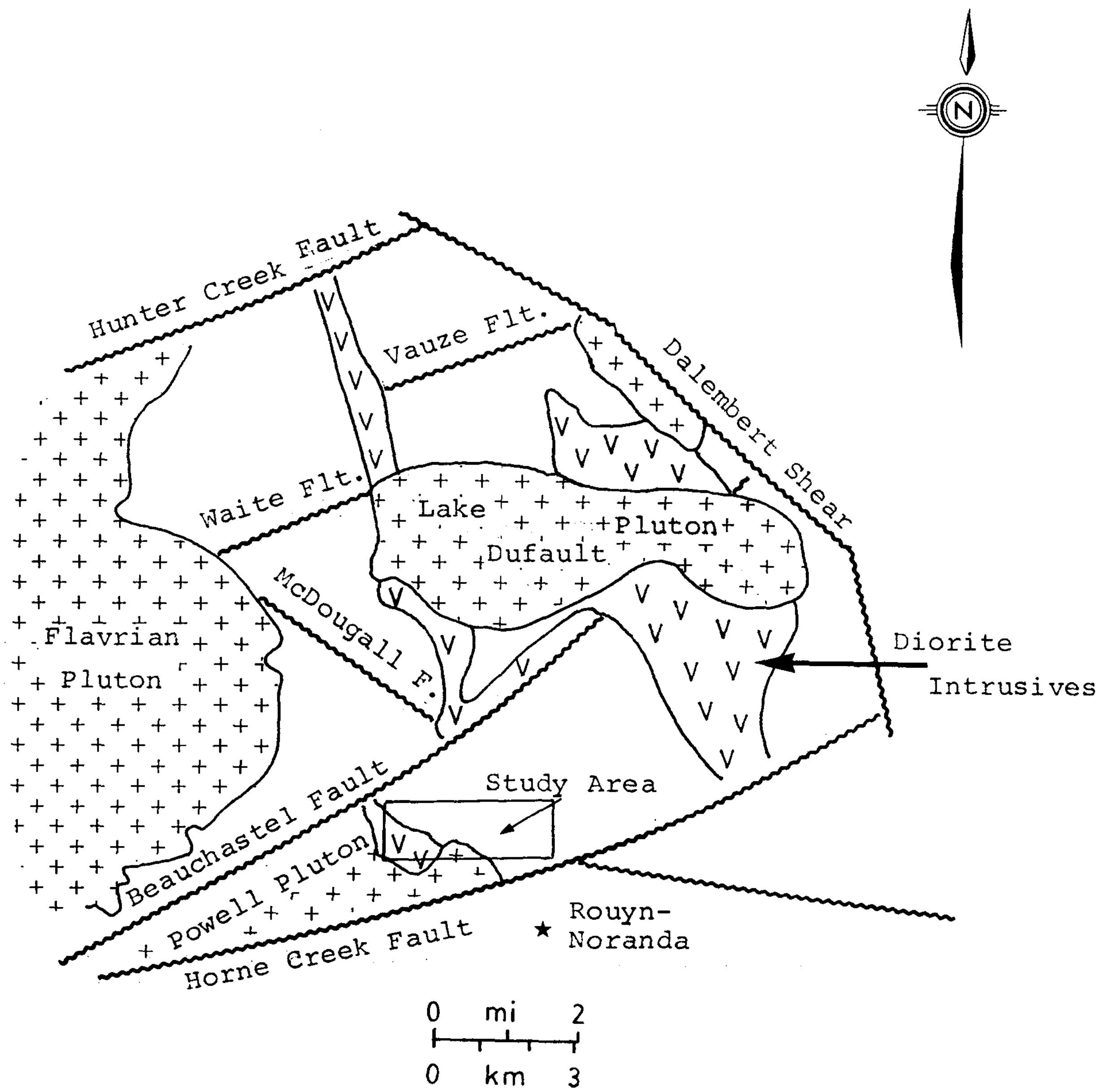


FIGURE 2 **CENTRAL NORANDA VOLCANIC COMPLEX**

Extrusive formations are left unshaded.

after de Rosen-Spence (1976)

was capped by overlying formations.

V
STRATIGRAPHY

V 1. INTRODUCTION

On the basis of rapid lateral discontinuities (detailed below) the study area may be divided into two distinct blocks: the region lying SE of the northernmost Quemont Feeder Dyke, comprising Fault Block 1; and the region NW of the Dyke, encompassing Fault Blocks 2, 3, 4 and 5 (Fig. 3 and end-piece map).

The area NW of the Quemont Dyke forms the basinal depression of a caldera proposed by de ROSEN-SPENCE (1976). Fault Block 1 comprises its rim. As is detailed below, a lateral stratigraphic break is evident along the site of the northern Quemont Feeder Dyke: the Powell formation, a sequence of 1500m of interbedded flows and volcaniclastics within the basin, laps onto and wedges out over the Dyke and its associated rhyolite flow.

V 2. STRATIGRAPHY SOUTHEAST OF THE QUEMONT FEEDER DYKE

Brownlee Rhyolite (Table 1)

The Powell segment of the Flavrian Pluton has obliterated the volcanic succession beneath the uppermost 600m of Brownlee Rhyolite. It forms the base of the stratigraphic columnfor the 5km of terrain lying between the Horne Creek Fault to the south and the Beauchastel Fault to the north (Fig. 3), crossing all of the fault blocks of the area.

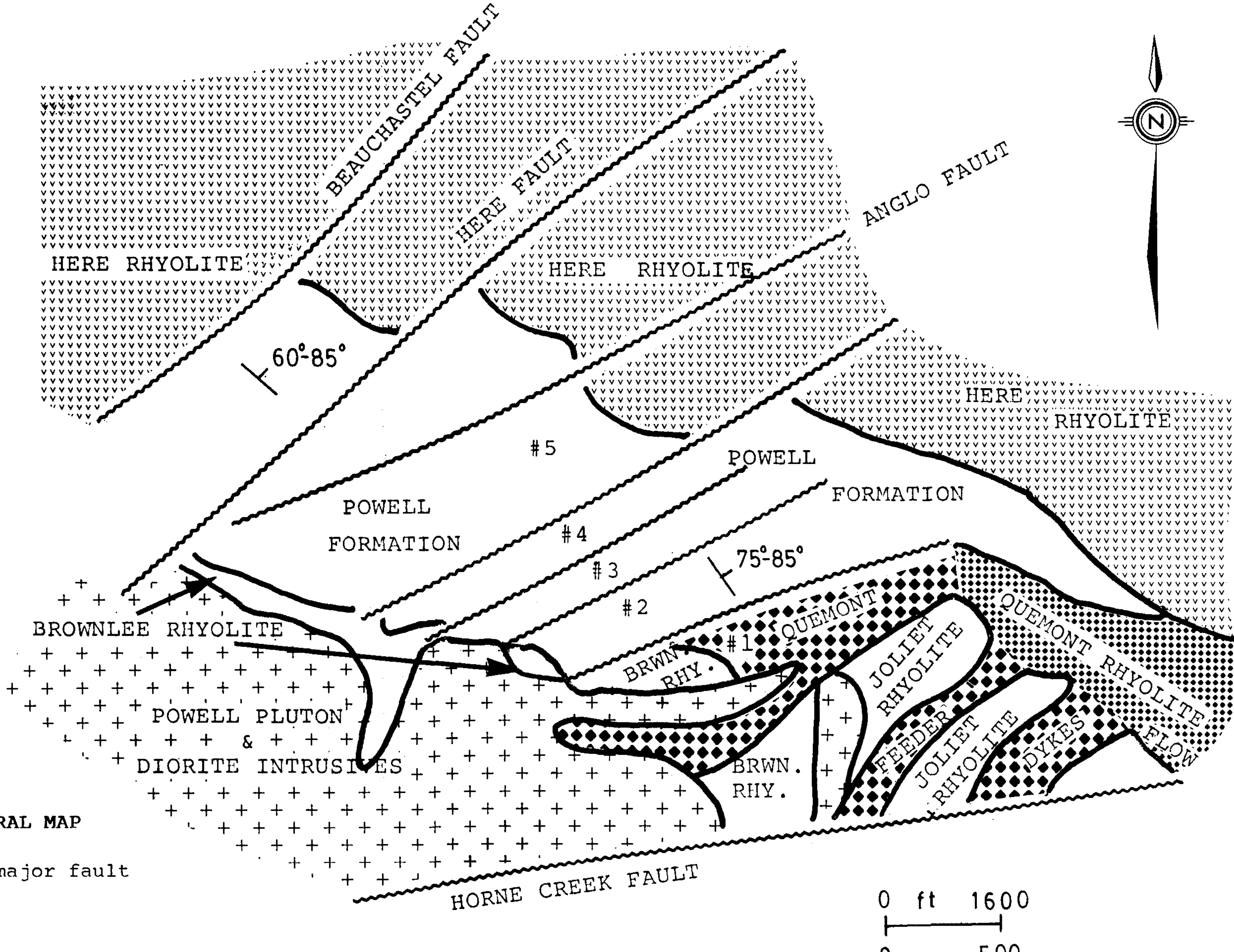


FIGURE 3

SCHEMATIC STRUCTURAL MAP

Numbers refer to major fault blocks.

TABLE 1: STRATIGRAPHY OF THE POWELL AREA

FORMATION NW OF QUEMONT FEEDER	FORMATION SE OF QUEMONT FEEDER	LITHOLOGY
Flavrian (Powell), Lake Dufault Plutons and associated mafic intrusives		Granitoids; diorite, gabbro
Intrusive contact		
Héré Rhyolite Formation, including feeder dyke		Rhyolite; massive, laminated, breccia; intercalated tuff and andesite at base
Powell Formation:		
Upper Powell		Andesite; massive, pillowed, pillow breccia
Upper Marker Joliet Breccia		Explosion pit fill and associated debris and tubidity current deposits
Powell Tuff		Tuff; tuff-breccias; some reworking
Powell Rhyolite, including feeder	Powell Rhyolite intrusive dykes	Rhyolite; massive, breccia; dykes
Middle Powell		Andesite; massive, pillowed, pillow breccia
	Quemont Rhyolite Formation including feeder dykes	Rhyolite; massive, laminated; steam breccias
	Quemont breccia II	Oligomict breccia
Lower Marker	Quemont Breccia I	Oligomict pyroclastic lag deposit and associated debris and turbidity flow deposits
Lower Powell		Andesite; massive, pillowed, pillow breccia
	Joliet Rhyolite Formation	Rhyolite; flows and flow breccias, some pyroclastic breccias
Brownlee Rhyolite Formation		Rhyolite; massive

Brownlee Rhyolite is a creamy weathering feldspar microphyric, predominantly massive rhyolite, displaying flow laminated phases near its top contact. Chemically, it is a low silica rhyolite (65.1% SiO_2, sample BRJ.10 of de ROSEN-SPENCE, 1976). It appears to have been sericitized and carbonatised immediately beneath the overlying formation.

Brownlee Rhyolite forms the base of the extrusive volcanic succession throughout the map area. In Fault Block 1 it is overlain by thin flows and flow breccias of Joliet Rhyolite.

Joliet Rhyolite

Joliet Rhyolite is found exclusively in Fault Block 1, between the Horne Creek Fault to the south and the northern Quemont Feeder Dyke, a strike length of 450m. It attains maximum thickness south of the Joliet-Québec Mines shaft, where 400m of Joliet overlie Brownlee Rhyolite.

The Joliet Rhyolite is a creamy weathering, feldspar microphyric rhyolite, of normal silica content (72.2% SiO_2, average of samples A.830 and A.831 of de ROSEN-SPENCE, 1976). It is composed of numerous thin (10m) flows, flow breccias and minor explosive breccias, mapped in detail by MORRIS (1959) and de ROSEN-SPENCE (1976).

Joliet Rhyolite is an areally restricted and more flow brecciated phase of rhyolite than underlying, massive Brownlee. Topographically, the Joliet most likely formed a hill, confined to Fault Block 1, above a Brownlee substrate. This sequence of eruptive activity culminated in the emplacement of the pyroclastic lower unit of the overlying Quemont Breccia Pile.

No feeder dykes to Joliet Rhyolite are exposed, although the formation is cut by at least three feeders to a later rhyolitic episode (Quemont Feeder Dykes). These younger dykes may have used pre-existing conduits and intruded the same fracture system as had earlier feeders to Joliet Rhyolite.

In addition to the Quemont Dykes, the Joliet formation is cut by the coarse-grained quartz phyric Powell Rhyolite dykes and various mafic intrusives (Table 1).

Quemont Breccia Pile (Fig. 4)

The Quemont Breccia Pile is composed of two distinct breccia facies overlying Joliet Rhyolite. It is capped by Quemont Rhyolite (flow 4, terminology of de ROSEN-SPENCE, 1976), and intruded by the Quemont Feeder Dykes and Powell Rhyolite dykes.

The Breccia Pile can be traced 450m between the Quemont Dykes, and like the Joliet is found exclusively in Fault Block 1. It attains a maximum thickness of 240m. The lower breccia facies, Breccia I, is 120m thick and comprises plagioclase microphyric rhyolite and andesite lapilli and blocks in a polymict groundmass of plagioclase microphyric rhyolite, basalt, andesite and acid phanerite. Rhyolite lapilli and blocks are massive to moderately vesiculated (chlorite-filled) and may display flow banding; in this regard they strongly resemble underlying Joliet

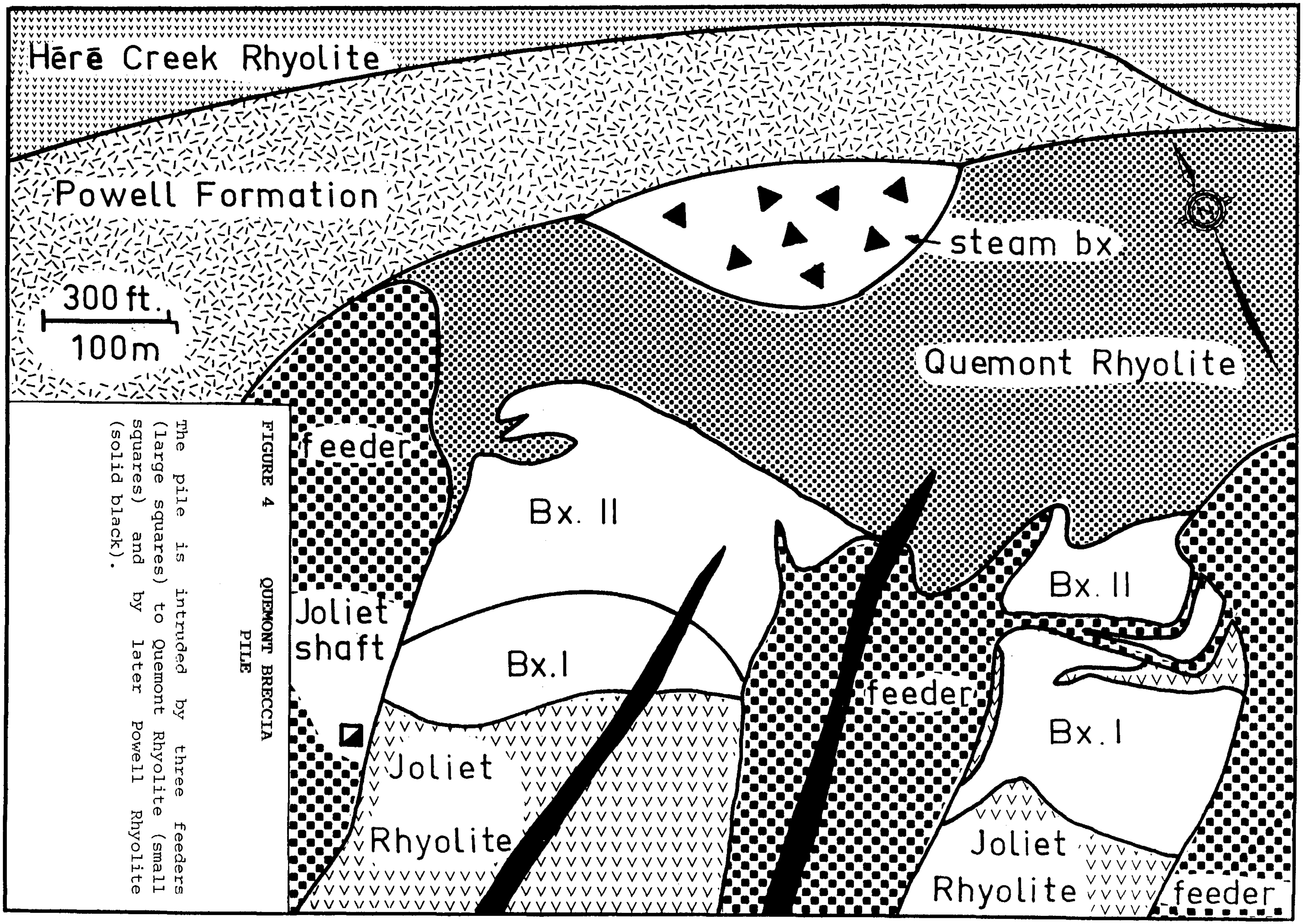


FIGURE 4 QUEMONT BRECCIA PILE

The pile is intruded by three feeders (large squares) to Quemont Rhyolite (small squares) and by later Powell Rhyolite (solid black).

Rhyolite. Andesite clasts are typically massive. Both rhyolite and andesite fragments are angular to sub-rounded.

Breccia I directly overlies flow banded Joliet Rhyolite (Fig. 4 and sector E-10, end-piece map) and always underlies Breccia II. The latter contains clasts of plagioclase microphyric rhyolite, quartz phyric rhyolite and andesite in a dark groundmass enclosing quartz grains. Fragments range in size from lapilli to block and are angular to sub-rounded.

Breccia II is poorly exposed and its exact contact relationships are not known. The quartz phyric fragments in the breccia, however, strongly resemble overlying Quemont Rhyolite, and the plagioclase microphyric rhyolite fragments are identical to those in Breccia I and the Joliet Rhyolite.

A thin (0-5m) inter-breccia rhyolite flow (itself autobrecciated) separates Breccias I and II in the eastern exposures (Fig. 5); in the west it occurs within Breccia I, defining the contact between internal primary texture sequences. At the eastern margin of the middle Quemont Feeder Dyke, the flow appears draped over steeply inclined Breccia I beds, although lack of well defined stratification within the pyroclasts makes attitude determination difficult in all but one or two localities. Alternatively, it may have the form of an intrusive (feeder?) dyke, cutting Breccia I. Texturally it strongly resembles Joliet Rhyolite.

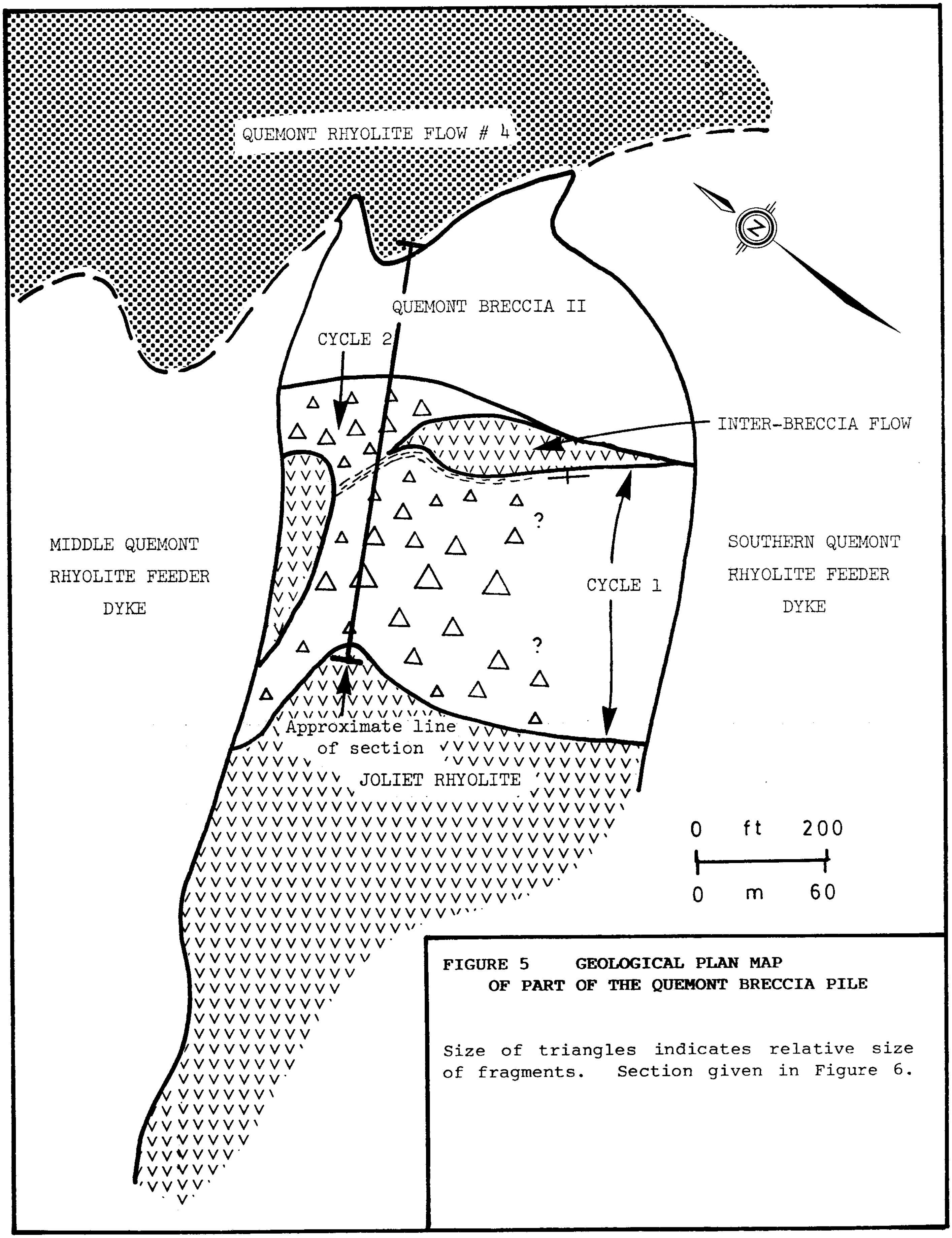


FIGURE 5 GEOLOGICAL PLAN MAP OF PART OF THE QUEMONT BRECCIA PILE

Size of triangles indicates relative size of fragments. Section given in Figure 6.

Facies Description - Quemont Breccia I (Facies 1)

From the base upwards, Quemont Breccia I is comprised of an upward coarsening, then gradually upward fining cycle; a discontinuous rhyolite flow; and an overlying upward coarsening, then upward fining cycle (Fig. 5). The lower cycle (Cycle 1) rests directly upon flow laminated Joliet Rhyolite.

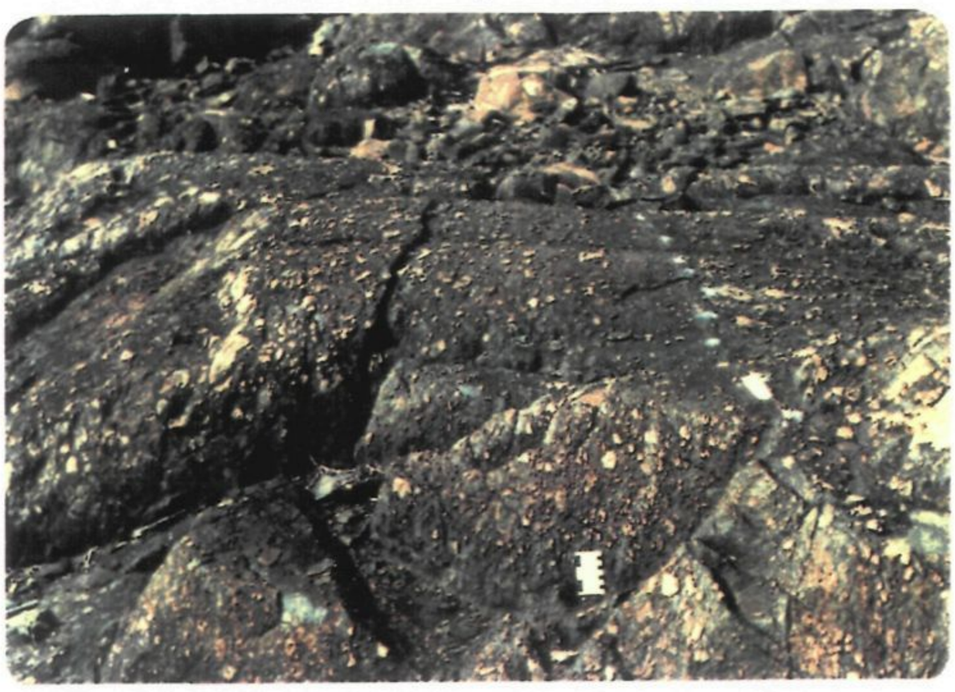
In Cycle 1 fragment size increases from lapilli at the base to block size within 20m (Plate 1); size then decreases to lapilli tuff within 40m and finally grades into a poorly parallel laminated coarse ash tuff 1/2m thick marking the top of the cycle (Plate 2).

Cycle 2 overlies the inter-breccia flow in the central exposures, but directly overlies Cycle 1 in the west. The fragment size variation is repeated, with clasts reaching block size 5m above the base of the cycle. No laminated ash is exposed, however. A lateral size variation is evident throughout Cycle 2; although vertical size variation is maintained, clasts generally increase to a maximum 20m east of the middle Quemont Dyke then gradually decrease further east, where Cycle 2 appears to pinch out. A similar lateral size variation is seen in the underlying breccias of Cycle 1.

In addition to upward fining and coarsening the only other primary sedimentary textures observed in Breccia I were poorly defined planar stratification (top of Cycle 1) and a weak orientation of long axes of clasts parallel to the lower contact of the Breccia Pile.

PLATE 1 QUEMONT BRECCIA I
General view up stratigraphy, across Cycle 1 of Quemont Breccia I. Note large aphyric rhyolite blocks. Foreground at coarsest phase of Cycle 1.

PLATE 2 QUEMONT BRECCIA I
Top of Cycle 1, Quemont Breccia I. Tops to the right. Beginning of Cycle 2 marked by white dots of paint. Note fining upward from left to right.



Quemont Breccia I contains poorly sorted, angular to subrounded fragments up to 50cm in longest dimension; vesiculation is never more than moderate and no pumice was found. A minor compositional zoning is evident in the sudden appearance of andesite lapilli at the top of the second cycle. This zonation also occurs in the ash component of the breccia: the top of Cycle 2 contains up to 42% combined andesite/basaltic fragments, compared with only 6%-8% at the bottom of the cycle, and contrasted with a range of 1%-15% andesite/basalt in Cycle 1 (data of DIMROTH and OWEN, 1979).

The structural form of Quemont Breccia I is not readilly apparent from surface exposures (Fig.5). Contacts of Cycle 2, however, show that it thins rapidly away from the Quemont Feeder Dyke, giving it a total strike length of approximately 90m. Cycle 2 is thickest where it is cut by the feeder, attaining a height of 50m above Cycle 1.

Origin of Quemont Breccia I

MORRIS (1959) regarded the breccia pile as pyroclastic and as having been deposited by nuée ardente-like eruptions. De ROSEN-SPENCE (1976) believed Breccia I to be a pyroclastic deposit related to the opening of the Quemont Feeder Dyke prior to the extrusion of Quemont Rhyolite Flow 4. DIMROTH (1975) believed it to be a pyroclastic fall-back breccia but the lack of both parallel stratification and excellent sorting in Breccia I led him later (DIMROTH and ROCHELEAU, 1979) to suggest that the breccia was a subaqueous analog of subaerial co-ignimbrite lag-falls described by WRIGHT and WALKER (1977).

Comparing WRIGHT and WALKER's Quaternary subaerial co-ignimbrite lag-falls with Quemont Breccia I discloses important similarities: (see also Fig. 6)

TABLE 2

	Subaerial co-ignimbrite lag-fall deposit (WRIGHT and WALKER, 1977)	Quemont Breccia I
Radial Extent	2km from vent	200m from Quemont dyke
Thickness	10m, 1.5km from vent	140m where cut by Quemont dyke
Stratigraphic Position	overlies associated ignimbrites; underlies welded bomb beds	overlies lithologically similar Joliet flows; underlies Breccia II
Textures	absence of fine grained fall units	1/2m thick fine grained unit present
	absence of discreet bedding planes	poor bedding in fine grained unit only
	variable pumice (10%-70% by volume)	no pumice; up to moderate vesiculation
	lithic fragments up to 1/2m in size	lithics up to 1/2m
	minor compositional zoning in light and dark pumice	minor compositional zoning at top of Cycle 2
	lateral correlation with consanginous ignimbrite (pumice flow deposit)	lateral correlation with consanginous pyroclastic deposit

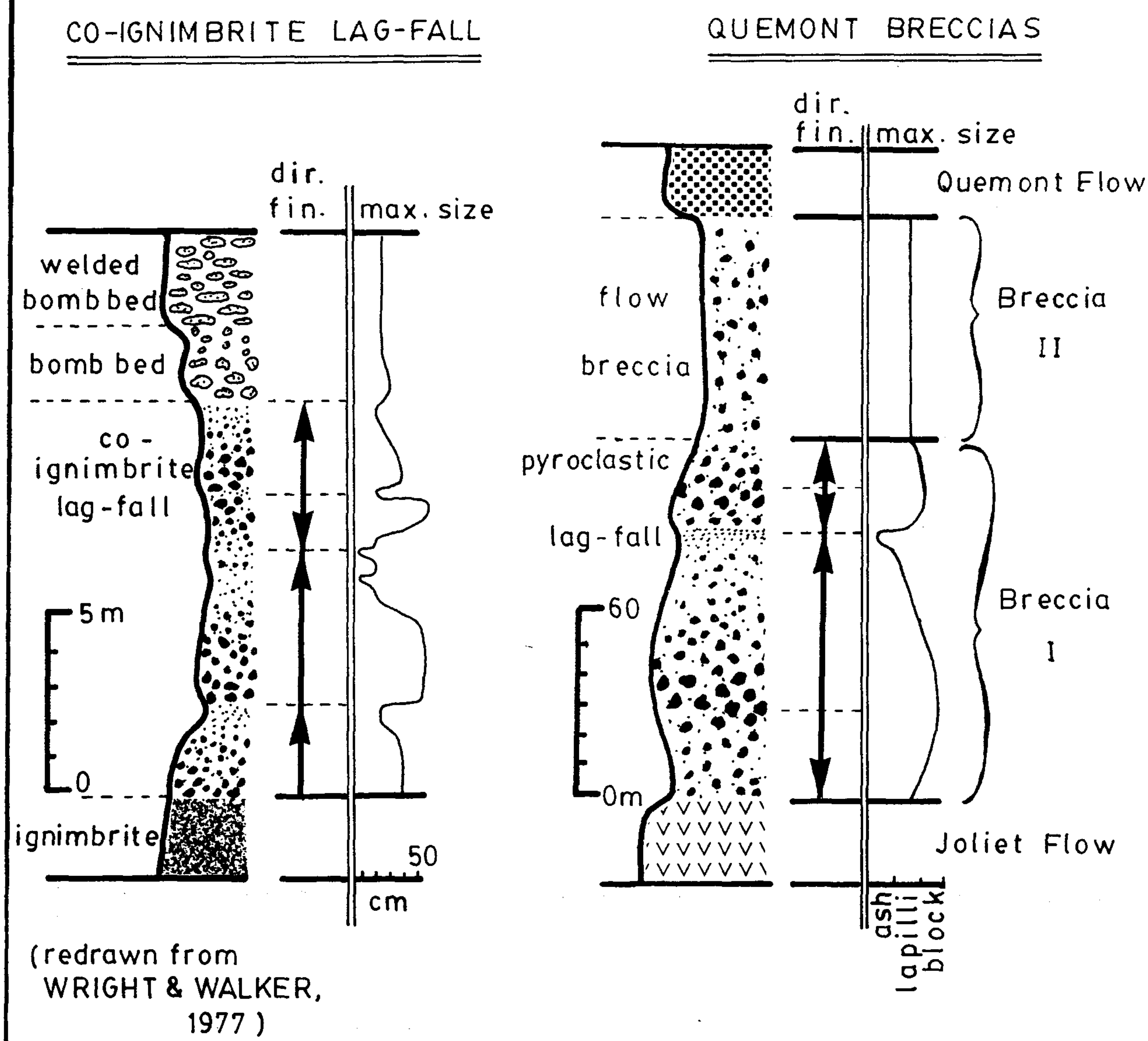


FIGURE 6 **COMPARISON OF QUEMONT BRECCIAS AND LAG-FALL**

The mechanism of emplacement is considered to be similar in both examples, although in different ambient mediums.

The most contrasting features of these two examples are the physical dimensions and eruptive mechanisms. Whereas the subaerially erupted co-ignimbrite lag-falls extend radially several kilometers from source, the maximum exposed strike length of Quemont Breccia I is 200m radially from the middle Quemont Feeder Dyke. The total thickness of Breccia I and the fining/coarsening upward sequences in particular are about one order of magnitude thicker than in co-ignimbrite lag-falls.

The co-ignimbrite lag-fall deposits, consisting of up to 70% (volume) essential pumiceous component, are vertically and laterally associated with lithologically similar ignimbrite deposits (pumice flows). These are interpreted as subaerial, magmatically erupted deposits.

The essential component of Quemont Breccia I consists of massive to moderately vesiculated, angular to subrounded material and suggests an origin by phreatic explosion. Pillowed andesites in the time-equivalent Powell formation (exposed in the Fault Blocks NW of the northern Quemont Feeder) were undoubtedly emplaced subqueously.

WRIGHT and WALKER's (1977) co-ignimbrite lag-falls were deposited near the site of eruption column collapse due to the inability or the pumice flows to transport the largest and densest lithics. A cut-off size existed which resulted in these clasts being dropped near the vent, forming coarse, unstratified deposits rich in lithics and dense juvenile material. Laterally they may be correlated with pumice flows of the same eruptive episode. This general restriction, i.e. the competency of a flow to transport only a certain size fraction should be valid for any collapsing eruption column, regardless of explosive mechanism or ambient medium.

In a subaqueous environment an ascending eruption column, formed by phreatic explosion, would expend most of its kinetic energy in expansion against the ambient medium: water. Hence, subaqueous eruption columns will not attain heights of kinetically comparable subaerial eruptions. Material on ballistic trajectories will be similarly retarded; conversely, the "residence" time of fine ash will be greater than in air and the sorting of water-fall ash sould be much better than the more rapidly settled air-fall. Eruption in an subaqueous environment would therefore tend to form voluminous but spatially restricted deposits clustered closely about the vent.

The eruptive centre of Quemont Breccia I is interpreted to have been at the site of the middle Quemont Feeder Dyke: the largest breccia fragments occur in close proximity to the edges of the dykes,

Cycle 2 lenses-out rapidly SE of the dyke,

Breccia I is generally radially symmetric, NW and SE, about the dyke.

These are features to be expected if the eruptive centre were at the site of the middle Quemont Feeder Dyke.

Quemont Breccia I was erupted subaqueously by a series of phreatic explosions at the site of the present middle Quemont Feeder Dyke. A rapidly collapsing eruption column rimmed the vent with coarse debris left behind as a lag deposit by pyroclastic flows. A sequence of two eruptive cycles is indicated by the upward coarsening/fining breccias. The cycles are separated by a hiatus in explosive activity having permitted the quiet extrusion of a lava flow. The lack of stratification indicates very rapid dumping; coarsening then fining upward cycles reflect increasing, then decreasing explosivity during individual cycles. Poorly planar stratified coarse ash at the top of Cycle 1 is water-fall material of the waning stage of eruptive Cycle 1.

The absence of quartz-phyric Quemont Rhyolite fragments in Breccia I would appear to preclude the direct influence of Quemont rhyolite magma in the production of the phreatic explosions responsible for Breccia I. The presence of a small Joliet Rhyolite type flow within the breccias attests to the continued presence of this type of magma in the vent.

This model predicts the presence of laterally correlative subaqueous pyroclastic flow deposits (ignimbrites in the subaerial examples of WRIGHT and WALKER, 1977). Above the competency level of the flows, less dense lithic material must have been entrained and transported away from the vent and its lag deposits. Quemont Breccia I has such a laterally correlative pyroclastic flow deposit exposed along a strike length of 1100m in Fault Blocks 3, 4, and 5 (discussed below under "Lower Pyroclastic Marker").

Origin of Quemont Breccia II

The poorly exposed nature of Breccia II obscures its origin. The deposit has the general appearance of being a chaotic, unsorted tuff-breccia, composed of plagioclase microphyric rhyolite (as the underlying Breccia I) and quartz phyric rhyolite (identical to overlying Quemont Rhyolite Flow 4) fragments. This breccia is assumed to be, at least in part, a flow foot breccia of the Quemont Rhyolite. The Joliet Rhyolite component may have been incorporated from unconsolidated Breccia I.

Quemont Rhyolite Flow

The Quemont Rhyolite formation is composed of several distinct rhyolite flows, differentiated by their unique concentration and size of quartz phenocrysts (see de ROSEN-SPENCE, 1976, for a full description). The entire formation is restricted to the 4km between the northern Quemont Feeder Dyke and the Horne Creek Fault. It attains a maximum thickness of 1km and is comprised of at least seven distinct flows and three breccias.

Three feeder dykes to Flow 4 are recognised at the northwestern limit of the formation. They cut underlying Joliet and Brownlee Rhyolite and the Quemont Breccia Pile. Rhyolite Flow 4 overlies the Breccia Pile and is transitional into its feeder dykes. The flow is not present northwest of the northern feeder dyke, but does continue 4km to the southeast where it is truncated by the Horne Creek Fault.

The entire Quemont Rhyolite formation is overlain by Héré Rhyolite formation.

Quemont Rhyolite Flow 4 is massive, quartz phyric (1-3mm dia., 2 crystals per cm^2), normal silica (75% SiO_2, analysis no. 134 of the ROSEN-SPENCE, 1976) rhyolite. At its northern extremity the flow pinches out where it overlies its feeder; it reaches a thickness of at least 700m in its south-eastern exposures, where it is truncated by the Horne Creek Fault.

Héré Rhyolite

The Héré Rhyolite formation is composed of an extensive series of rhyolite flows and flow breccias, stretching from outcrops south of the Lake Dufault Pluton to the vicinity of the Horne Creek Fault, a strike distance of 12 km. From a thickness of only 60m near the Lake Dufault Pluton it thickens to about 1km adjacent to the Beauchastel Fault, but then thins considerably and wedges out 2km east of the Quemont Breccia Pile and 700m north of the Horne Creek Fault.

The Héré Rhyolite is a massive, white to light grey weathering, plagioclase microphyric rhyolite. Flow laminations are ubiquitous; columnar jointing is prominent near the base of the formation (sector A-5). Flow foot and flow top breccias are common. De ROSEN-SPENCE has subdivided the formation into five distinct flows on the basis of lithology.

Northwest of the Quemont Feeder Dykes the Héré Rhyolite is underlain by the andesites of the Powell formation; to the southeast Quemont Rhyolite underlies the Héré. Eighty meters of interbedded Héré rhyolite flow breccia, parallel laminated fine to coarse ash tuff and andesitic flows marks the contact between Powell and Héré formations in Fault Blocks 2, 3, 4 and 5 (Fig. 4 ; Sector C-10). A thin wedge of Powell andesite laps over the Quemont Rhyolite above the feeders in the northwestern part of Fault Block I and underlies the Héré, but further southeast, where the Héré Rhyolites themselves start to pinch out, they directly overlie the Quemont Rhyolites.

Neither the Héré nor the Powell formations are faulted above the Quemont Feeder Dykes.

V 3. STRATIGRAPHY NORTHWEST OF THE QUEMONT FEEDER DYKE

Brownlee Rhyolite

The characteristics and distribution of the Brownlee Rhyolite have been discussed under a previous section.

Powell Formation-General

The Powell formation, as delimited by de ROSEN-SPENCE (1976) and mapped for this study, can be traced for 3.6km from the Beauchastel Fault in the NW, to where it pinches out above Quemont Rhyolite (sector C-10). It attains a maximum thickness of 1km adjacent to the Beauchastel Fault where it is composed of an alternating series of massive and pillowed flows and isolated pillow breccias. In contrast, varying thicknesses of massive and brecciated rhyolite, tuffs and pyroclastics are interbedded within andesites in the southeastern fault blocks.

The Powell formation directly overlies Brownlee Rhyolite in all the Fault Blocks except Block I: here, Quemont Rhyolite Flow 4 lies between the Brownlee and the Powell.

The Powell formation is everywhere overlain by the Héré Rhyolite formation. The contact is locally gradational through as much as 80m of interbedded Powell andesite flows, flow breccias and volcaniclastics.

Powell Formation-Andesitic Member

Massive, pillowed and pillow brecciated andesitic flows comprise at least 80% of exposures of Powell formation in the map area.

The rocks are typically grey-green on fresh surface and weather grey or greyish-brown. Vesiculation is poor (less than 1%) to moderate (10%-15%; especially near pillow margins); vesicles are generally filled with quartz and/or chlorite. Pillows display excellent concentric and radial quartz filled cooling cracks (Plate 3). Massive flows and, rarely, pillows display columnar joints perpendicular or subperpendicular to outcrop surface.

Columns making an angle of less than about 40° with respect to outcrop surface are not distinguishable from tectonic fractures; thus, since pillow attitudes are near vertical , it is likely that columns perpendicular to flow or pillow contacts are also present. These are common features of cooling lava tubes or megapillows (see DIMROTH et al, 1978, p.907).

An in-situ brecciation of intra-pillow material was found in some pillows. It consists of randomly oriented quartz filled fractures usually confined to the centre of pillows. The cracks strongly resemble cooling fractures and may be an irregular type of radial fracture.

PLATE 3 RADIAL AND CONCENTRIC COOLING FRACTURES

PLATE 4
TUFF DRAPED
OVER PILLOW

Local paleotopographic irregularities, of up to 2m, at the tops of pillow or pillow breccia facies are well preserved when overlain by tuff (Plates 4,5 & 6). Jagged tops of pillows and pillow fragments scattered over the tops of flows are due to submarine weathering before subsequent draping by ash.

Powell Formation-Andesitic Member-Facies Description

Exposures of massive facies andesite predominates slightly over pillowed facies; isolated pillow breccia is relatively rare. Due to small-scale faulting in Fault Blocks 2, 3 & 4 individual andesite flows could not be traced between outcrops. The Lower Marker Horizon, however, traverses Fault Block 5 and provides an excellent time-stratigraphic marker. By this means, correlation of andesite facies over $3km^2$ was attempted (Fig. 7).

Massive andesite is the predominant facies in Fault Block 5. Single, massive andesite flows were not distinguished. No chilled selvedges were observed; grain size changes were not in evidence (for example, medium grained in the centre, fine grained at chilled margins of flows). Exposures generally consisted of uniformly fine grained andesite.

The absence of phenocrysts, amygdules, varioles and felsic segregations precluded the development of recognisable flow lamination. The absence of flow lamination in fine grained flows more than 5m thick was indicated by

PLATES 5&6

BROKEN PILLOWS

Broken pillows and pillow fragments overlain by massive ash tuff. Original outlines of pillows shown by faint white line.

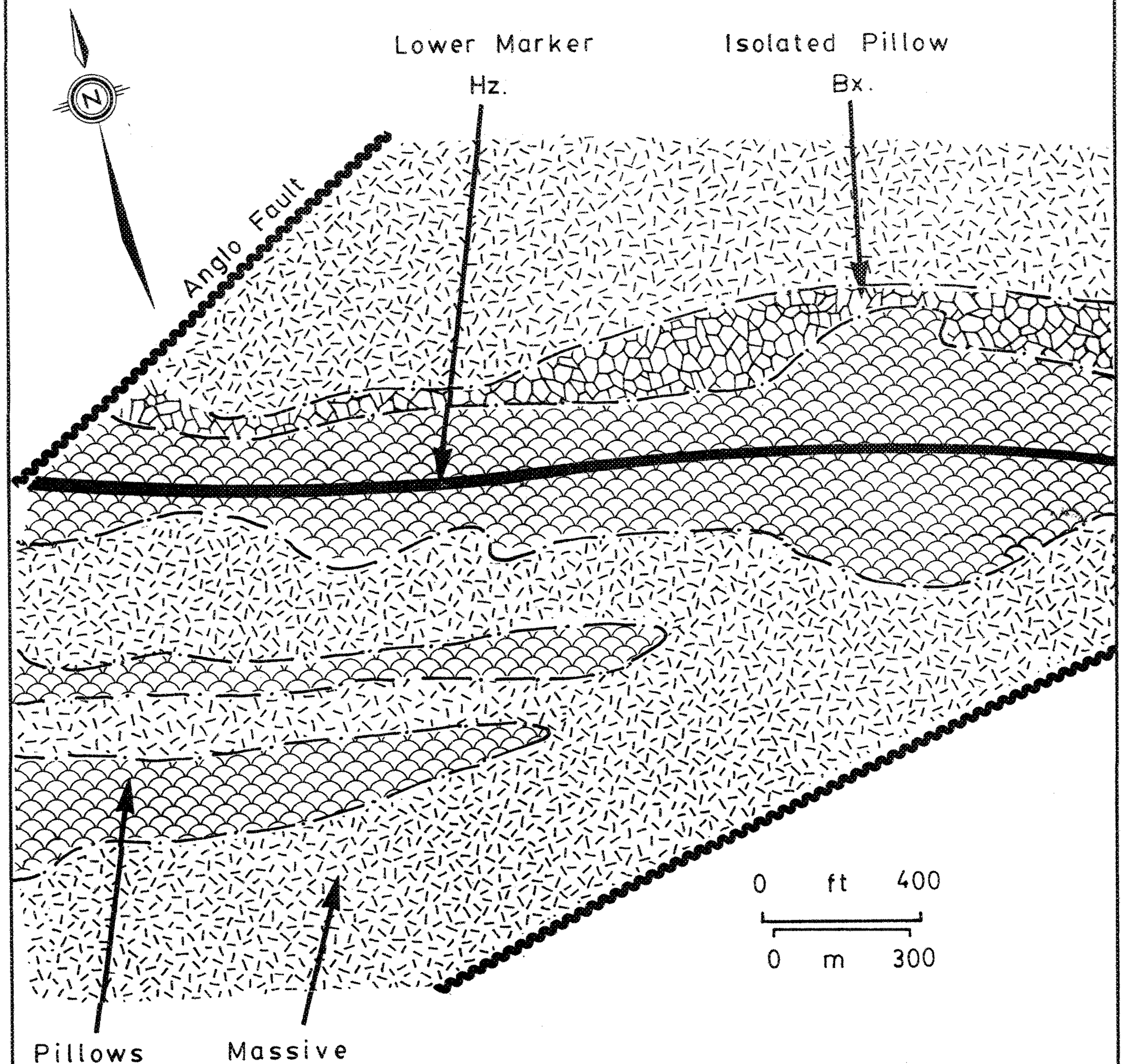


FIGURE 7 **FACIES OF POWELL ANDESITE**

The Lower Marker Horizon traverses this section (Fault Block 5) of Powell Andesite and provides stratigraphic control for the reconstruction.

DIMROTH et al (1978) to be suggestive of large welded pillows. "Massive" Powell Andesite facies attains thicknesses in excess of 200m and cross-sectional lengths of at least 2.5km.

Vertical transitions from massive (welded pillow) to pillowed facies occur over a few metres. No distinct upper, chilled contact of massive facies was present. Rather, the transition consisted of the gradual change from massive facies through intermediate ghost-like, poorly formed pillows to the overlying closely packed pillowed division.

Pillows were generally well formed, normal sized (1m to 3m longest cross-sectional dimension), bun and mattress shaped, with little original interpillow porosity. Chloritized hyaloclastite forms the outer pillow crust and fills spaces between pillows. Sparse cm-sized amygdules are rimmed internally with quartz and have chloritic centres. Rarely, quartz/chlorite filled amygdules 5cm or larger are present and are flattened parallel to the longest cross-sectional pillow dimension.

Vertical transition from pillowed facies to isolated pillow breccia (terminology of DIMROTH et al, 1978) is well exposed in Sector B-3 above the Lower Marker Horizon. The transition occurs over a few metres and is marked by a gradual increase in the amount of interpillow hyaloclastic material until about 40% to 50% of the outcrop surface (almost a perfect cross-section due to the steep dip) is hyaloclastic matrix. Pillows retain their bun or mattress shapes although some are amoeboid with re-entrant angles (Plates 7 & 8). Pillow size decreases to approximately 1m in isolated pillow breccias. Vesiculation increases to moderate in pillow breccias compared with the weak vesiculation of pillowed facies and the rare occurrence of vesicles in massive facies.

Lack of outcrop at the top of the isolated pillow breccia of Figure 7 (Sector B-3) did not permit examination of the transition to overlying massive facies.

The overall vertical sequence of andesite facies has been analysed using the standard sequence developed by DIMROTH et al (1978). Facies of Fault Block 5 show the following sequence:

1. massive facies (including two minor pillowed lenses),
2. pillowed facies,
3. isolated pillow breccia facies,
4. massive facies.

This correspond with an uncommon sequence in the Rouyn-Noranda area (sequence 2b, Fig. 11 of DIMROTH et al, 1978, capped by massive flows) and is interpreted as follows:

1. Lower massive facies is emplaced and behaved as one cooling unit, hence the welding of megapillows; minor pillowed units within massive facies represent slower surges of cooler, more viscous lava.

2. Upward transition to the main pillowed facies occurs during the waning stage of eruption when supply of lava decreased.

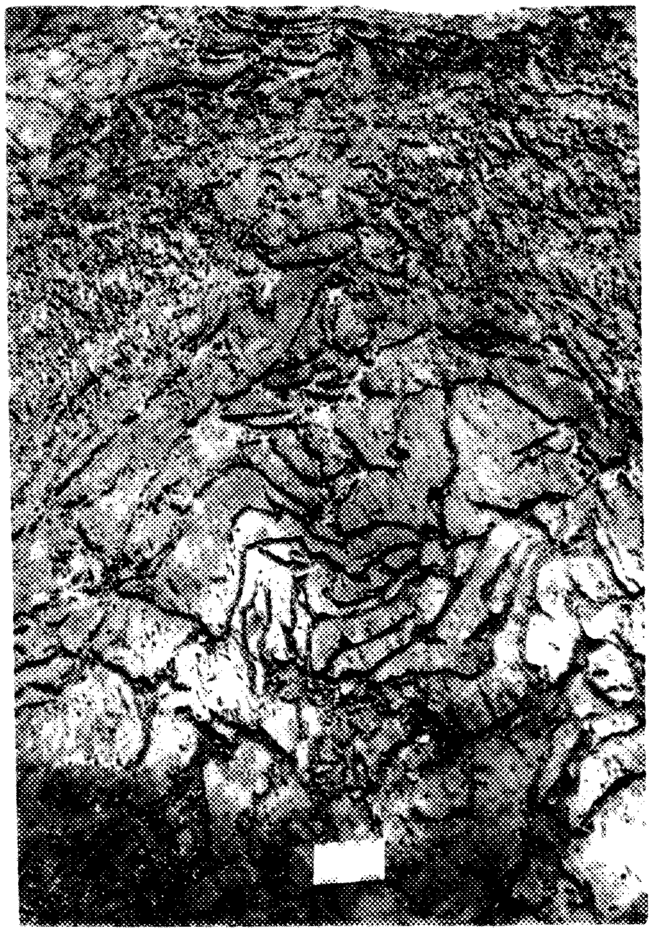


PLATE 7 AMOEBOID PILLOWS

Unusually shaped amoeboid pillows in hyaloclastic breccia. Overlain by Facies 7 tuffs at extreme top of photograph.

PLATE 8 ISOLATED PILLOW BX.

Small amoeboid pillows in hyalo-clastic matrix. Note distinctive rough texture of the inter-pillow hyaloclastite. Top of photograph is stratigraphic top.

3. Formation of isolated pillow breccia is due to strong interaction of hot lava and cold seawater during the last stage of the eruption.

4. Mantling of the sequence by massive facies indicates a resumption of extrusive andesitic activity.

Lensing-out of the two lower pillowed units in an easterly direction suggests distal termination of the flows. Source vents or fissures are therefore assumed to be toward the west (Anglo Fault?).

Powell Formation-Lower Marker Horizon (Facies 3 & 4)

The Lower Marker Horizon is an exceptional pyroclastic unit that can be traced from Fault Block 3 (sector D-4) 1100m northwest into Fault Block 5 (sector D-4). It is truncated in the north by the Anglo Fault and in the southeast by the western Quemont Feeder Dyke.

The Lower Marker Horizon lies within the Powell Andesite formation (Fig. 7 & Table 1) and is under and overlain by massive and pillowed facies Powell andesite. The Marker is typically between 3m and 15m thick and generally comprises one normally graded and stratified bed (Photos 9, 10 &11): in the eastern part of Fault Block 3 the Marker comprises three superposed graded beds (Fig. 8).

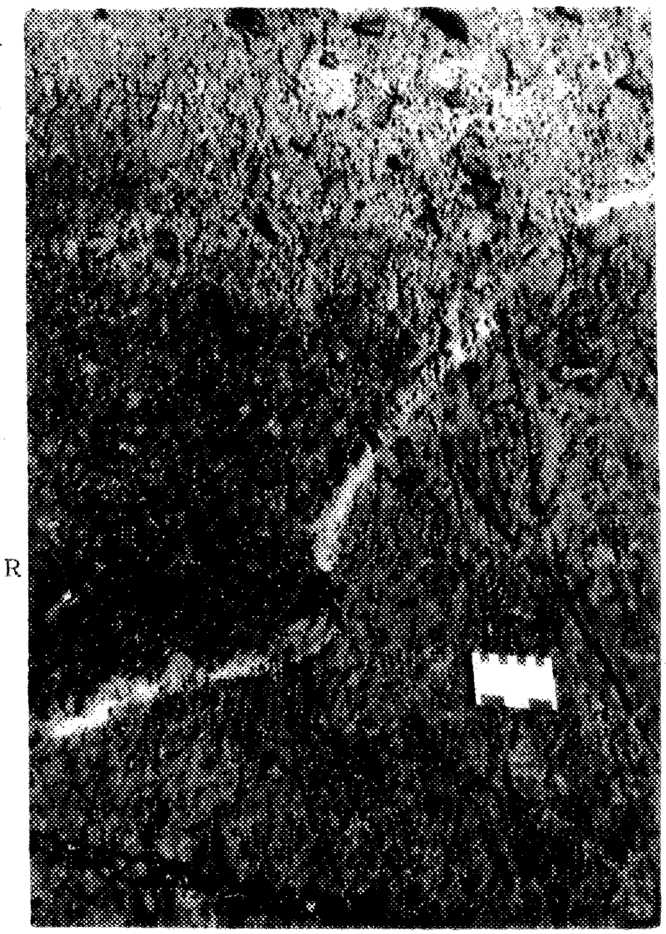
Clasts are predominantly massive to poorly vesiculated, creamy weathering, plagioclase microphyric rhyolite similar in lithology to Joliet/Brownlee Rhyolite. Rare

PLATE 9 LOWER MARKER HORIZON

Coarse lower part of Marker Horizon contains aphyric rhyolite lapilli and block (rip-up) of Powell Andesite.

PLATE 10 LOWER MARKER HORIZON

Coarse lower part of Marker Horizon overlies pillowed Powell Andesite. White line delineates the contact.



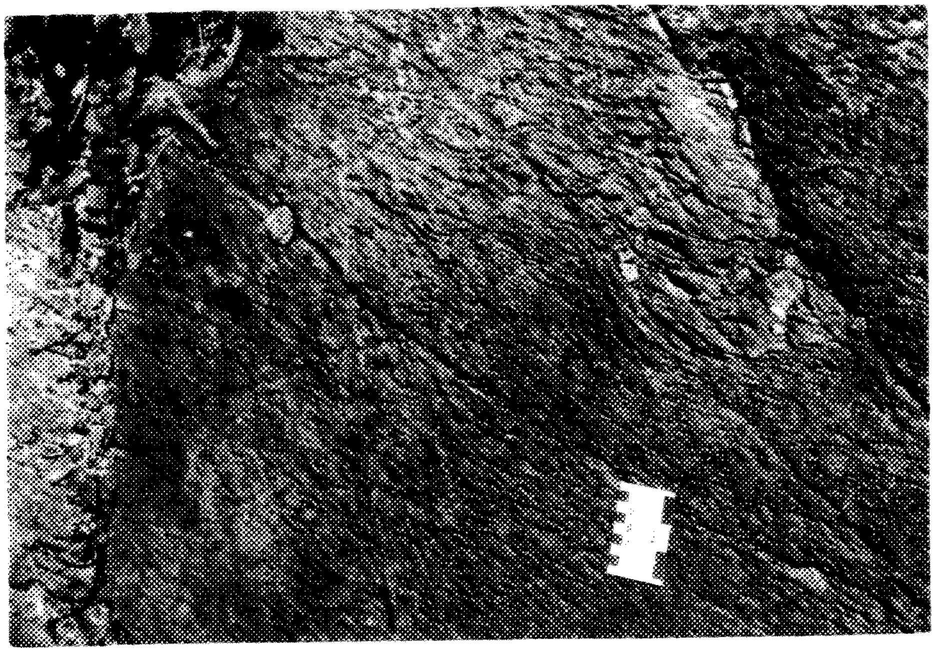
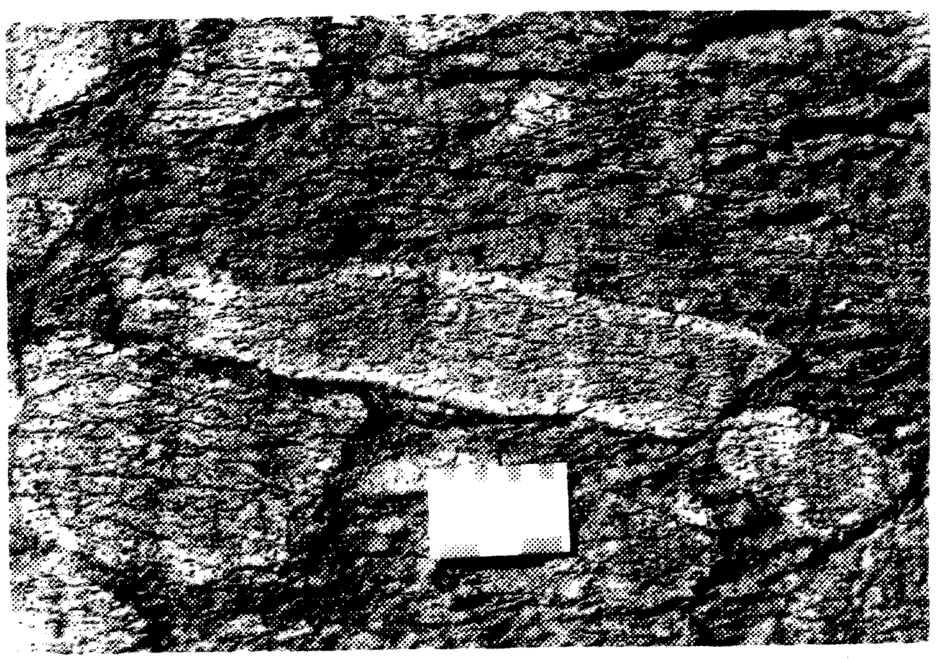


PLATE 11 LOWER MARKER HORIZON
Fine grained top part of Marker Horizon. Note vague parallel laminae. Overlain by Powell Andesite at left of photograph.

PLATE 12 POWELL RHYOLITE BRECCIA
Close-up of Powell Rhyolite in the chaotic breccia phase. Note bleached and silicified rim. Sector C-3.



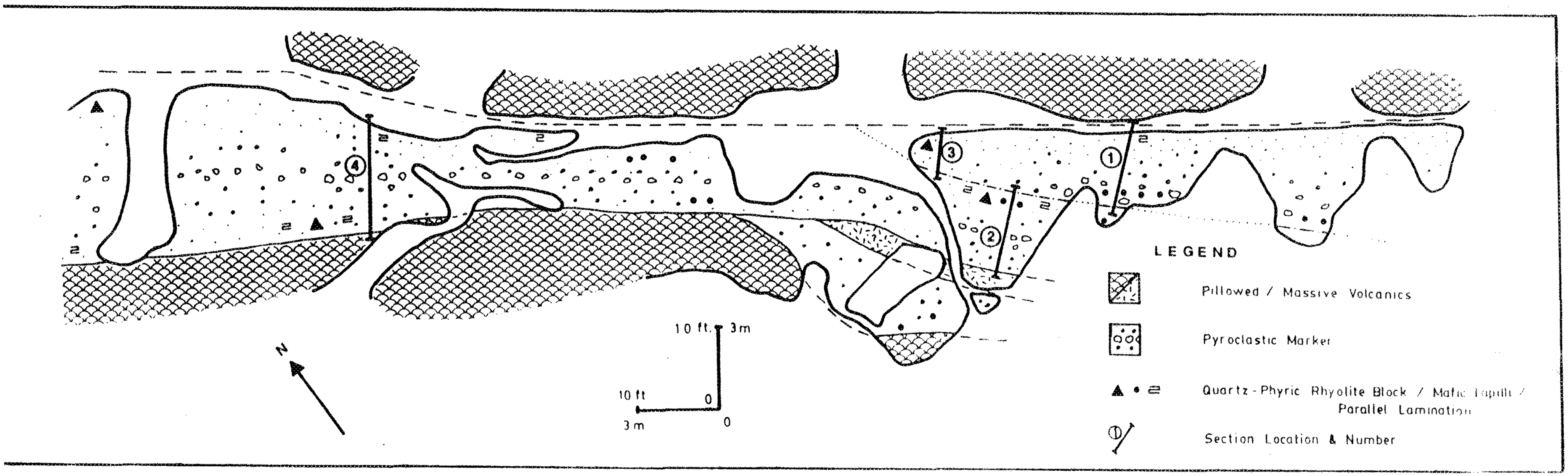


FIGURE 8

Plan Map of Proximal Lower Marker Horizon intermediate to mafic lithic rip-ups occur near the stratigraphic top or bottom of the bed; they strongly resemble the underlying Powell Andesite, and represent entrained andesitic rubble. A very small quantity of sparsely quartz phyric rhyolite blocks are present in the Marker Horizon in the eastern part of Fault Block 3.

Facies of Lower Marker Horizon-Fault Block 3

The most proximal facies of Lower Marker Horizon is exposed in Fault Block 3 (sector D-4), adjacent to the western Quemont Feeder Dyke. Here, the Marker consists of three superposed inverse to normally graded, stratified beds, each about 3m thick (Fig. 8), intercalated within pillowed Powell Andesite. Only the middle bed is continuous along strike: the other two may have had components of flow more normal to the plane of the section presently exposed by erosion and are subsequently viewed as "channels".

The bottom-most bed is poorly exposed and affords no representative sections. The topmost bed, however, furnished two sections about 6m apart (sections 1 and 3 in Figs. 8 & 9). Clast size diminishes rapidly where the bed pinches out and all clasts, except one, are less then 5mm in size. The top part of the graded division of section 1 is crudely parallel laminated; the finer clasts encountered in section 3 are poorly graded and unstratified.

The difference in primary structure sequences between sections 1 and 3 is directly related to the relative sites of deposition of material from a single turbidity current. The lower graded division (Bouma A) and overlying stratified division (Bouma B) of section 1 are the result of deposition from a higher flow regime compared to the finer Bouma A of section 3. Section 3 represents deposition at the slower margins of the flow whereas section 1 is located closer to the faster centre of the current.

Scouring and channeling of consolidated rock by turbidity currents has not yet been demonstrated. The effects of one low density current on an indurated substrate are limited to the entrainment of loose débris. The lower bed in this sequence of the Marker Horizon probably occupies a pre-existing topographic low within pillowed andesite. The continuous middle bed represents flow more directly perpendicular to the depression; it was able to surmount the eastern lip and bevel the overlapping portion of the lower bed. The uppermost bed was deposited from a flow roughly parallel to the axis of the topographic low, during a later surge of the flow event.

Downstream facies changes in the middle bed of the Lower Marker Horizon are shown schematically in sections 2, 4, 5, 6, 7, 8, 9 and 10 of Figures 9 and 10. Primary structure sequences range from inverse to normally graded/stratified through graded/stratified to stratified. This corresponds to the sequence: inversely graded-Bouma A/B-Bouma B.

Clast size versus distance along strike is shown in Figure 10. Within the first 85m of exposure clast size increases within the inverse to normally graded/stratified

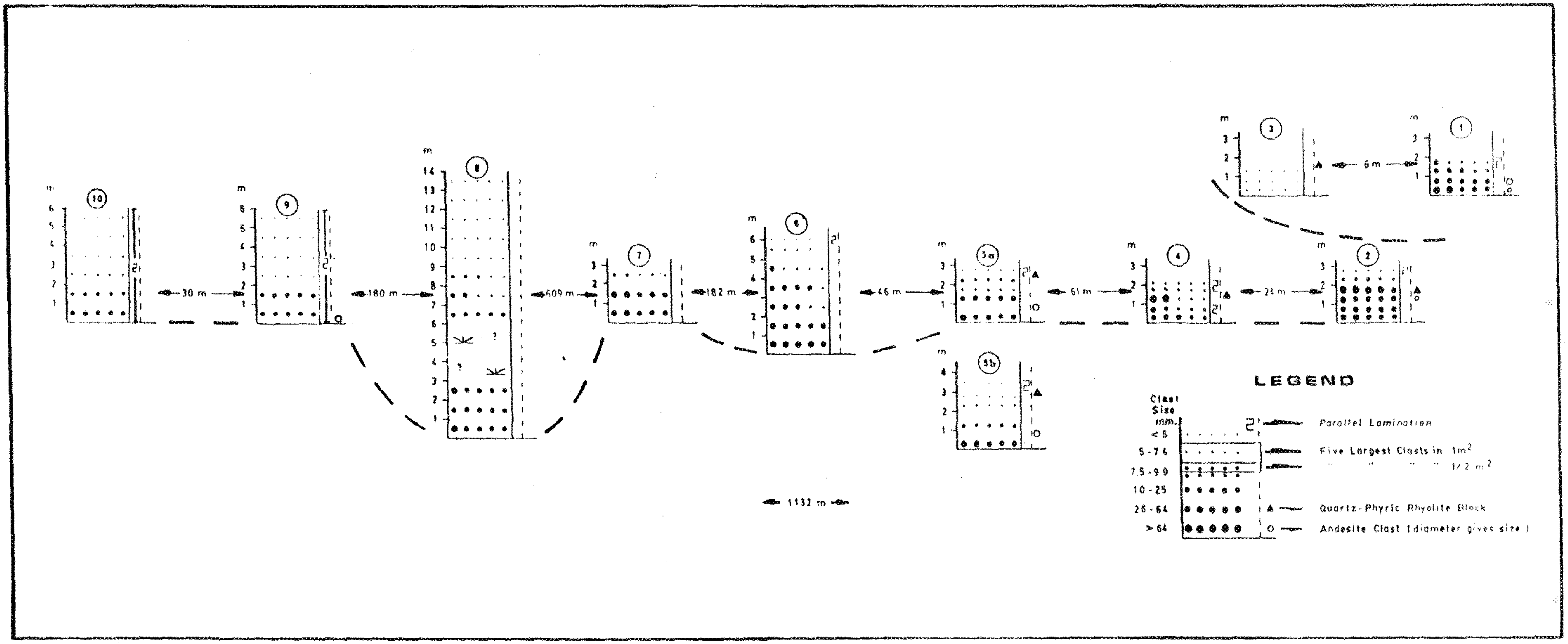


FIGURE 9

Schematic Sections along Lower Marker Horizon

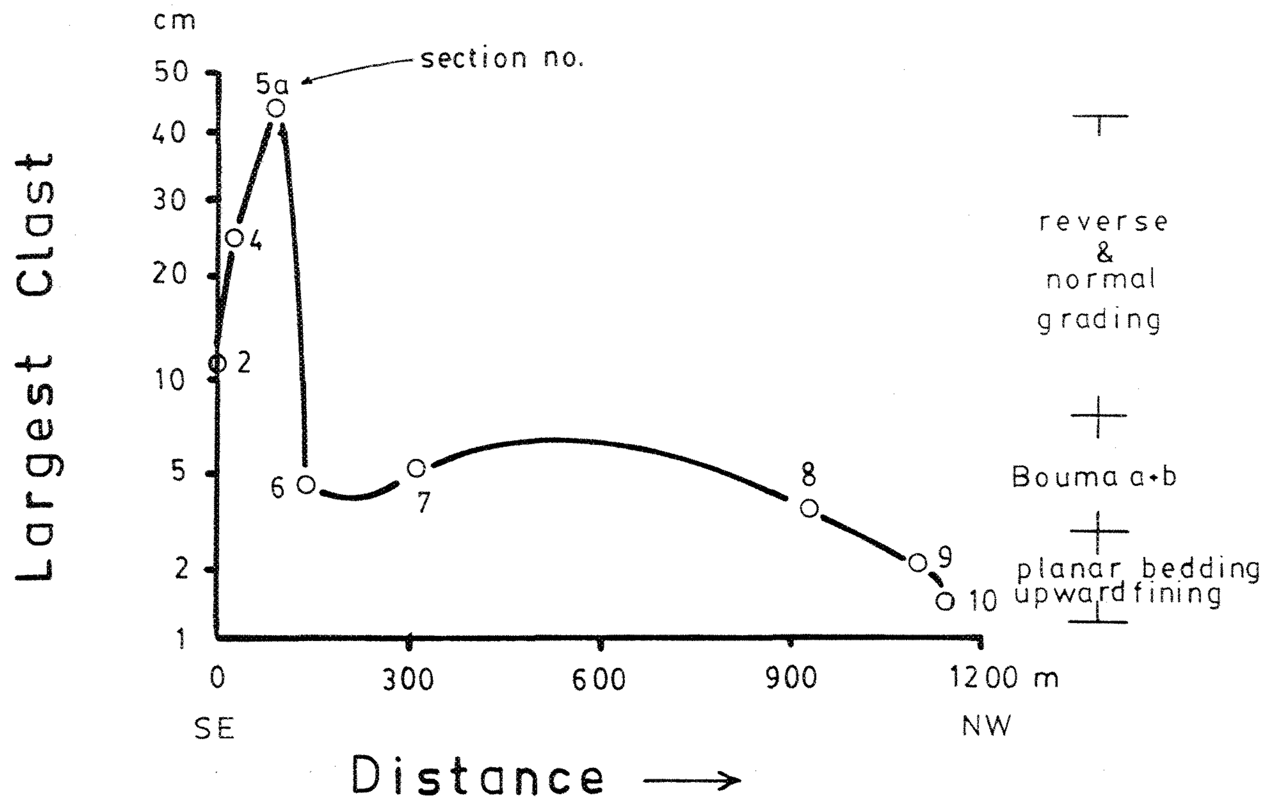


FIGURE 10 TEXTURE SEQUENCES

Distance from most proximal outcrop of Lower Marker Horizon.

bed (sections 2, 4, 5 in Figs. 9 & 10). As the primary texture sequence changes to graded/stratified clast size rapidly decreases (compare sections 5 & 6, Fig. 10, which are only 46m apart). The more distal sections comprise an increasingly planar stratified bed. Clasts within individual laminae are of uniform size, but clast size decreases upwards.

Interpretation of Vertical and Lateral Variations

Lateral structure sequences mimic vertical sequences in the middle bed of the Lower Marker Horizon. Coarse, inversely to normally graded material predominates at the base of the bed and proximally. Parallel stratification develops and eventually prodominates downstream (ie. NW) and at the top of the bed.

Coarse, chaotic to inversely graded deposits are products of dense, high viscosity débris flows in which flow was laminar (DOTT, 1963; SCHMINKE, 1967; FISHER, 1971; BLATT, MIDDLETON and MURRAY, 1972). This is in contrast to the finer, normally graded/stratified deposits of dilute turbidity currents. Upon decrease in velocity laminar flows "freeze" in place: the grains do not settle one by one, but are deposited in a bulk manner. An increase in velocity, perhaps brought on by an increase in slope, may disrupt laminar flow and a turbidity current develops. Alternately, turbidity currents may form at the top and sides of laminar flows (DOTT, 1963; FISHER, 1971). If a turbidity current then overides a "frozen", inversely graded débris flow and deposits a normally graded bed, a two-step graded unit is formed: inversely graded at the base overlain by normally graded suspension drop (Bouma A) and associated traction deposits (Bouma B & C) typical of turbidites.

The middle bed of Lower Marker Horizon is interpreted to have formed during a single episode of débris flow evolving into turbidity current. Laminar flow dominated proximally, was overidden by, and evolved downstream into turbid flow. Deposits of each type of flow regime were set down along a strike length of 1130m.

Vertical primary structure sequences of subaqueous pyroclastic flow are adequately described in the literature (FISKE, 1963; FISKE & MATSUDA, 1964; NIEM, 1977). Lateral facies variations were described by YAMADA (1973) for Pleistocene deposits in Japan, and by TASSE, LAJOIE and DIMROTH (1978) for a series of pyroclastic flows north of Noranda. Lateral variation in primary structure sequences show a trend from proximal coarse, chaotic to inversely graded beds deposited by a laminar flow regime. Primary structure sequences in the Lower Marker Horizon are also consistent with such an interpretation, indicating a source region in the direction of Fault Block 1: namely, the same source vent as Quemont Breccia 1. A hypothetical sequence of events depicting the origin of the Lower Marker Horizon is shown in Figure 11.

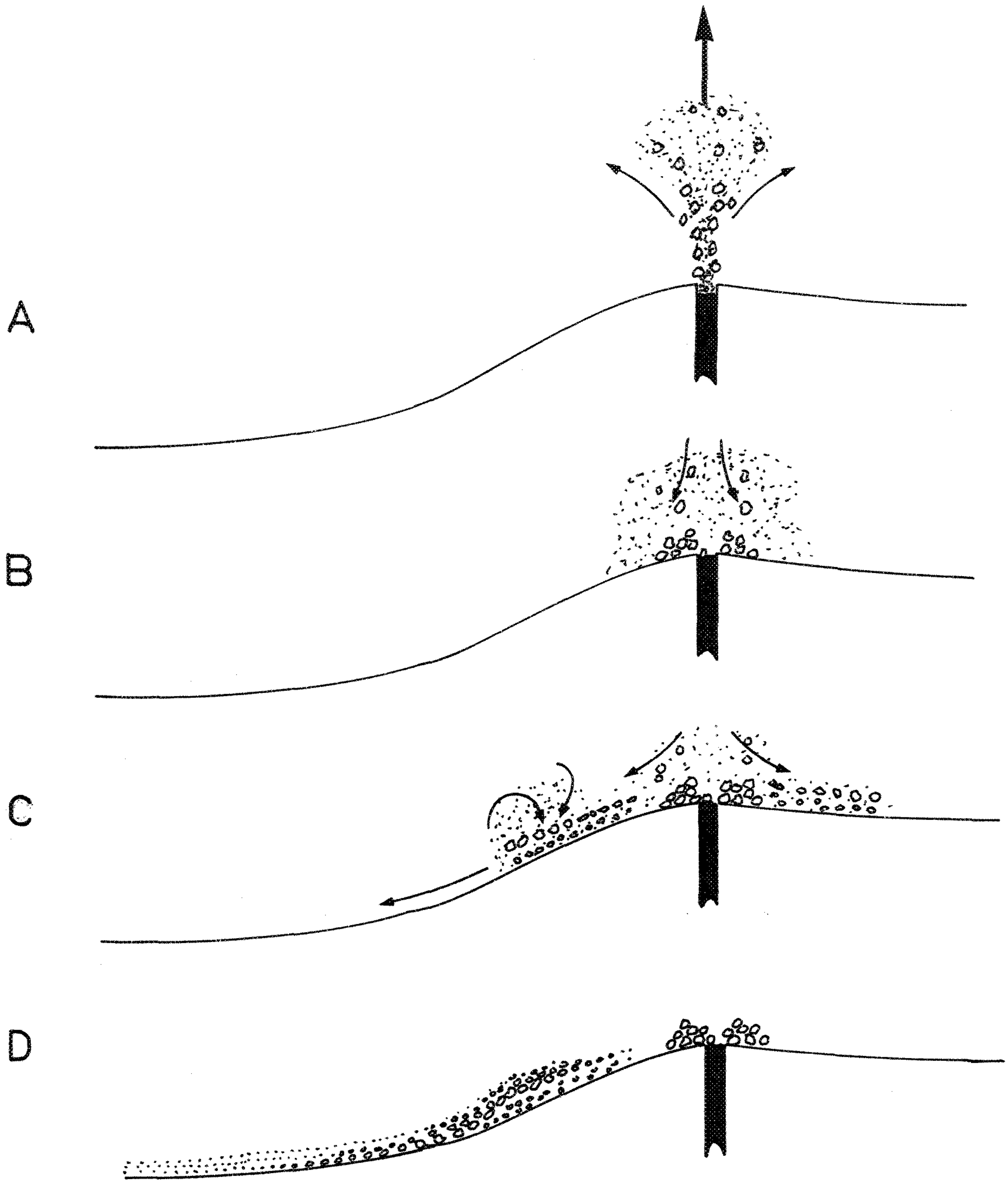


FIGURE 11 FORMATION OF LOWER MARKER HORIZON

A) Phreatic, subaqueous eruption

B) Collapsing eruption column drops dense lithics near vent (Quemont Breccia I)

C) Entrainment of finer clasts by pyroclastic flow (proximal Lower Marker deposits)

D) Distal Lower Marker deposits

Powell Formation-Rhyolitic Member

Powell Rhyolite can be traced 700m along strike. A few tens of metres thick above its feeder dyke system in the southeast (Sector D-5), it attains a maximum thickness of 140m in Fault Block 4 (Fig. 12) and disappears north of the Anglo-Rouyn Mine road (Sector B-4).

Powell Rhyolite is a hard, white weathering, coarsely quartz phyric, massive and brecciated rhyolite. Quartz phenocrysts are typically 2-4mm in longest dimension, with about 4 crystals/cm^2. Feldspar crystals are rarely seen in hand samples due to saussuritization.

Where exposed, the lower contact of Powell Rhyolite is exclusively with parallel laminated coarse to fine ash tuff, typically about 1m thick. The tuff itself always overlies Powell Andesite. The upper contact of Powell Rhyolite is always with various facies of Powell Tuff (discussed below).

Powell Rhyolite can be subdivided into massive and brecciated phases. The latter is structureless except for decimetre-scale changes in quartz phenocryst concentration. This feature may represent minor segregation along flow laminae. Blocks, large lapilli and coarse ash comprise the brecciated phase. Clasts and matrix strongly resemble each other (Plate 12).

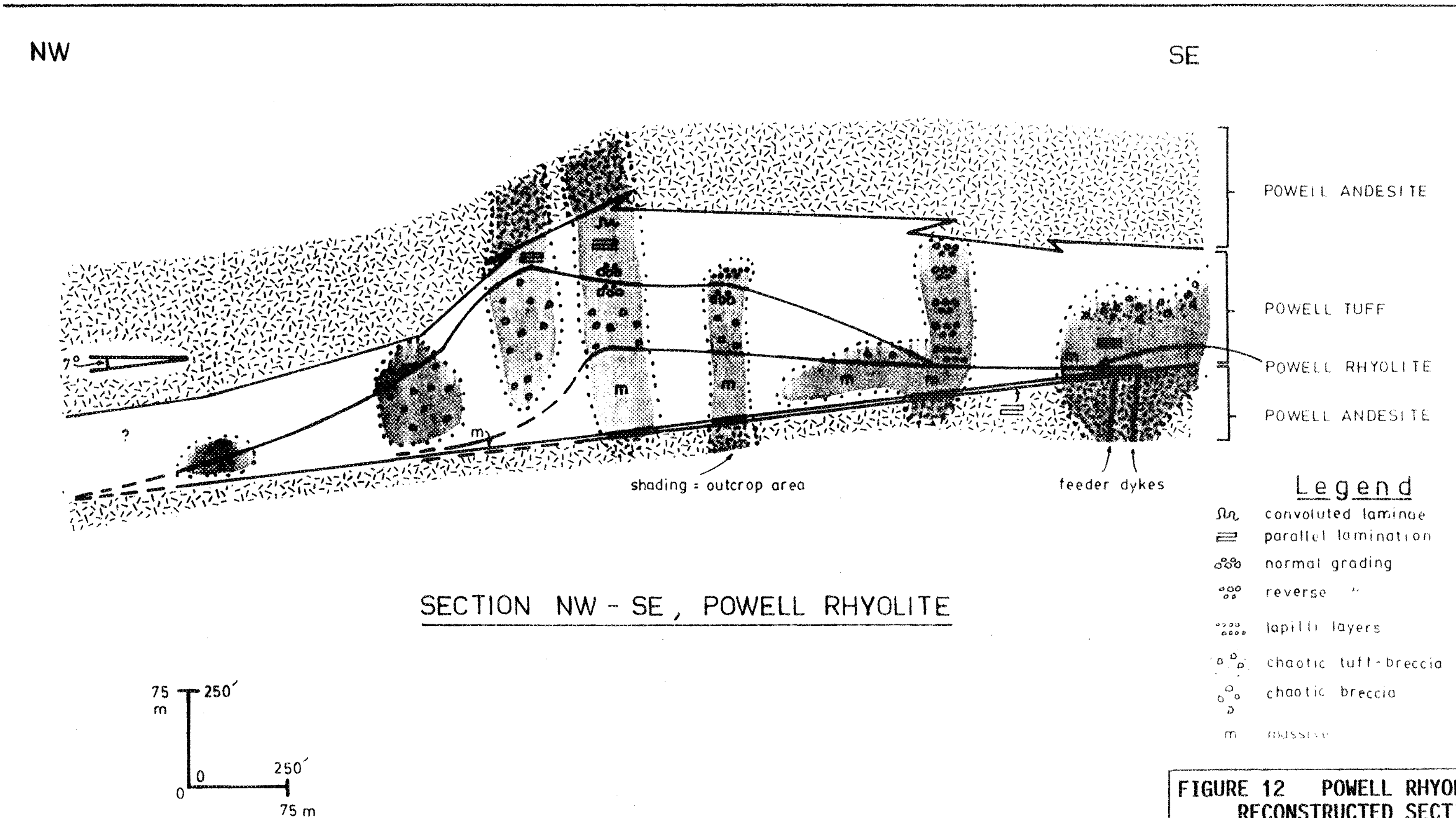


FIGURE 12 POWELL RHYOLITE RECONSTRUCTED SECTION

The Rhyolite is over and underlain by Powell Tuff. Assumed angle of repose of 7° with respect to Lower Marker Horizon

Fragments are recognised on outcrop by their silicified rims. The breccia is monomict in Powell Rhyolite clasts and has an open framework.

Massive Powell Rhyolite was fed by two 1-2m thick coarsely quartz phyric rhyolite feeder dykes (Sector D-5 and Fig. 12). The feeders cut across the immediately underlying thin tuff unit and Powell Andesite. No Powell Rhyolite exists SE of the feeders: lava flowed NW into the basinal depression.

Massive Powell Rhyolite has a rather steep flow front of close to 45° (in the plane of the section exposed by erosion) and a strike length of 525m. It attains its maximum thickness of 60m about 400m from the feeders (Sector D-3).

Origin of Massive Powell Rhyolite

Massive Powell Rhyolite is manifestly a short stubby rhyolite flow, fed from at least two known feeders. The thin ash tuff unit underlying the flow is a product of the commencement of pyroclastic activity which continued well after the emplacement of the flow (and formed the Powell Tuff member). The tuffs are considered consanginous with Powell Rhyolite (discussed further below).

Facies of Powell Rhyolite Breccia (Facies 3 & 4)

The breccia phase of Powell Rhyolite is dividedinto an underlying chaotic breccia (Plate 13) and an overlying facies comprising normally graded breccia beds. The graded beds always occur in the uppermost part of the breccia. Individual graded beds are from 1 to 5m thick, at times show erosional lower contacts leading to amalgamation of beds and grade from large blocks and large lapilli at the base to small lapilli at the top. Other textures were not observed. In thin section relict coarse ash sized fragments are recognised in a well sorted close-packed framework comprising the matrix seen in hand sample.

Absence of lava lobes and in-situ brecciation and the presence of an open framework are features not commonly found in rhyolite flow breccias.

Origin of Powell Rhyolite Breccia

Rhyolite breccias are commonly associated with the development of subaerial (WILLIAMS,1929, 1932) and subaqueous (PICHLER, 1965) rhyolite edifices. Surfaces of domes and short flows are covered with large blocks broken-off from the solid crust of still moving lava or fractured by

PLATE 13 POWELL RHYOLITE BRECCIA
Chaotic phase. Looking towards top.

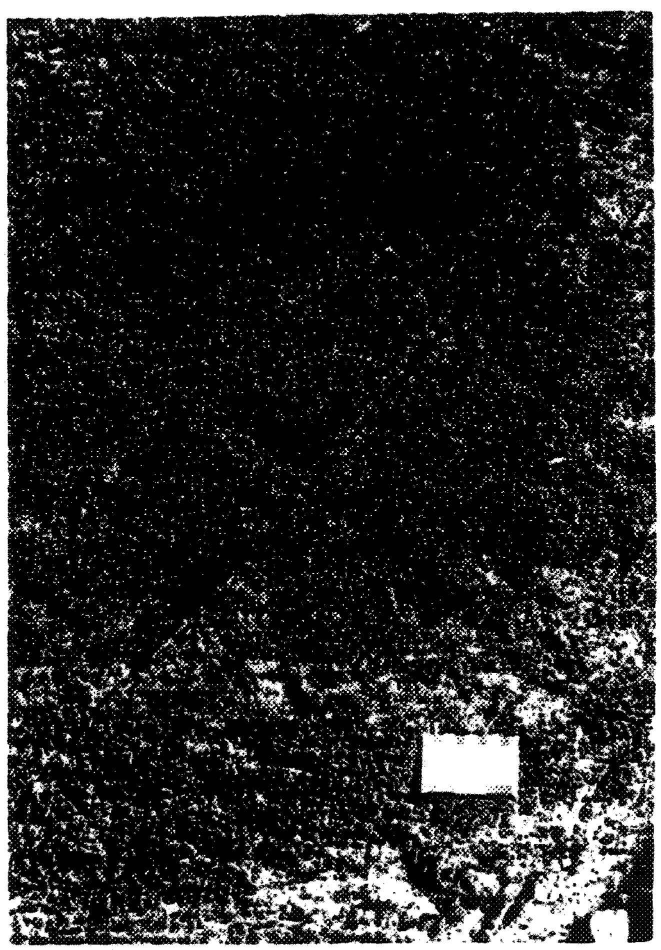


PLATE 14 POWELL TUFF

Upward coarsening unit of Facies 5. Note laminae are one lapilli diameter thick. Lapilli increase in size upwards. One complete upward coarsening unit and parts of over- and underlying units are shown. Section 4B, Unit 3.

sudden chilling or steam explosions. These blocks typically form talus banks surrounding growing domes.

The massive phase of Powell Rhyolite is a subaqueous rhyolite flow, ultimately over and underlain by pillowed andesites. Overlying chaotic breccia may be a type of flow top breccia, a subaqueous analog of WILLIAMS' (1929) talus or DIMROTH's (1977) friction breccia. Certainly the fragments were exclusively derived from massive Powell Rhyolite and form a mappable unit above the flow. But its open framework, the total absence of breccia at the base of the flow and its upward transition into normally graded beds puts the flow breccia interpretation into question. Rather, the chaotic breccia facies resembles deposits similar to those attributed to deposition by subaqueous debris flows; the graded beds were deposited in similar fashion to the Bouma A beds of turbidites. The facies sequence, chaotic to graded, implies a change in depositional mode from debris to turbidity current flow.

Chaotic breccia facies changing to graded facies is similar in aspect to matrix supported pebbly mudstones and sandstones such as the Squantum tillite, which is overlain by crudely graded pebble units (DOTT, 1963). Debris flow regimes (subaerial and subaqueous) lie at the limit between plastic and viscous fluid flow (DOTT, 1963) and define a type of mass flow in which movement is, at least in part, laminar (ENOS, 1977). Some of the consequences of laminar flow in subsequent deposits are a lack of internal stratification and poor sorting (BLATT, MIDDLETON and MURRAY, 1972), presence of large clasts in a matrix supported framework (DOTT, 1963; WALKER, 1976) and a downstream transition into turbidite deposits (HAMPTON, 1972).

WALKER (1976) ascribed chaotic, matrix supported pebbly sandstones and conglomerates as typical of inner submarine fan or slope to basin type regimes, characterized by rather steep slopes conducive to the initiation of slumps and debris flows. Resedimented carbonate breccia beds in shelf sediments of lower Cambrian age in the Northwest Territories, Canada, ideally show a lower disorganized interval and an upper turbidite interval (KRAUSE and OLDERSHAW, 1979); the disorganized, frequently matrix supported beds were deposited by debris flows initiated by slumping. The upper beds were deposited by turbidites that developed on top of the moving debris flow (this phenomenon was also observed in flume studies by HAMPTON, 1972).

The collapse of a rhyolite dome or spine in a subaqueous environment could have produced the observed rhyolite breccia facies. A lower chaotic, matrix supported debris flow facies was overridden by turbidity currents and was capped by their resultant Bouma A (normally graded) facies. Several surges of turbidites are indicated by the presence of amalgamated beds. Initiation of spine or dome collapse may have been cause by earth tremors of explosions at the vent. Oversteepening of a debris pile may also have led to mass flows.

Powell Formation-Tuff Member

Tuffs, lapilli-tuffs and tuff-breccias occur in close association with the Powell Rhyolite member: a metre of fine, parallel laminated tuff occurs directly beneath the massive flow and the upper contact of Powell Rhyolite (graded facies) is always with Powell Tuff. The lateral extent of the tuff member is limited by the inderlying rhyolite in that the tuff is not seen to extend further along strike than the rhyolite itself. Except where the tuff is directly overlain by aphyric Héré Rhyolite, clasts are consistently coarsely quartz phyric Powell Rhyolite.

Four facies are distinguished within Powell Tuff: lapilli and coarse ash-tuff, reworked lapilli and coarse ash-tuff, ash-tuff and coarse grained turbidites.

Powell Tuff-Lapilli and Coarse Ash-Tuff Facies (Facies 5)

Fragments within these tuffs are generally quite coarse grained (lapilli size) and consist uniquely of Powell Rhyolite. Minor large blocks of Powell Rhyolite are also encountered. Shapes of lapilli and coarse ash fragments have been deformed by the development of a regional NE trending schistosity, but original angular to subrounded shapes are still recognisable.

Parallel stratification predominates and some units show decimeter thick upward coarsening cycles (Section 4B, Unit 3; Plate 14). Planar lapilli beds are usually one lapilli diameter thick and are discontinuous over outcrop scale (metres). Coarse ash interbeds are a few centimeters thick and are massive or parallel laminated. Individual lapilli or coarse ash beds are well sorted.

Large lapilli and blocks have a tendency to be found in clusters of 5 to 15 fragments (Plate 15). Disturbed beds in the underlying fine ash-tuff are common (Plates 16 & 17). No clasts were found which actually cut underlying beds, although draping of ash laminae over clasts is common.

Thirty to 50cm thick upward coarsening cycles were found a few metres above Powell Rhyolite (Sector D/C 3; Section 4B; Plate 14). The cycle starts with coarse ash laminae, the clasts of individual laminae gradually increasing to lapilli size at the top of the cycle. Nine cycles are represented and can be traced across the outcrop (5m). Each lamina is a distinct layer deposited during a discreet time interval. Several beds, built up in succession and increasing grain size, form a cycle. This was repeated at least nine times to form the present exposure.

The origin of the cycles remains obscure, perhaps an explanation may be found in considering them as deposits of laminar flows: each cycle was built up by deposition from thin, laminar slurries (grain-flows) sloughed-off a dĕbris cone surrounding an active vent. At least nine similar events must have occured within a short time interval to produce the present deposit.

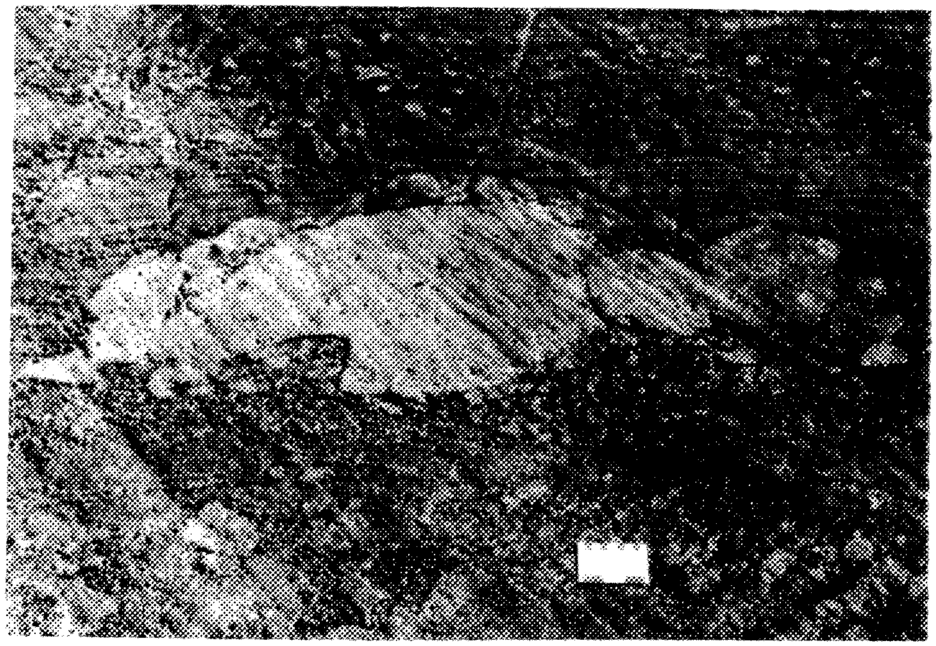


PLATE 15 POWELL RHYOLITE BLOCKS
Cluster of several Powell Rhyolite blocks (bombs) in lapilli and coarse ash tuff (Facies 5). Note equant shapes and right-angled outline of central block.

PLATE 16 ASH TUFF WITH BOMBS
Facies 7 with bomb cluster and subjacent convoluted beds. Blocks are Powell Rhyolite. Note undisturbed beds near scale-card. Section 4C, Unit 4.

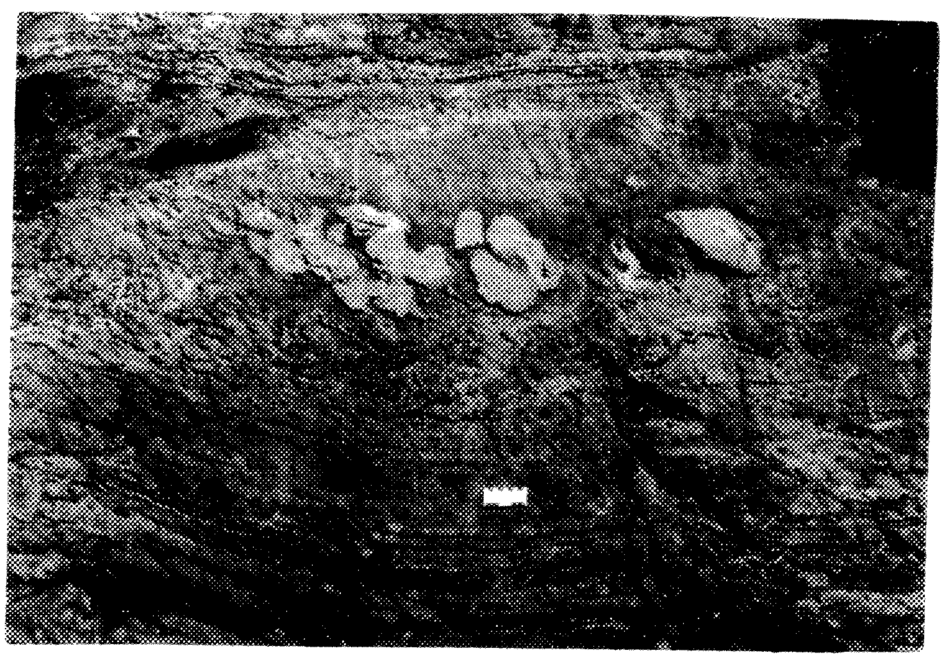


PLATE 17 POWELL RHYOLITE BLOCK AND CONVOLUTIONS
Close-up of Plate 16. Section 4C. Unit 4.

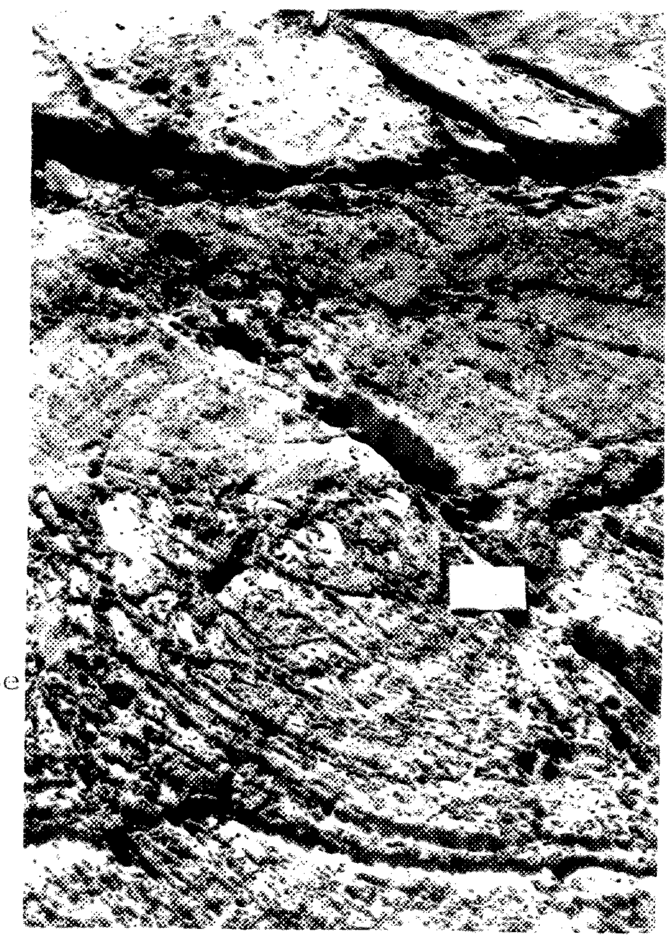


PLATE 18 BROKEN PILLOW

Broken pillow overlain by lapilli and coarse ash tuff (Facies 5). Concentric cooling cracks stand out in positive relief. Section 4E, Unit 4.

The lapilli and coarse ash-tuffs are interbedded with pillowed and massive Powell Andesite. Draping of tuff over pillows is common (Plate 4). Pillows with broken-off tops have also been observed (Plate 18). Space between pillows may be filled with tuff (Plate 19).

The presence of pillowed flows, coarseness of the clasts and the ubiquitous parallel stratification indicate that the tuffs were deposited subaqueously from settling out of lapilli to coarse ash sized pyroclastic ejecta. The monolithic character of the clasts indicates that activity was restricted to a Powell Rhyolite vent or vents. The angular, non-vesicular nature of the rhyolite fragments suggests phreatic eruptions with no, or little, magmatic component.

Powell Tuff-Reworked Lapilli and Coarse Ash-Tuff (Facies 6)

The occurrence of numerous erosional scours and cross-strata in lapilli and coarse ash-tuff define this unit.

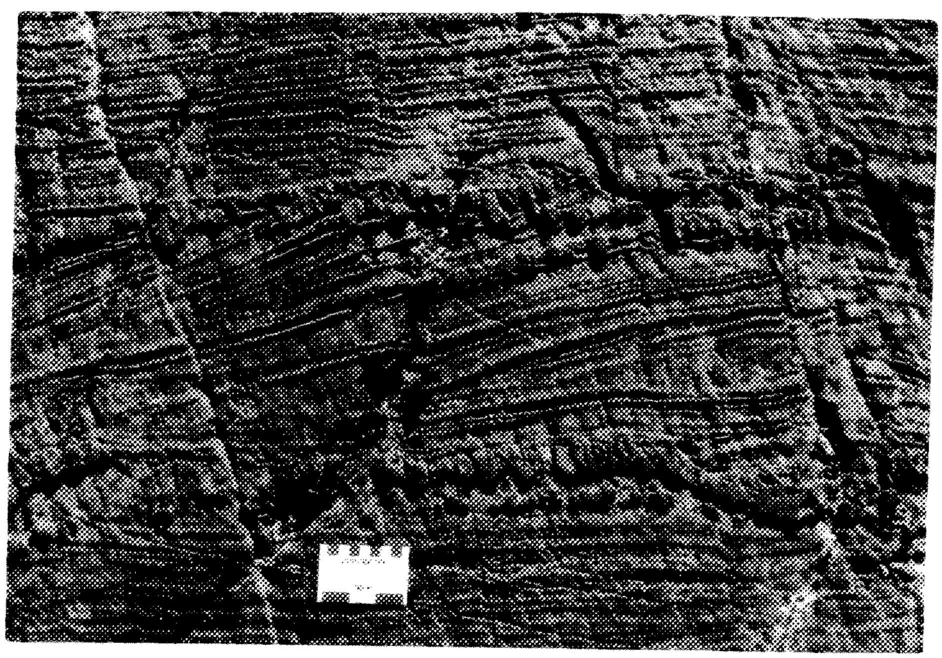
Scours are from 1cm to 100cm deep (as measured on outcrop) and are from 2cm to several metres long (Plates 20 & 21). Scours are typically filled with trough cross-beds in sets 10cm to 30cm thick. Various sizes of cross-beds may be present in one large scour, but there appears to be a general decrease in set thickeness with height in the scour (Fig. 13).

Small scours (5cm to 15cm deep) are commonly filled with dune or micro-delta bed-forms, showing excellent topset, foreset and bottomset laminae (Plates 22 to 24).

PLATE 19 TUFF SLAB

Broken slab of finely laminated ash tuff in massive tuff filling inter-pillow void. Over-lain by tuff at top of photograph. Section 4E, Unit 5.

PLATE 20 THIN SETS OF CROSS-BEDS
Lapilli are concentrated at base and top of individual laminae. Current flow from right to left. Section 4F.



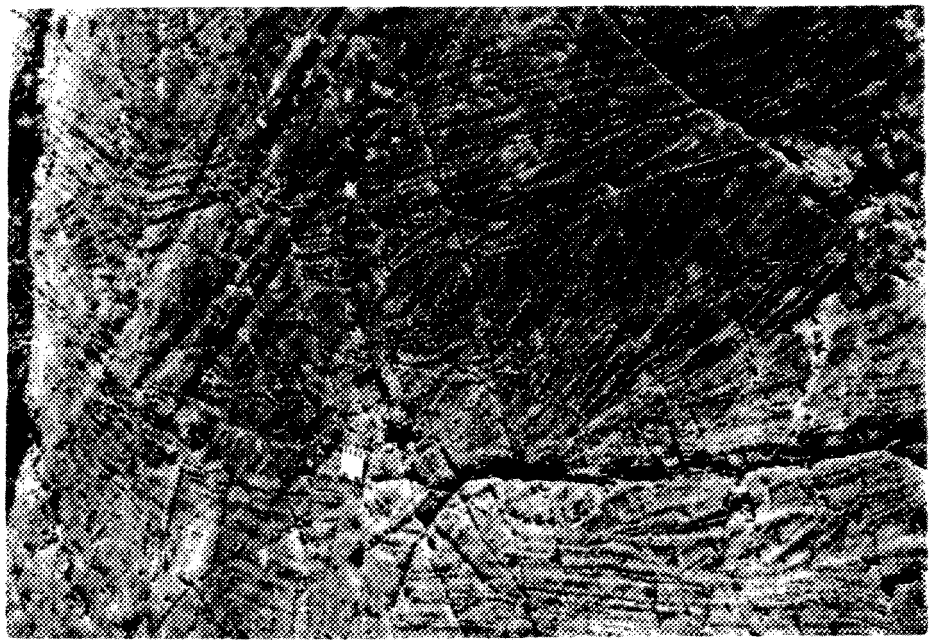
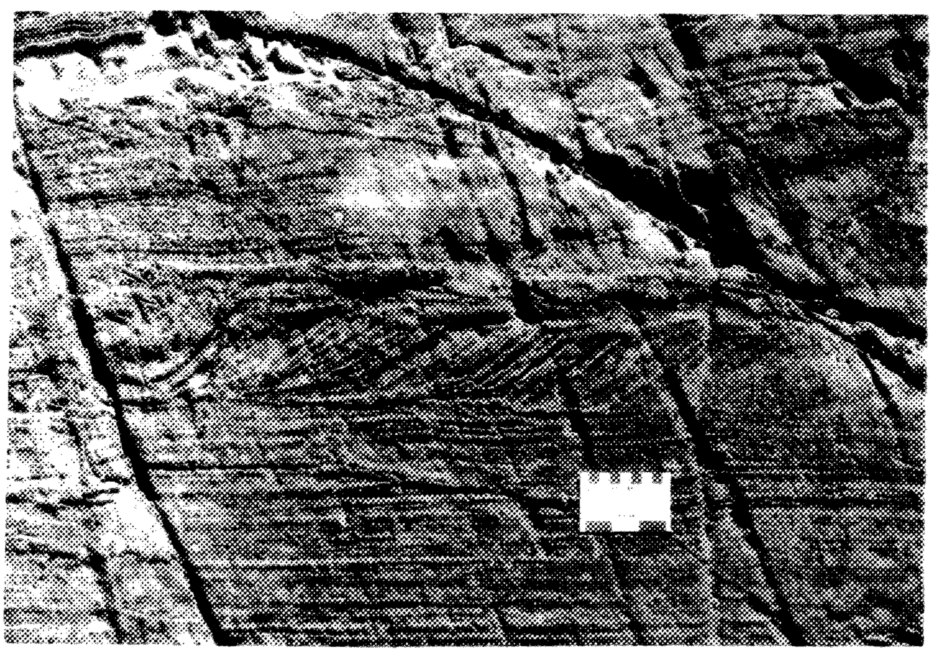


PLATE 21 TROUGH CROSS-BEDDING
Oblique view, looking downcurrent of unit (Facies 6). Over- and underlain by parallel laminated Facies 5 and 7. Section 4F, Unit 3.

PLATE 22 DUNE OR MICRO-DELTA BEDFORM
Topset, foreset and tangential bottomset laminae are well preserved. Scoured version of Facies 7.



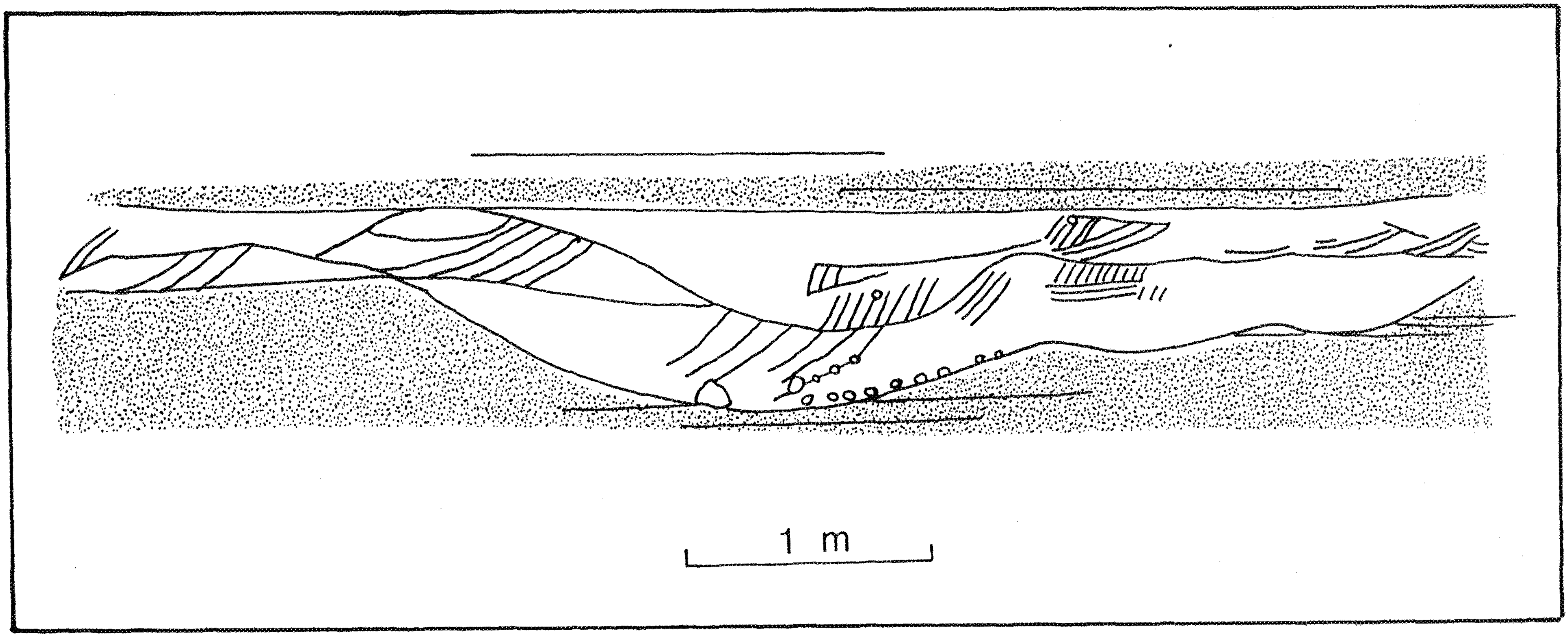


FIGURE 13 REWORKED LAPILLI AND COARSE ASH TUFF

Various sets of trough crossbeds fill a large scour. Note decrease in thickness of sets with height in scour.

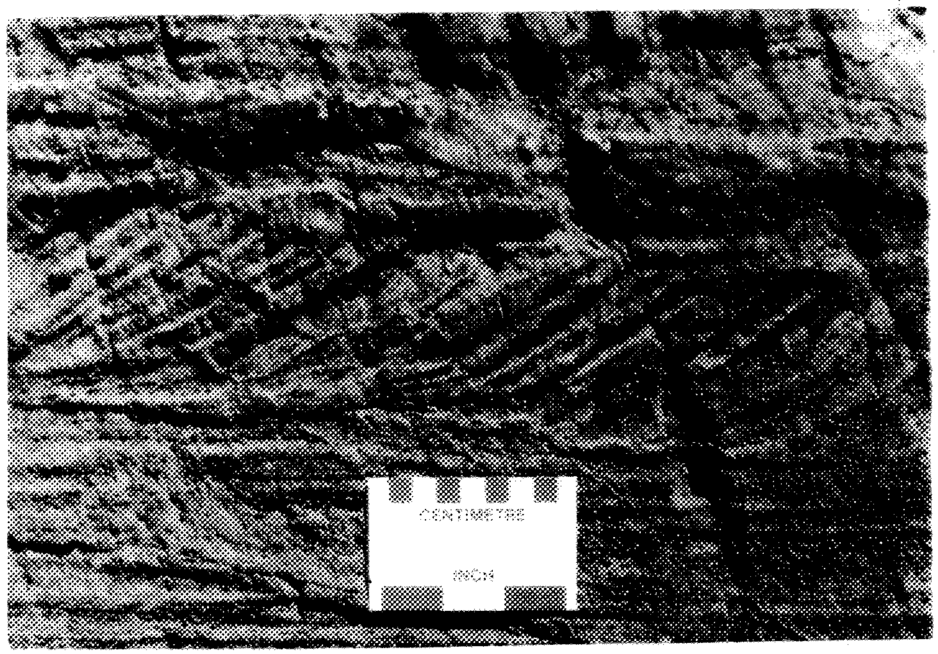
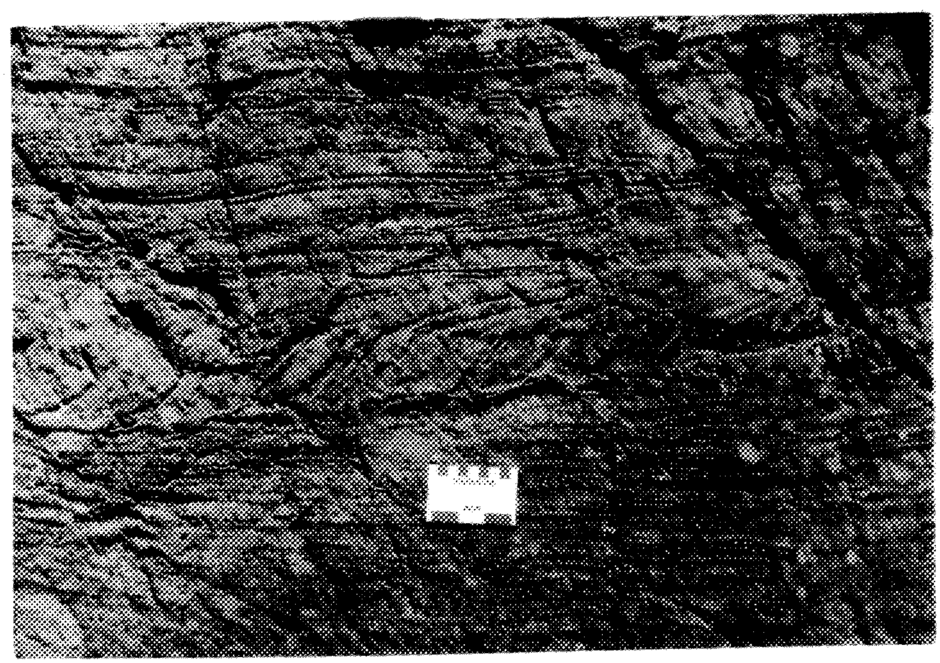


PLATE 23 DUNE OR MICRO-DELTA BEDFORM
Close-up of Plate 22, showing well preserved laminae.

PLATE 24 SCOURED PARALLEL LAMINATED TUFF
Scoured Facies 5 and 7 filled with dune or micro-delta bedform. Well preserved topset, foreset and tangential bottom-set laminae. Current flow from right to left (SE to NW). Section 4F.



Erosional scours only partially filled with dune bed forms may be completely covered with finer more massive ash (Plate 25 and Fig. 14). Conversely, a pre-existing dune-form may be truncated at the top by a superjacent, transgressive dune-form.

Lapilli laminae, occuring within finer trough cross-beds or dune bed-forms, are relatively common (Plate 26) as are large isolated blocks of Powell Rhyolite (Plate 27). Channeled lapilli lenses are up to 10m long, 10cm to 20cm thick and contain scours at the base, incised up to 10cm into the underlying beds (Plate 28; Fig. 15). They are commonly crudely graded but show no distinct parallel lamination at the top; rather, they grade into the overlying beds.

Current direction measurements on outcrop surfaces indicate unidirectional flow from the SE. All primary structures such as trough cross-beds, dune or microdelta bed-forms within this facies indicate that the component of flow exposed on outcrop surfaces was from the SE, from the direction of Fault Block 1.

The presence of a unidirectional current argues against tidal or wave influence. Rip-currents flowing perpendicularly away from shore beneath storm wave and tidal effects, may have been responsible for reworking of the pyroclastics. This implies Fault Block 1 to have been very shallow (above storm wave base) or to have been emergent for at least the length of time represented by the thickness of reworked lapilli and coarse ash-tuff.

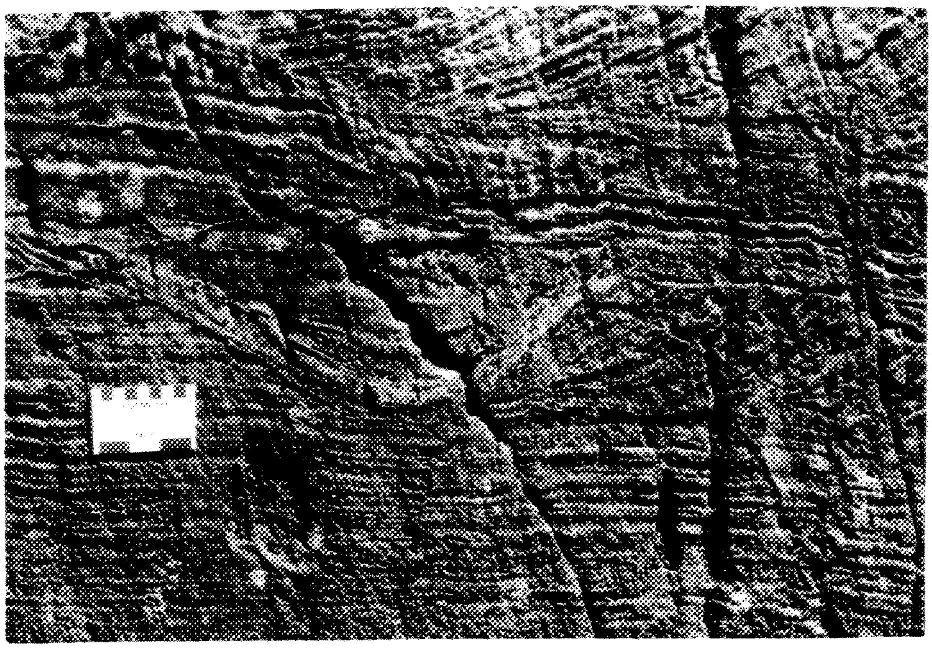
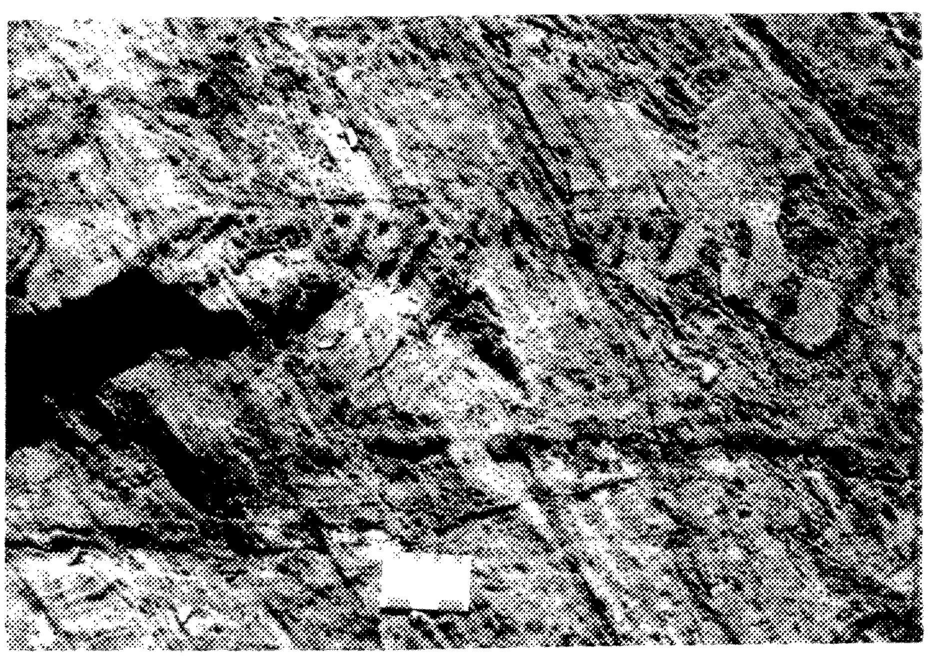


PLATE 25 DUNE BEDFORM
Dune bedform occupying an erosional scour in underlying Facies 7. Foreset and bottomset laminae and left side of scour are blanketed by massive fine grained ash. Re-activation of dune followed, filling the scour with more cross-beds. Current from right to left.

PLATE 26 TROUGH CROSS-BEDDED FACIES 6
Small lapilli are concentrated in upper part of laminae.



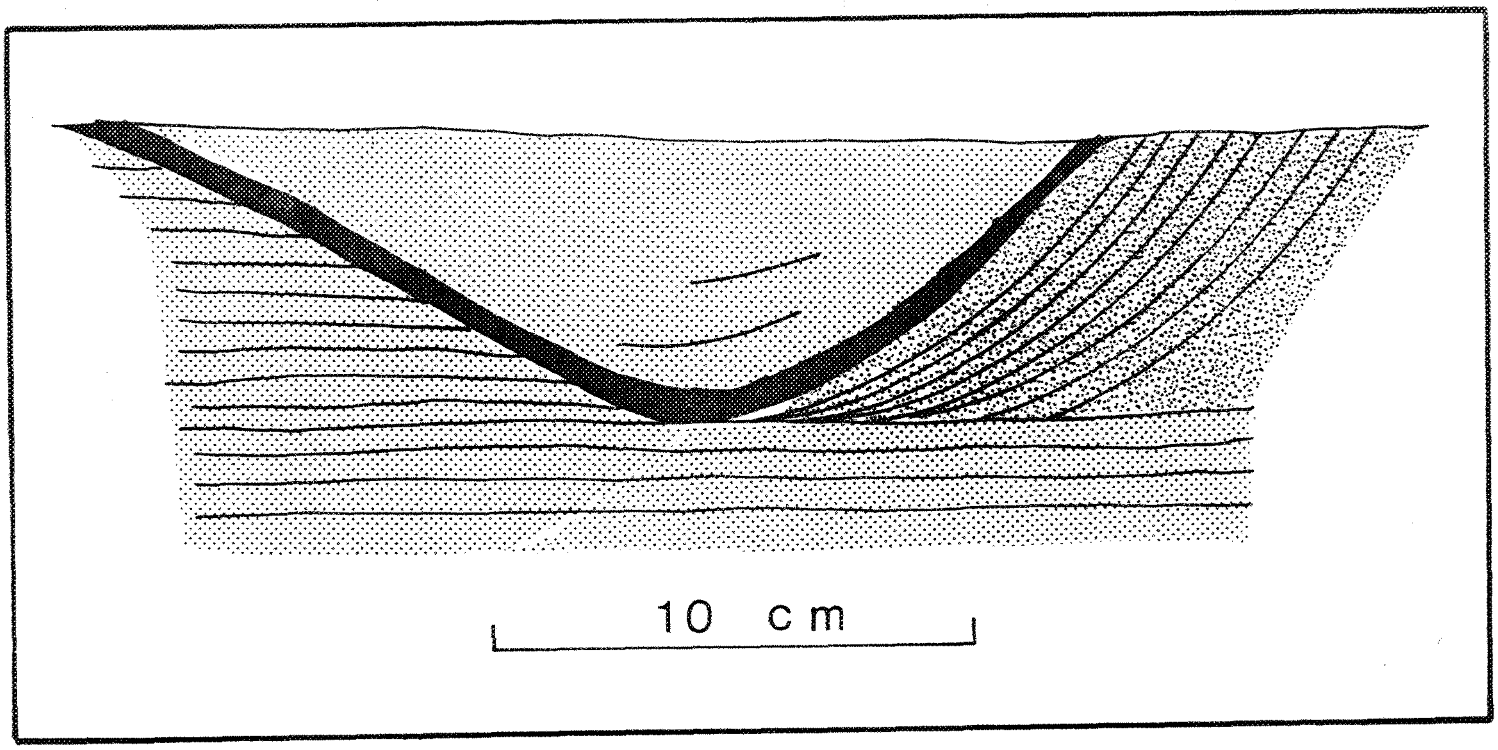


FIGURE 14 REWORKED LAPILLI AND COARSE ASH TUFF

Dune bed-form filling a scour. Solid black is fine ash layer draped over laminae and unfilled scour surface. Re-activated dune form fills scour.

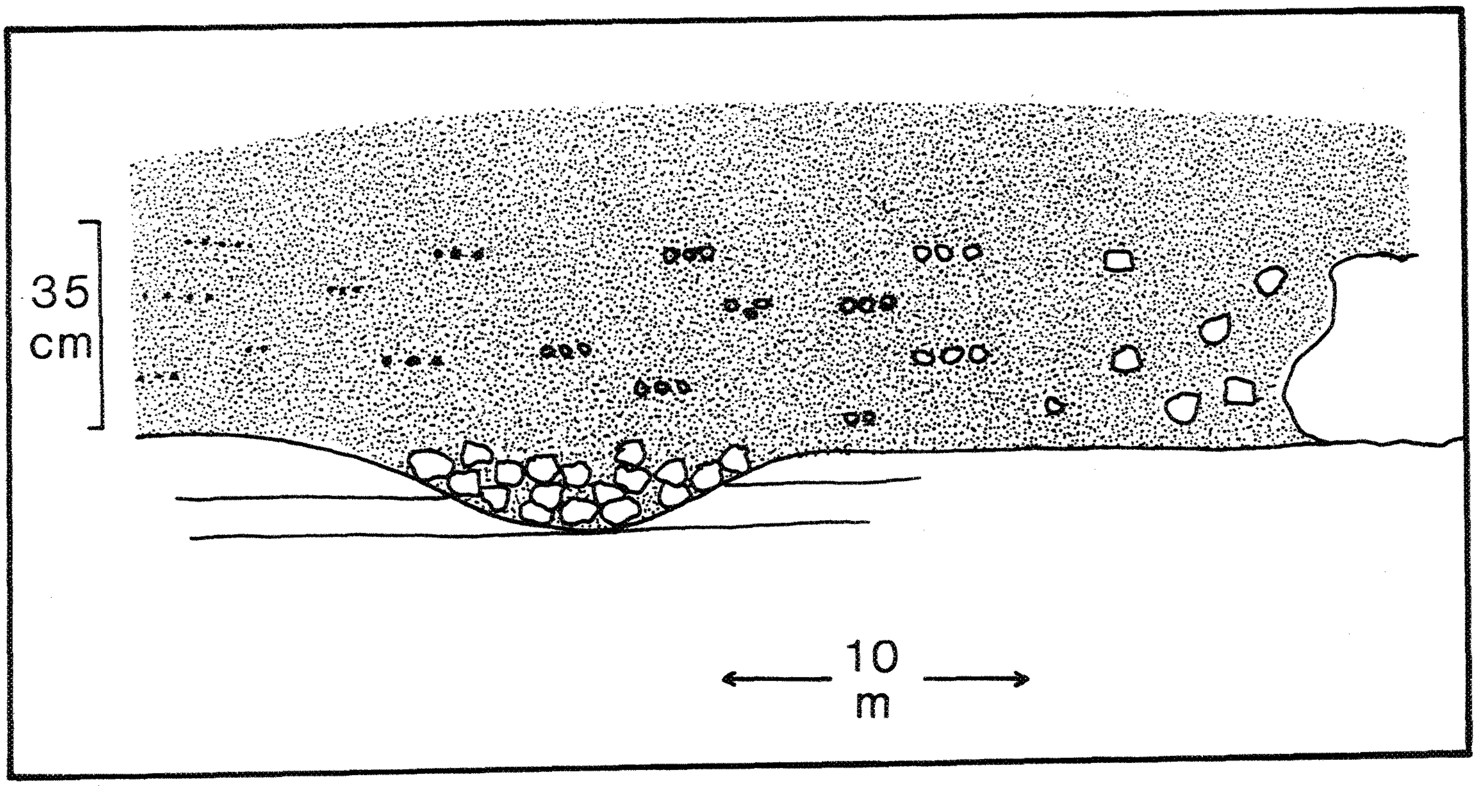


FIGURE 15 CHANNELLED LAPILLI LENSE

See also Photo 28

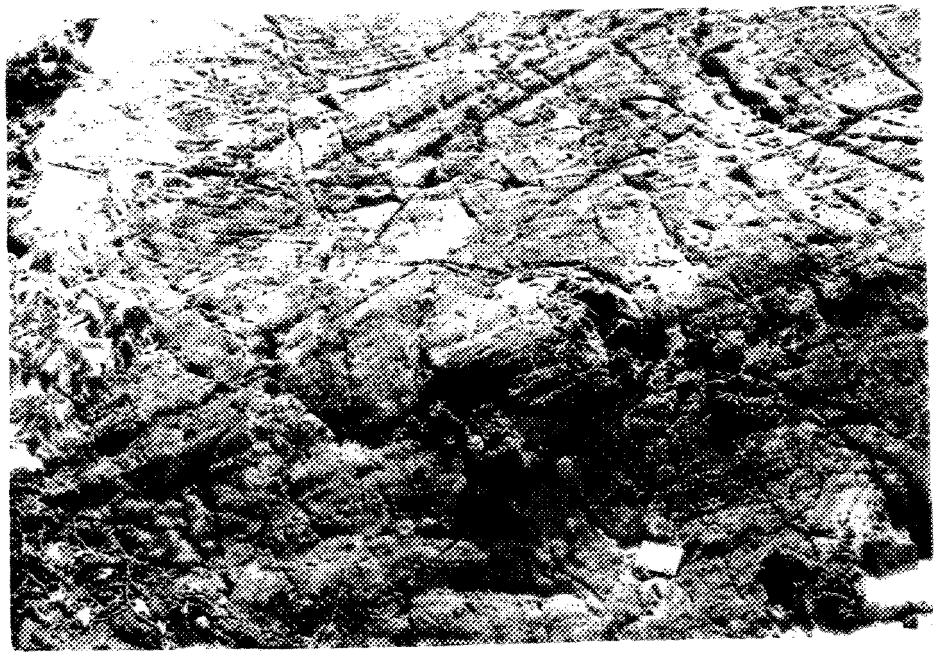
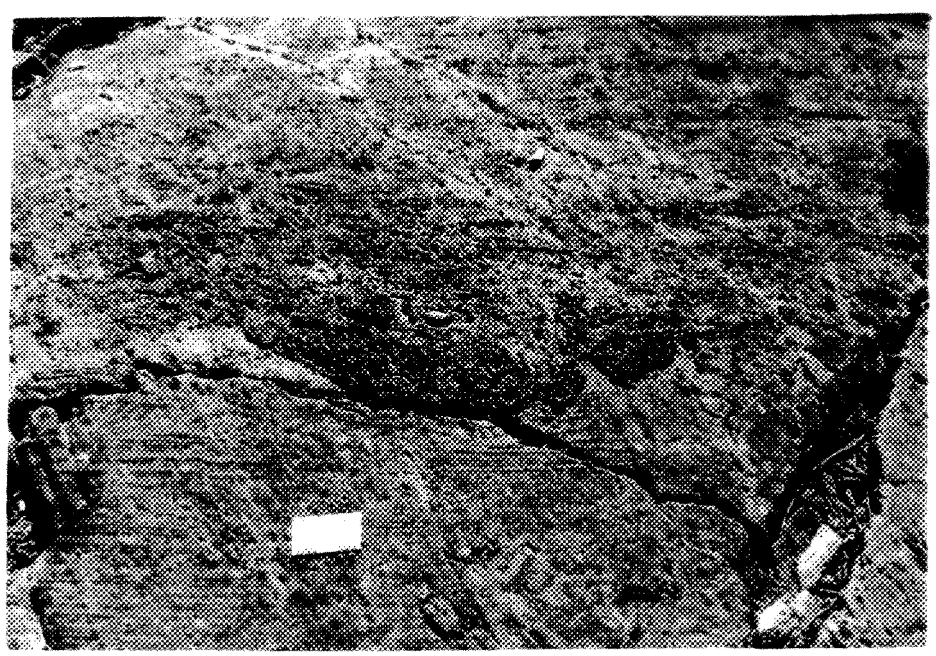


PLATE 27 POWELL RHYOLITE BLOCK
Large Powell Rhyolite block in Facies 6, reworked lapilli and coarse ash tuff. A cross-bedded unit overlies the block. Section 4F, Unit 4.

PLATE 28 CHANNELLED LAPILLI LENSE
Lense overlies thin cross-bedded unit (Facies 6) and finely laminated ash tuff (Facies 7). Crude grading is evident in the lense. Section 4E, Unit 1.



Powell Tuff-Ash-Tuff Facies (**Facies 7**)

This facies is characterised by its predominant component of thinly bedded (mm to cm) parallel laminated ash-tuff. Common to this type of tuff are soft sediment deformational structures, such as convolute bedding, which have given rise to similar facies in Japan being called "dancing tuffs" (T. URABE, personal communication, 1979).

Convolute laminae (caused by block impact) in superjacent beds (Plates 16 & 17), broken or pulled apart beds (Plate 29), pseudo-nodules (Plate 30) and loaded current ripples (Plate 31) are the most abundant synsedimentary deformation features. No graded beds were encountered; the finely laminated ash-tuffs of this facies are not associated with the Bouma turbidite series of structures (ie. graded bedding, parallel overlain by oblique bedding).

The finely laminated nature and the good sorting within laminae, the general absence of traction features (except for some small-scale scouring (Fig. 16) and small wave-length (1cm to 3 cm) ripples and the tendency for the tuffs to display typically subaqueous soft sediment deformation features, imply that the tuffs were deposited as fine pyroclastic fall-out in water (ie. in water for at least the final stages of settling). Each lamina marks a separate depositional event specific to the area it covers: laminae are lensoid and rarely extend for more than a few metres. Quite conceivably they are related to one eruption or eruptive cycle.

PLATE 29 BROKEN AND CONVOLUTED BEDS
Ash tuff of Facies 7. Separated fragments of the bed form pseudo-nodules. Section 4E, Unit 2.

PLATE 30 PSEUDO-NODULES
Close-up of pseudo-nodules of Plate 29. Overlain by parallel laminated ash tuff.

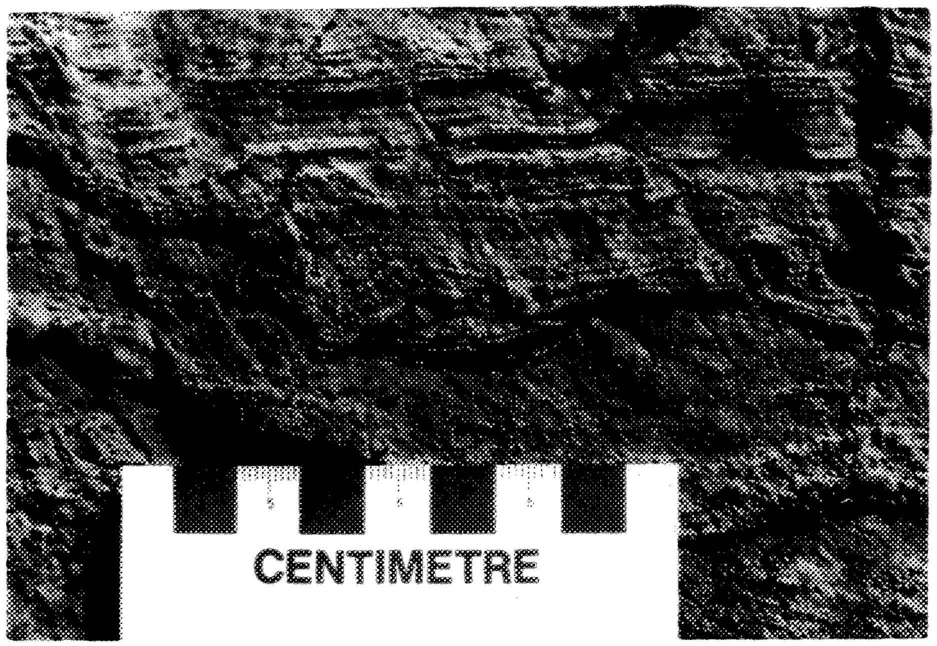
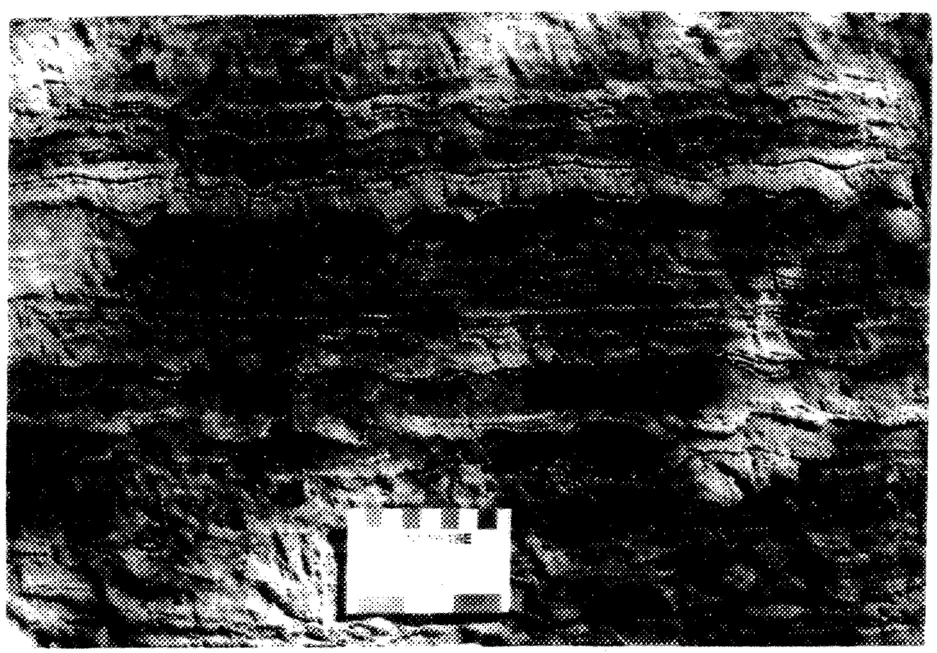


PLATE 31 SOFT SEDIMENT DEFORMATION
Loading of coarser grained rippled ash into underlying soft, muddy ash tuff. Section 4F, Unit 3.

PLATE 32 REWORKED FINE ASH TUFF
Fine ash tuff of Facies 7 reworked by thin rippled and scoured lenses. Current from right to left. Section 4G, Unit 14.



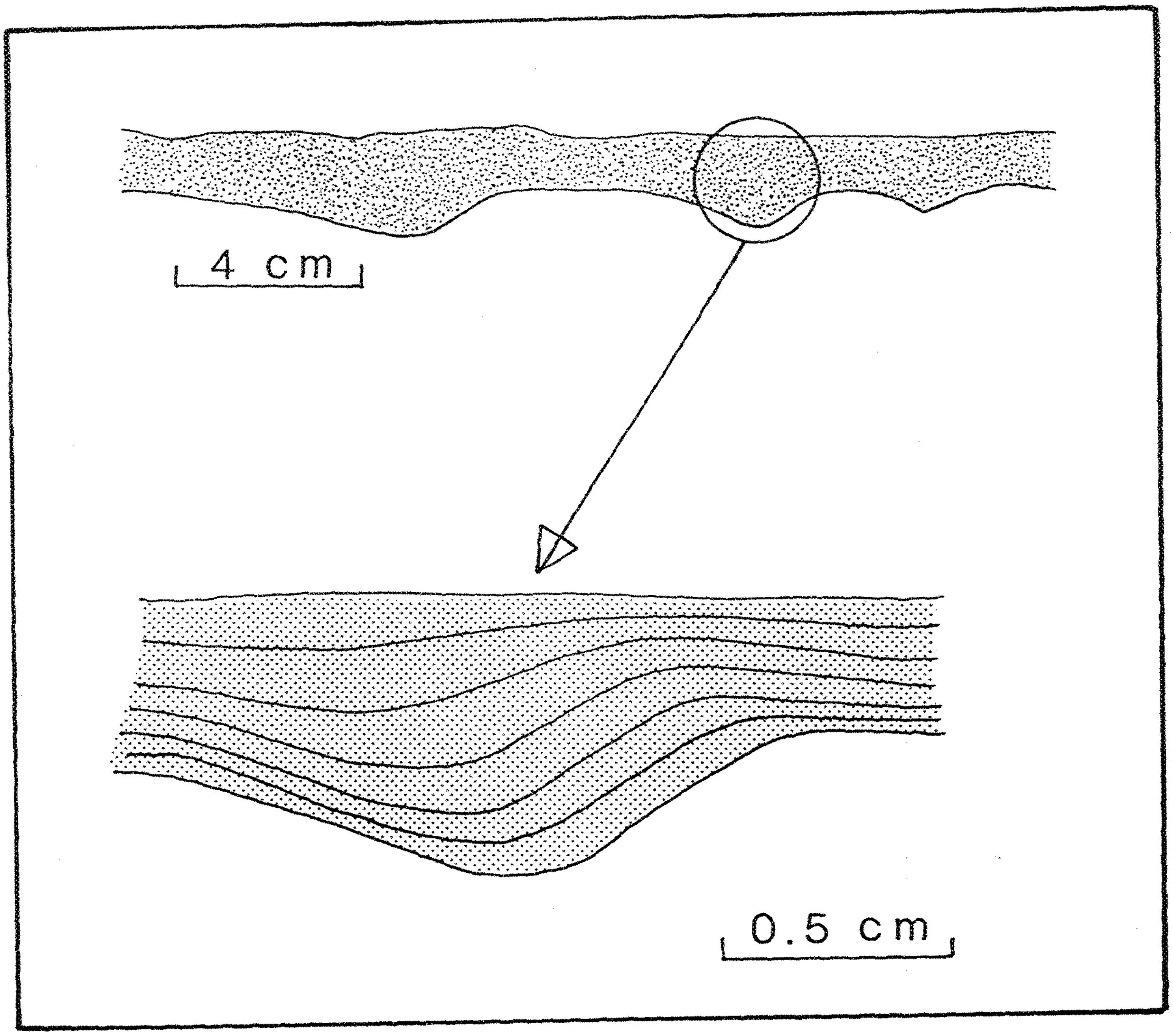


FIGURE 16

SMALL-SCALE SCOURING IN FINE ASH TUFF

Note planar top surface of bed and scoured undersurface. Current flow from right to left (SE to NW). See also Photo 32.

Small-scale ripple marks and scours, where not too deformed by sediment loading, indicate current flow from the SE (Plate 32).

In a representative section of Powell Tuff (Sections 4A,B,C-4D-4E,F-4G) coarse ash, lapilli tuffs and pyroclastic flows dominate the lower sequence; ash tuffs and reworked equivalents dominate the upper parts of the sequence. As the pyroclastics are directly related to Powell Rhyolite volcanism, this upward fining sequence indicates gradual cessation of pyroclastic activity. Overlying, lithologically bimodal turbidites (following chapter) attest to the growth of a new centre of volcanism (Héré Rhyolite).

Powell Tuff-Pyroclastic Flows

The Powell formation is overlain by massive aphyric Héré Rhyolite (see previous chapter "Héré Rhyolite"). In sectof C-4 of the map area, thin flows and flow breccias typical of Héré Rhyolite (Plate 33) overlies Powell Tuff. The upper few metres of Powell Tuff are dominated by graded beds, tens of centimetres thick, comprised of small blocks and lapilli. The upper beds contain solely aphyric rhyolite clasts, identical to Héré Rhyolite, whereas the lower beds are of mixed aphyric and coarsely quartz phyric rhyolite lithology (Plate 34).

The commencement of aphyric rhyolite activity was heralded by the emplacement of pyroclastic flows, perhaps as turbulent rubble flows at the head of advancing tongues of Héré Rhyolite. Clasts of underlying Powell Rhyolite were

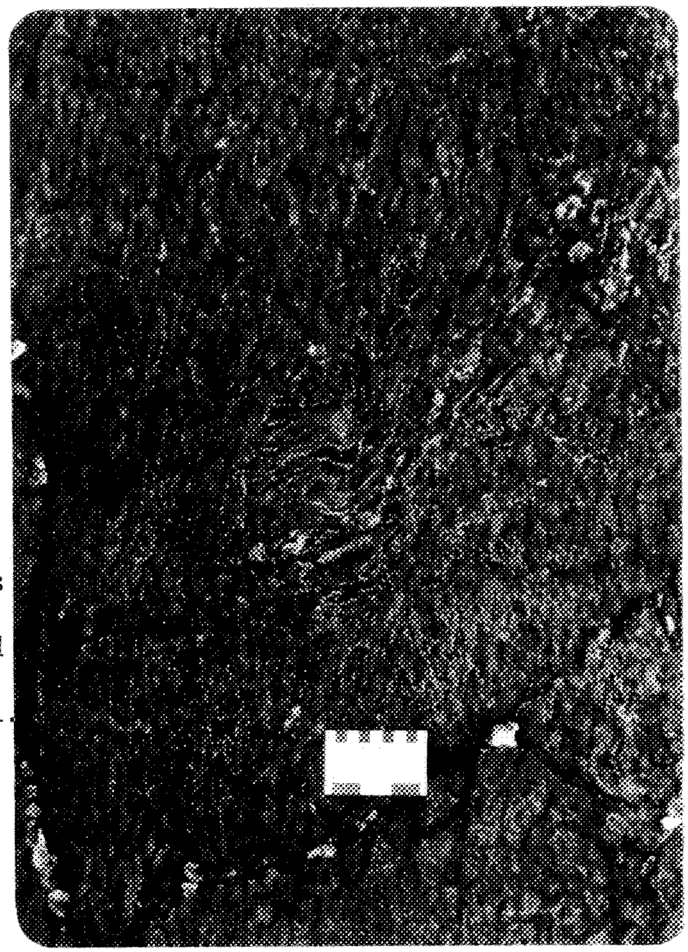
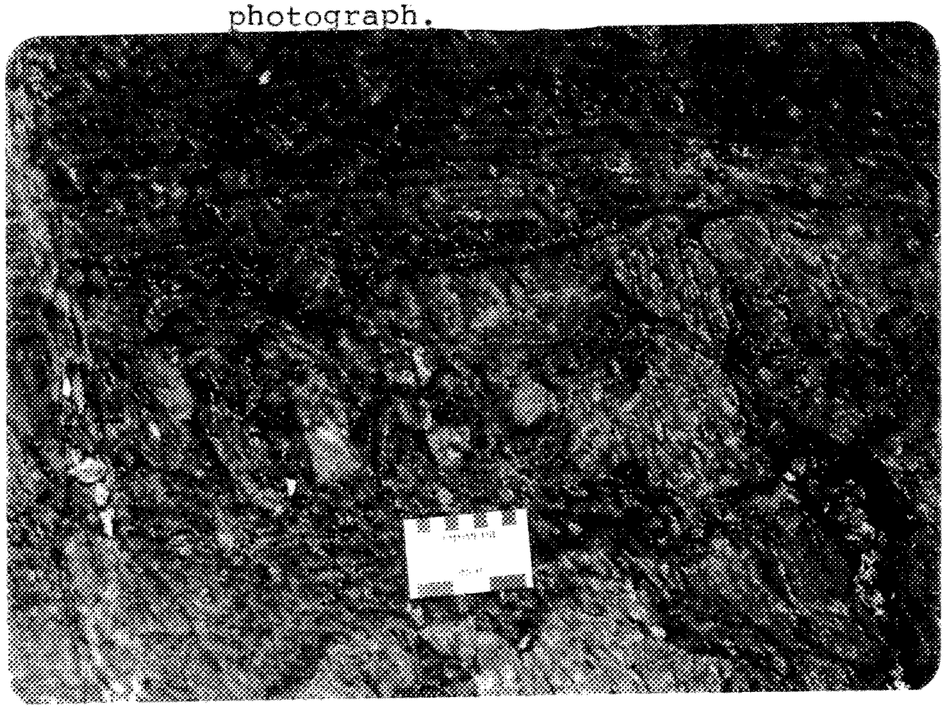


PLATE 33 HERE
RHYOLITE
FLOW BX.

Note bleached rims on some fragments and flow laminated nature of others. Section 4H, Unit 1.

PLATE 34 NORMALLY GRADED HERE BLOCK BEDS
Lapilli and small block beds of Here Rhyolite fragments. Note slight draping of finer laminae over blocks and into hollows near centre of photograph.



incorporated into the lower beds.

In a representative section of Powell Tuff (Sections 4A,B,C-4D-4E,F-4G), coarse ash, lapilli tuffs and pyroclastic flows dominate the lower sequence; ash tuffs and reworked equivalents dominate the upper parts of the sequence. The pyroclastics are directly related to Powell Rhyolite activity. Hence, the upward fining sequence indicates the gradual cessation of Powell pyroclastic volcanism in the area. Overlying,bimodal lithologic turbidites attest to the commencement of a new stage of volcanism, the Hêrê Rhyolite.

Powell Tuff-Joliet Breccia

The Joliet Breccia is an oligomict breccia composed of coarse, angular and chaotic fragments, situated within the northern edge of the northernmost Quemont Feeder Dyke (sector C-7). It has been previously described by de ROSEN-SPENCE (1976) and DIMROTH & ROCHELEAU (1979).

The Breccia consists uniquely of Quemont Dyke and Powell Andesite blocks. It is compositionally zoned from top to bottom and fills a crater 180m in diameter and 150m deep.

The base of the lower cycle, Cycle 1, is rooted in massive Quemont Dyke rock. Thin fractures (filled with quartz and/or chlorite) penetrate upwards and outwards out of the dyke and into in-situ brecciated dyke rock. This, in turn, grades upward into brecciated dyke rock in which fragments have been rotated and displaced. The uppermost part of Cycle 1 is composed of a chaotic jumble of Quemont Dyke rock (Photos 35 & 36).

A thin (0 to 2m) slab of brecciated rhyolite separates Cycles 1 and 2. In the eastern part of the exposure, where the slab of rhyolite is absent, Cycle 1 grades abruptly into overlying Cycle 2.

Cycle 2 is composed of a chaotic assortment of Powell Andesite and Quemont Dyke blocks. Porosity is predominantly filled with chlorite. Frequency of andesitic fragments increases towards the top.

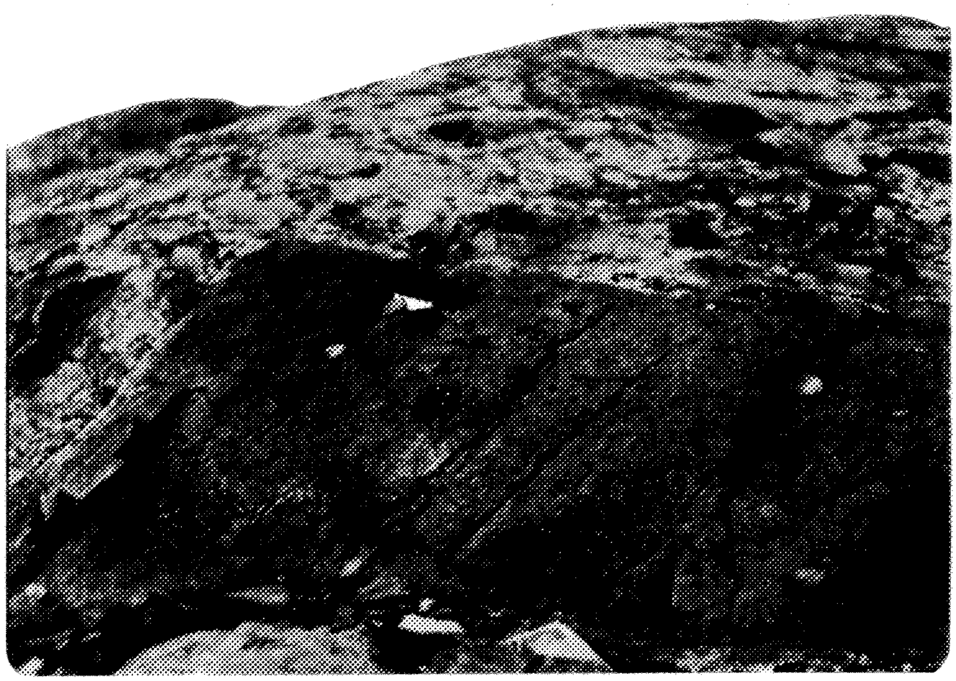
Alignment of long axes of blocks parallel to the intercycle slab of rhyolite and to the bottom of the crater is the only primary sedimentary structure found in both cycles of Joliet Breccia. No size gradations were observed; interfragment voids are filled with massive chlorite and/or quartz; ash or fine débris is nonexistant. All fragments are massive and angular, and some show re-entrant angles.

Powell Tuff-Origin of Joliet Breccia (Fig. 17)

The Joliet Breccia pile is the fragmental in-filling of a small crater situated on the northern edge of the northernmost Quemont Feeder Dyke. The pile displays no primary sedimentary features other than a poor alignment of long axes of blocks parallel to the crater bottom.

PLATE 35 JOLIET BRECCIA
Cycle 2, Joliet Breccia. Large, jumbled blocks of dyke rock and andesite in a chlorite and silica rich matrix.

PLATE 36 JOLIET BRECCIA
Top of Cycle 2, Joliet Breccia. Very large Powell Andesite block, several meters across, surrounded by smaller dyke rhyolite and andesite blocks.



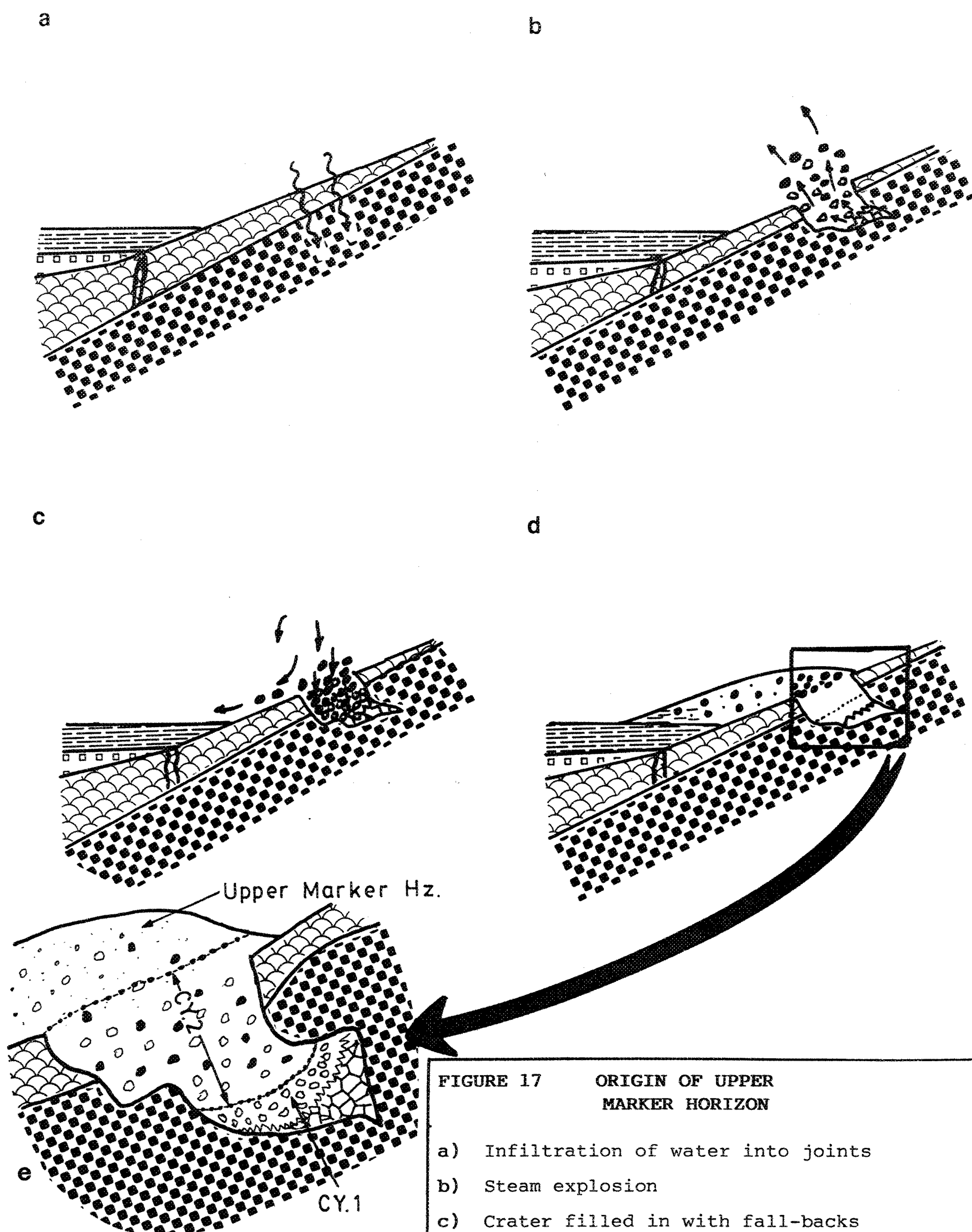


FIGURE 17 ORIGIN OF UPPER MARKER HORIZON

a) Infiltration of water into joints

b) Steam explosion

c) Crater filled in with fall-backs

d) Debris flows slough-off crater rim and grade distally into turbidites

e) Close-up of Joliet Breccia crater and cycles of crater-fill

The breccia pile is compositionally and structurally zoned. Massive dyke rock grades outward into in-situ fractured dyke, which in turn grades into chaotic and brecciated dyke rock. This lower cycle grades abruptly into a chaotic breccia in which the frequency of andesitic blocks increases outwards.

De ROSEN-SPENCE (1976) believed the breccia to have been caused by steam explosions in the Quemont Dyke: joints in the still hot dyke allowed relatively cool water to percolate inward where it flashed to steam and exploded due to the confining pressure of the dyke. At the base of the site of explosion dyke rock was only fractured and brecciated in-situ; farther toward the margin of the dyke, where confining pressures were less, fractured rocks were jumbled about and rotated (Cycle 1). Near the contact with host Powell Andesite, the explosion was capable of ejecting some of the dyke and overlying andesite flows. In general, the fragments fell back into the newly formed crater in a mixed and chaotic fashion, forming Cycle 2 (DIMROTH & ROCHELEAU, 1979).

This type of mechanism is similar to that responsible for subaerial hydrothermal explosion craters in Yellowstone Park described by MUFFLER et al (1971). Shallow oval to circular craters, tens to thousands of feet in diameter, are produces in both consolidated and unconsolidated material when water, contained near the surface at high temperatures and low confining pressures, flashes to steam and violently disrupts the containing rocks. Craters have steep inner slopes (as does the Joliet crater); outer slopes are gentle and are formed by ejected débris.

The absence of a fine ash component in the Joliet Breccia produced a porous breccia framework. Fractures in dyke rock and interfragment porosity were filled with silica most probably derived from the host rocks during early sea-floor metamorphism (DIMROTH & LICHTBLAU, 1979). The admixture of andesitic blocks in Cycle 2 gave rise to a clay component in the silica cement. Recrystallization of these early cements during diagenesis and orogeny led to the formation of coarse grained quartz and massive chlorite.

Powell Formation-Upper Marker Horizon

The upper Marker Horizon is gradational to Cycle 2 of the Joliet Breccia. The transition is marked by a decrease in frequency of large blocks and a concomitant increase in coarse ash sized matrix above the top of the Joliet crater (Sector C-7).

The Upper Marker can be traced westward from the Joliet Breccia for a distance of 700m, lying entirely within Fault Block 2. Stratigraphically it occurs at the top of the Powell Tuff sequence and is in partial fault contact with overlying Powell Andesite. The Marker attains a thickness of 150m immediately downslope of the Joliet crater. It can be traced to the western exposures of Fault Block 2.

The proximal (eastern) 600m of Upper Marker Horizon are characterized by the presence of sparse Quemont Rhyolite blocks and lapilli in a coarse ash matrix. No sedimentary textures are apparent; exposures consist of massive and unbedded tuff-breccia.

The distal 100m of Upper Marker Horizon are characterized by the appearance of distinct metre-thick tuff-breccia beds interbedded with centimetre to decimetre thick graded/stratified turbidites. Over a lateral distance of only 30m the massive and unbedded deposits of the proximal Upper Marker Horizon are seen to grade into predominantly bedded tuff-breccias, intercalated with turbidites. As the frequency of turbidites increases distally (westward) the thickness and frequency of tuff-breccia beds decreases. At the western limit of exposures in Fault Block 2, the Marker is recognised by the metre thick beds of tuff-breccia interbedded with the Ash Tuff facies of Powell Tuff (see section 2b).

Powell Tuff-Origin of Upper Marker Horizon

The lateral primary texture sequence of the Upper Marker Horizon exhibits an evolution from east to west: massive, unbedded tuff-breccias grade into bedded tuff-breccias which are intercalated with thinly graded turbidites. The coarsest and thickest deposits lie on top of and immediately west of the Joliet Breccia. The bedded and graded deposits lie 700m to the west, overlying Powell Tuff.

Proximally the Upper Marker consists of ungraded, massive débris flow deposits that evolved distally (downflow) into bedded débris flow deposits and thinly bedded turbidites. The turbidite deposits were probably formed from turbulent eddy currents produced near the edges of the predominantly laminar débris flows.

Héré Rhyolite

The Héré Rhyolite is found at the top of the stratigraphic section encompassed by this report. It has already been described in a previous chapter.

VI
CORRELATIONS

VI 1. INTRODUCTION

Stratigraphic correlation across the five major fault blocks of Figure 3 was accomplished by means of marker horizons: rock units of identical or similar lithology, occuring in similar stratigraphic sequences and with consistent facies relationships were deemed marker horizons.

Figure 18 depicts generalized stratigraphic sections through the five fault blocks of the study area. Sections were measured with respect to the Lower Marker Horizon which was used as a reference horizon in Figure 18. The Upper Marker was used where the Lower was absent (Sections 1 & 2, Fig. 18). Since the Upper Marker crosses from Fault Block 1 into Fault Block 2, and the Lower crosses Blocks 3, 4 and 5, correlation between Blocks 2 and 3 was done by means of Powell Rhyolite which crosses Fault Blocks 2, 3, 4 and 5. The lower contact of the Rhyolite flow dips at 7° with respect to a horizontal Lower Marker Horizon (exagerated in Fig. 18 due to the unequal distances between sections).

VI 2. BROWNLEE RHYOLITE CORRELATIONS

Brownlee Rhyolite is found at the base of the stratigraphic succession throughout the map-area. Figure 18 shows that its upper contact is displaced by about 300m to 500m between Fault Blocks 2 and 3. This may represent the original topographic

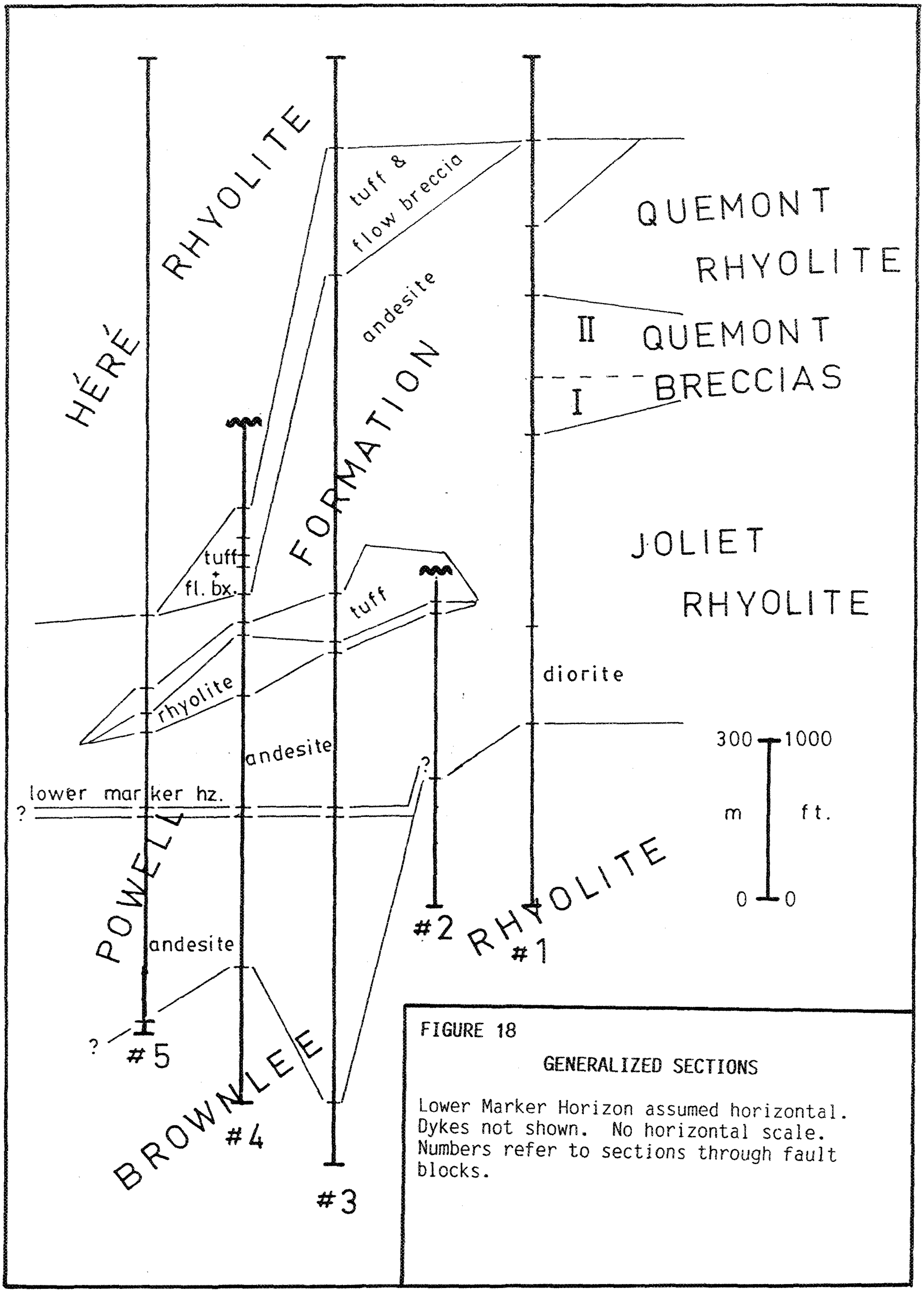


FIGURE 18

GENERALIZED SECTIONS

Lower Marker Horizon assumed horizontal. Dykes not shown. No horizontal scale. Numbers refer to sections through fault blocks.

expression of a domal feature having a crest in Blocks 1 and 2: the rhyolite in Blocks 3, 4 and 5 representing the western flank. Alternately, the western part of a once level rhyolite plain may have subsided along faults (in part occupied by rhyolite dykes; see end-piece map) situated between Blocks 2 and 3.

Faulting, shearing, vein-faults and hydrothermal alteration of country rocks (see further below) marks the region between Fault Blocks 2 and 3. It is likely that these are syn- or immediately post-volcanic features and may have had control over basinal subsidence.

VI 3. QUEMONT BRECCIA I/LOWER MARKER HORIZON CORRELATION

Quemont Breccia I is composed of two cycles of pyroclastic lag-fall consisting of an oligomict assemblage of aphyric rhyolite and minor andesite and basalt. The Breccia rests upon Joliet Rhyolite, which in turn rests on Brownlee Rhyolite. Breccia I is overlain by Breccia II and the Quemont Rhyolite flow. All these units are cut by the coarsely quartz phyric rhyolite dykes of the Powell Rhyolite.

The Lower Marker Horizon is a bed composed of an oligomict assemblage of aphyric rhyolite and minor mafic lithics intercalated within andesite flows. The Marker is found 300m to 500m above Brownlee Rhyolite and is ultimately overlain by Powell Rhyolite.

Correlation between Quemont Breccia I and the Lower Marker Horizon is proposed on the following grounds:

i) they are lithologically identical, both consisting of aphyric rhyolite and minor mafics;

ii) they occur within the same stratigraphic interval, above Joliet/Brownlee Rhyolite and below Powell Rhyolite;

iii) inferred source vent for both is from the present site of the northern Quemont Feeder Dyke;

iv) mechanism of emplacement of both units is postulated to be the result of pyroclastic activity at the vent refered to in iii) above;

v) development of facies sequences from a proximal Breccia I to a distal Lower Marker are internally consistent.

The eruption and emplacement of Quemont Breccia I and the Lower Marker Horizon, a geologically instantaneous event, serve to correlate events on the rim and within the basinal depression refered to above.

VI 4. JOLIET BRECCIA/UPPER MARKER HORIZON CORRELATION

Joliet Breccia represents the in-filling of a pit created by phreatic explosions in the side of the western Quemont Feeder Dyke. The deposit grades successively outward from in-situ brecciated dyke rock through displaced and jumbled dyke rock, to a chaotic mixture of dyke rock and andesitic and basaltic host rocks. These deposits all occur within and just beyond the original walls of the crater.

The correlation of Joliet Breccia with the Upper Marker Horizon is made with reasonable confidence because the former can be traced outcrop by outcrop into the latter. Facies sequences develop westwards (basinward) from coarse, chaotic crater fill (Joliet Breccia) through dêbris flows to distal turbidites (both representative of the Upper Marker Horizon).

The Upper Marker Horizon serves as a marker of limited extent NW ot the Quemont Feeder Dyke. Its on-strike extension as the Joliet Breccia facies indicates no relative movement occured between Fault Blocks 1 and 2 after the emplacement of the Marker and Breccia units.

VI 5. HERE RHYOLITE CORRELATIONS

The Héré Rhyolite is situated at the stratigraphic top of the sections studied, and can be traced continuously across all the fault blocks of the area.

Southeast of the Quemont Feeder Dyke, in Fault Block 1, it overlies Quemont Rhyolite flow; towards the NW, in Fault Blocks 2, 3, 4 and 5, it overlies Powell formation. The restored sections of Figure 18 suggest that Héré Rhyolite filled in the remnants of a basin located in Fault Blocks 4 and 5. It is to be noted that no displacement occurs in the Héré above the Quemont Feeder Dykes.

VII
FACIES OF FRAGMENTALS

Fragmental rocks of the map-area fall into the categories discussed above, namely:

Quemont Breccia I
Lower Marker Horizon
Joliet Breccia
Upper Marker Horizon
Lapilli and coarse ash tuff
Reworked lapilli and coarse ash tuff
Ash tuff

It has been shown that the pyroclastic lag-fall deposit (Quemont Breccia I) can be traced into the dêbris flows and turbidites of the Lower Marker Horizon; and that the steam explosion of the Joliet Breccia can be traced into the characteristic dêbris flows and turbidites of the Upper Marker Horizon. Pyroclastic air/water fall lapilli and ash tuffs are associated with Powell Rhyolite and were later reworked by marine currents. These relationships are tabled in flow-chart form in Table 3, where facies development and relationships are highlighted. Descriptive summaries of each facies type are given in Table 4.

FACIES RELATIONS

TABLE 3

Facies of Fragmental Rocks	Pyroclastic Activity	Rhyolitic Dome Collapse
1. Pyroclastic Lag Deposit	1	
2. Explosion-pit Filling	2	
3. Debris Flows	3a, 3b	3c
4. Pyroclastic Flows "turbidites"	4a, 4b	4c, 4d
5. Lapilli & Coarse Ash Tuff	5	
6. Lapilli & Coarse Ash Tuff -reworked	6	
7. Ash Tuff	7	

FACIES DESCRIPTIONS Table 4				
Facies No.	Facies Name	Sub-Facies	Description	Origin
1	Pyroclastic Lag-Fall (Quemont Breccia I)		Adjacent to vent; lens shaped in section; up to 120m thick, 200m long. Large-scale upward coarsening then fining cycles; poor parallel lamination in fines at top of cycles; long axes of fragments parallel to bottom contact. Fragments poorly to moderately vesiculated derived from underlying rhyolite flows; minor amounts mafic clasts.	Lag deposit near pyroclastic eruption. Incompetency of collapsing eruption column to entrain large lithics results in breccia pile rimming vent.
2	Steam-Explosion (Joliet Breccia Crater-Fill)	2a	In-situ brecciated rock of Quemont Feeder Dyke; no displacement of fragments; "crackle breccia"; fractures filled with coarse chlorite/quartz.	Crater and fall back breccia produced by steam explosion within Quemont Feeder Dyke. Rooted in dyke rock the explosion successively displaced dyke and then country rocks. Little amounts of fine grained material formed during the steam explosion hence porosity filled by clay (chlorite) and silica (quartz) during diagenesis.
		2b	Chaotic rhyolite breccia passing gradationally from Sub-Facies 2a into jumbled mass of dyke fragments; long axes of some fragments parallel to bottom of crater; little fine material.	
		2c	Gradational to 2b; chaotic mixture of andesitic country rocks and dyke rocks; proportion of andesite blocks increases out of crater; chloritic matrix.	

FACIES DESCRIPTIONS TABLE 4 cont'd

Facies No.	Facies Name	Sub-Facies	Discription	Origin
3	Débris Flows	3a	Generally monomict, inverse to mormally graded beds 3-4cm thick, occuring as first 30cm of exposure of Lower Marker Hz. (sections 2 & 4).	High density subaqueous débris flows generated by pyroclastic eruption at site of Quemont Feeder Dyke; downslope equivalent of Facies 1.
		3b	Chaotic beds of block, lapilli and coarse ash sized material overlying and downslope from Joliet Breccia sub-facies 2c; up to 150m thick. No sedimentary textures, massive beds. Constitutes proximal Upper Marker Horizon.	Débris flows originating on slopes of breccia-fill of Joliet steam-explosion crater deposit massive chaotic beds downslope.
		3c	Massive, chaotic bx. overlying Powell Rhyolite flow; clasts are all massive, non-vesiculated Powell Rhyolite; blocks float in ash matrix; attains thickness of 100m and strike length of 600m. Underlies, and grades into sub-facies 4c.	Débris flows from collapsing rhyolite spine of dome deposits chaotic, monomict breccia overlying consanginous rhyolite flow.
4	Pyroclastic Flows	4a	One normally graded/stratified bed, 3-14m thick, at least 1100m long. Generally monomict in aphyric rhyolite, with andesitic rip-ups. Under and overlain by andesitic flows. Constitutes distal sections of Lower Marker Horizon; downflow equivalent of sub-facies 3a.	Demonstrates classical evolution from debris flow, sub-facies 3a, to turbid flow deposits. Frequency of parallel stratification increases and clast size decreases downflow.

FACIES DESCRIPTIONS TABLE 4 cont'd

Facies No.	Facies Name	Sub-Facies	Description	Origin
		4b	Tabular beds 1-50m thick of normally graded coarse to fine ash. Laterally gradational to subfacies 3b debris flows; constitutes distal Upper Marker Horizon.	Primary texture sequence of debris changing to turbidity current flow regime. Thin, graded Beds deposited distally relative to source at breccia-fill of Joliet steam-explosion crater.
4	Pyrocalstic Flows (cont'd)	4c	Thick, graded beds of Powell Rhyolite clasts overlying chaotic breccia subfacies 3c; non-vesiculation of clasts; some bed amalgamation. Overlain by Powell Tuffs.	Graded beds deposited by turbidity currents generated by debris flows (which deposited underlying subfacies 3c). Initially caused by dome or spine collapse.
		4d	Decimeter thick, massive or normally graded tabular beds in the Upper Powell Tuff. Fragments angular and unvesiculated. Bimodal lithology; frequency of aphyric rhyolite clasts increases upwards as Powell Rhyolite clast frequency decreases. Overlain by aphyric Héré Rhyolite.	Turbidity current deposits. Dumping of fragmental rhyolite ejecta caused slumping and formation of turbidity currents. As Héré Rhyolite activity increased the frequency of Héré Rhyolite clasts in the deposits also increased.

FACIES DESCRIPTIONS TABLE 4 cont'd

Facies No.	Facies Name	Sub-Facies	Description	Origin
5	Lapilli and Coarse Ash Tuff		Parallel laminated beds; lapilli beds are one lapilli diameter thick, coarse ash laminae are centimeters thick. Rare upward coarsening cycles (decimeter thicknesses). Isolated lapilli and block clusters displaying impact structures and scours in lee of fragments.	Pyroclastic ejecta dispersed in air and ultimately settled and deposited in water. Little evidence of reworking by marine currents Clusters of blocks and lapilli are bombs settled through water.
6	Reworked Lapilli and Coarse Ash Tuff		As Facies 5, above, but with numerous erosional scours. Trough cross-beds (10-30cm sets) and micro-delta or dune forms fill scours. Fine grained ash may drape dune forms; re-activation of dunes common. All directional sedimentary textures indicate a component of current flow towards WNW. Large isolated blocks present. Chanelled, discontinous sometimes graded lapilli lenses are also present.	Air/water-fall pyroclastics reworked by unidirectional current. Large blocks are air/water-fall bombs. Chanelled lenses are re-sedimented volcaniclastics occuring as chanellized turbidites.
7	Ash Tuff		Thinly bedded (mm to cm) fine ash tuff. Soft sediment deformation features common: convolute laminations, sand balls, loaded ripples, broken beds. Isolated blocks with impact structures.	Air-fall ash settled through water. Some reworking into ripples; synsedimentary deformation features common beneath air/water-fall bombs.

VIII
DYKES

VIII 1. QUEMONT FEEDER DYKES

Three NE trending quartz phyric rhyolite dykes were mapped in detail by MORRIS (1959). These were recognised as feeders to Quemont Rhyolite Flow 4 by de ROSEN-SPENCE (1976). Quartz crystals are 1mm-3mm in diameter and occur with a frequency of about 2 crystals per cm^2.

The southern dyke is cut by the Horne Creek Fault and as a consequence is not well exposed. The northern dyke is the most extensive: on the average it is 350m wide and can be traced 1300m from the Powell Pluton to the Quemont Flow. Dips are near vertical.

Internal flow laminations are common, especially near the transition from dyke to flow; no other textural changes are seen to mark the intrusive/extrusive boundary.

The northern Quemont Feeder Dyke occurs along a postulated fault zone separating Fault Blocks 1 and 2. The northern edge of the dyke appears to form the wall of the basinal depression formed by subsidence of all of the Blocks west of Block 1.

The Quemont Dykes cut Lower Powell Andesite and the Brownlee/Joliet Rhyolites. No intrusives of Quemont affinity are found within the basinal depression refered to above: all Quemont Rhyolite intrusive activity was confined to Fault Block 1.

VIII 2. POWELL RHYOLITE FEEDER DYKES

Two separate feeder dykes to Powell Rhyolite are exposed in Sector D/C 5 (end-piece map). Both dykes clearly cross-cut underlying Powell Andesite and are transitional to the Powell Rhyolite Flow (see map, Appendix II,i).

The dykes are nearly vertical, one to a few metres thicks, are highly altered (see below under chapter heading "Alteration") and are quartz phyric in the manner of Powell Rhyolite (ie. quartz crystals 2mm-4mm diameter, 4 crystals/cm^2). Similar intrusions, but not traceable into extrusive Powell Rhyolite occur in the immediate vicinity, cutting Powell Tuff and Andesite. These dykes also intrude Joliet Breccia, Brownlee/Joliet Rhyolite, Quemont Breccia Pile and the Quemont Dykes and flow.

The two Powell Rhyolite Feeders fed the overlying rhyolite flow. The various facies of underlying andesite flows (including a thin tuff layer) are not displaced, hence no relative movement has occurred along the feeder vents. This also holds true for the other Powell Rhyolite intrusives in the area: no displacements are evident and the country rocks are generally unfaulted.

VIII 3. HERE RHYOLITE FEEDER DYKES

A dyke of Héré Rhyolite can be traced almost continuously from the Powell Pluton (sector E-1) to within 150m of the lower contact of Héré Rhyolite (sector B-5). Dip is steep to and its average thickness is 25m. Is is generally massive, but its northern contact in Sector D-3 is flow laminated and brecciated over a distance of 8m.

All observed contacts are intrusive: the dyke cuts Brownlee Rhyolite, Héré Rhyolite and the entire Powell formation. Lack of outcrop in Sector B-5 makes the intrusive relationship questionable, but it appears that the dyke may die out before reaching the lower Héré Rhyolite contact. In any case, the dyke does not extend into the formation and it may well be that it is a feeder for Héré flows.

Several minor, parallel off-shoots of the Héré Rhyolite Dyke are found cutting both Powell Andesite and Powell Rhyolite. Outcrops adjacent to the dyke are moderately sheared and silicified and the dyke itself is altered in varying amounts (further discussed below, under "Alteration").

In the southwest part of the map-area the main dyke forms the boundary between Fault Blocks 3 and 4, whereas in the northern area it occurs as the eastern boundary of Fault Block 5. A rotational fault (activated during orogeny?) may have produced the relative displacement between Fault Block 4 and Blocks 2 and 5. This also results in the absence of the Héré Rhyolite Dyke in Sector C-5.

VIII 4. MAFIC DYKES

Diorite dykes and sills are a common occurrence near the Powell Pluton; diorite intrusives rim the Lake Dufault Pluton (Fig. 2). The diorite in Sectors E-7 and C-1 and the gabbro in Sector D-3 are examples of mafic to intermediate intrusives surrounding the Powell Pluton.

The intrusive rocks are generally medium to coarse grained rocks; the gabbro of Sector D-3 is excellently feldspar-glomeroporphyritic. They are typically black on fresh surface and weather a rusty brown.

Only the gabbro plug of Sector D-3 appears to have been intruded along a recognised fault zone. The mafic intrusive has been emplaced along a portion of the Héré Rhyolite structure, extending from surface to a depth of approximately 400m (from level plans of Powell-Rouyn Mines; on file at the office of the Resident Geologist, Rouyn).

The close spatial association of diorite/granitoid pluton infers at least a close structural, if not genetic, association. The granitoid plutons are thought to be shallow subvolcanic intrusions, and the dioritic bodies surrounding them may have had a similar origin.

Thin (cm to m scale) sinuous, fine grained mafic dykes are relatively common in the map area. They cut all volcanic rocks of the region but cannot be traced from outcrop to outcrop.

A ten metre wide, vertical, north-south striking Proterozoic diabase dyke is the youngest rock in the area (see Table 1). It can be traced northwards for at least 15km to the Norbec Mine area (WILSON, 1941).

VIII 5. BRECCIA DYKES

Only two examples of breccia dykes were found. They are characteristically short (about 25m) dykes less than 1m wide and appear to be steeply dipping. They contain an oligomict assemblage of highly altered (carbonate and chlorite) lapilli sized fragments of the host rocks. They typically intrude Powell Andesite and Héré Rhyolite.

One breccia dyke (Appendix II,ii) was observed to pinch out in andesite after having traversed the Héré Rhyolite Dyke. No apparent strike slip movement was noted. The second, more easterly, breccia dyke has a right strike slip displacement of 1.5m along the Héré Rhyolite Dyke and flow.

Because of their rarity the origin of the breccia dykes remains obscure. They cut both intrusive and extrusive rocks and contain altered fragments of both. They occur in the area between Fault Block 3 and 4 and cut the Héré Rhyolite Dyke at right angles. The breccia dykes may have formed when the hot Héré Dyke came into contact with water saturated host rocks; the resulting steam explosion ruptured dyke and host rocks, and some movement of breccia fragments took place along fissures perpendicular to the dyke.

IX
ALTERATION

The intrusive, extrusive and fragmental rocks of the map area have been altered and recrystalized to varying degrees. Chlorite, carbonate, sericite, quartz and epidote alteration masks most primary igneous and sedimentary textures.

Original glassy pillow selvedges and hyaloclastic fragments have undergone pervasive chloritization, with minor epidotization. Shards commonly exhibit thin siliceous rims.

The igneous texture of massive and pillowed andesites has been recrystallized into a metamorphic polygonal framework of albite, quartz and chlorite. Vesicles are typically filled with blocky quartz and a felted chlorite core.

Because of the fragmental nature of the tuffs, alteration and recrystallization are intense and pervasive. Under the microscope, the tuff matrix is seen to be a polygonal assemblage of quartz, chlorite, albite, carbonate and epidote. Ash sized clasts in hand-samples are diffuse sericitic, carbonate and epidote rich relicts in thin section. Original feldspar crystals are difficult to identify, having been strongly saussuritized.

A "spotted" alteration of andesites, rhyolites and tuffs is encountered in Sectors D-5, D-3 and C-7. The spots are centimeter-sized, positively weathering, felted masses of quartz, carbonate and sericite, with minor epidote, set in a recrystallized andesite or rhyolite matrix. The spots have a tendency to cluster about thin, siliceous veinlets in the host rocks and sometimes appear in dense clusters at pillow rims.

Some ash and lapilli tuffs show the development of spotted alteration in the finer parts of beds, thus making grain size determinations difficult.

Spatially, this type of alteration is prominent around and within Héré Rhyolite dykes and the two Powell Rhyolite Feeders. Both host rocks and dyke have undergone "spotted" alteration. Fragments of Powell Andesite in the Joliet Breccia are partially altered in this manner.

Spotted alteration in clasts within the Joliet Breccia takes the form of a 5cm thick concentric band of spots occurring 5cm to 10cm within the fragments. This relationship suggests that the spots formed after fracturation and emplacement of the blocks by early, diagenetic, fluids percolating through a permeable medium. The presence of massive chlorite and quartz as cementing agents within Joliet Breccia certainly attests to the early presence of silica and clay minerals within interbreccia pore spaces.

The clustering of some spots around veinlets within dykes demonstrates the close association "spotted" alteration has for sites of fracturing and dyking: presumably accompanied by hydrothermal fluids.

Irregular spotted alteration within pillows and dense clusters between pillows indicate a pervasive alteration of pillow interiors and preferential alteration at the more permeable and glassy pillow selvedges. Similar alteration patterns of the fine fraction of some tuff beds intruded by dykes also argues in favour of an early diagenetic alteration of permeable unconsolidated clastics, favourably located near hydrothermally active fractures, possibly by shallow sub-volcanic dyking. Spotted alteration halos are therefore expected to occur in the rocks intruded by the Héré Rhyolite dykes and the Quemont and Rhyolite Feeders. The intrusives are altered to a generally lesser degree than the host Powell Andesites and Tuffs.

Early sea-floor alteration of fine clastic material in the Powell Tuff has produced an apparent bimodal composition: clasts larger than fine ash retain their felsic appearance; fine ash sized material, however, appears intermediate in composition due to chloritization.

The preferential chloritic alteration of fine ashy material is evident in Quemont Breccia I and the Lower and Upper Marker Horizons. Chloritization of hyaloclastic shards has been shown (DIMROTH & LICHTBLAU, 1979) to be an early sea-floor metamorphic process. The presence of chloritic cement in the Joliet Breccia attests to the intermediate/mafic nature of some of the pore fluids. Preservation of original compositions of the fine ash component (rhyolite) is therefore not expected. Coarser ash escaped appreciable chloritization because of reduced ratio of surface area to volume compared with the finer material.

X
DISCUSSION

X 1. FACIES CHANGES

Lateral facies changes in primary textures of the Lower Marker Horizon indicate a source area in the direction of Fault Block 1. Source area of the Upper Marker Horizon is known to be in Fault Block 1 (the northern Quemont Feeder Dyke). Lateral facies changes for both markers indicate a downslope or basinward development toward Fault Block 5.

Trough-cross bedding, dune bed forms and ripple marks in the Powell Tuff imply a unidirectional current flow from the southeast.

Powell Andesite is interbedded with Powell Tuff and forms the predominant lithologic type of the Powell formation. Facies relations between pillowed, massive and brecciated flows indicate feeding fissures toward the west.

Interfingering of the andesitic flows, Powell Tuffs and Marker Horizons demonstrates the interplay between the various volcanic activities. A relatively continuous extrusion of Powell Andesite from feeders in the west was coupled with Powell Rhyolite activity and the emplacement of the Upper and Lower Marker Horizons in the east.

Subsidence of a basin and its gradual filling-in by the Powell formation is the over-all process evinced by the stratigraphic and facies relations of the formations of the map area.

Synvolcanic faulting, especially between Fault Block 1 and all the blocks to the west, produced a basinal depression which was almost continuously filled-in by the various members of the Powell formation. Hence, no great relief existed between the basin and its rim. No scree, talus or fault scarp breccias were formed.

Metamorphism typical of sea-floor environments led to the chloritization of the fine ash component of pyroclastic ejecta. Chloritic clay minerals and silica were the cementing and porosity filling agents in the near sea-floor environment and filled intraparticle (vesicles) and interparticle voids.

A "spotted" quartz-carbonate-sericite alteration is present around, and in part within, rhyolite dykes. This type of alteration is also found as sea-floor alteration in andesitic fragments of the Joliet Breccia. Spotted alteration, therefore, is probably confined to zones of hydrothermal activity close to the sea-floor (as in the Joliet Breccia) or confined to zones adjacent to shallow rhyolite intrusives (Powell and Héré Dykes).

X 2. HISTORY OF THE POWELL AREA (FIG 19)

The map area is underlain by several extrusive volcanic formations; a substrate of Brownlee Rhyolite underlies the entire region. Upon this formation synvolcanic faulting played a role in the building of a hill or dome of Joliet Rhyolite. This, in effect, creates a basin at least to the northwest.

The Powell formation filled-in basinal depression and, after the extrusion of Quemont Rhyolite, lapped onto and over the Quemont Dykes and flows. Héré Rhyolite finally capped the Powell formation and filled-in the remnants of the basin.

Facies of Powell Andesite indicate a feeding vent or fissure toward the west, within the basin.

The Powell Tuff member was deposited in close spatial and temporal association with Powell Rhyolite. The rhyolite was emplaced shortly after pyroclastic activity commenced. This activity continued after the formation of the rhyolite flow and breccia: the monomict nature of clasts within the Powell Tuff demonstrates that the pyroclastic activity was of Powell Rhyolite type. The gradual disappearance of Powell Rhyolite clasts in the top few metres of Tuff and the concomitant increase in frequency of Héré Rhyolite clasts indicates the commencement of Héré Rhyolite volcanism.

The beginning of Héré Rhyolite activity marked the end of the basin. No further subsidence occurred and the first Héré flows were ponded within the last vestiges of the basin.

LEGEND

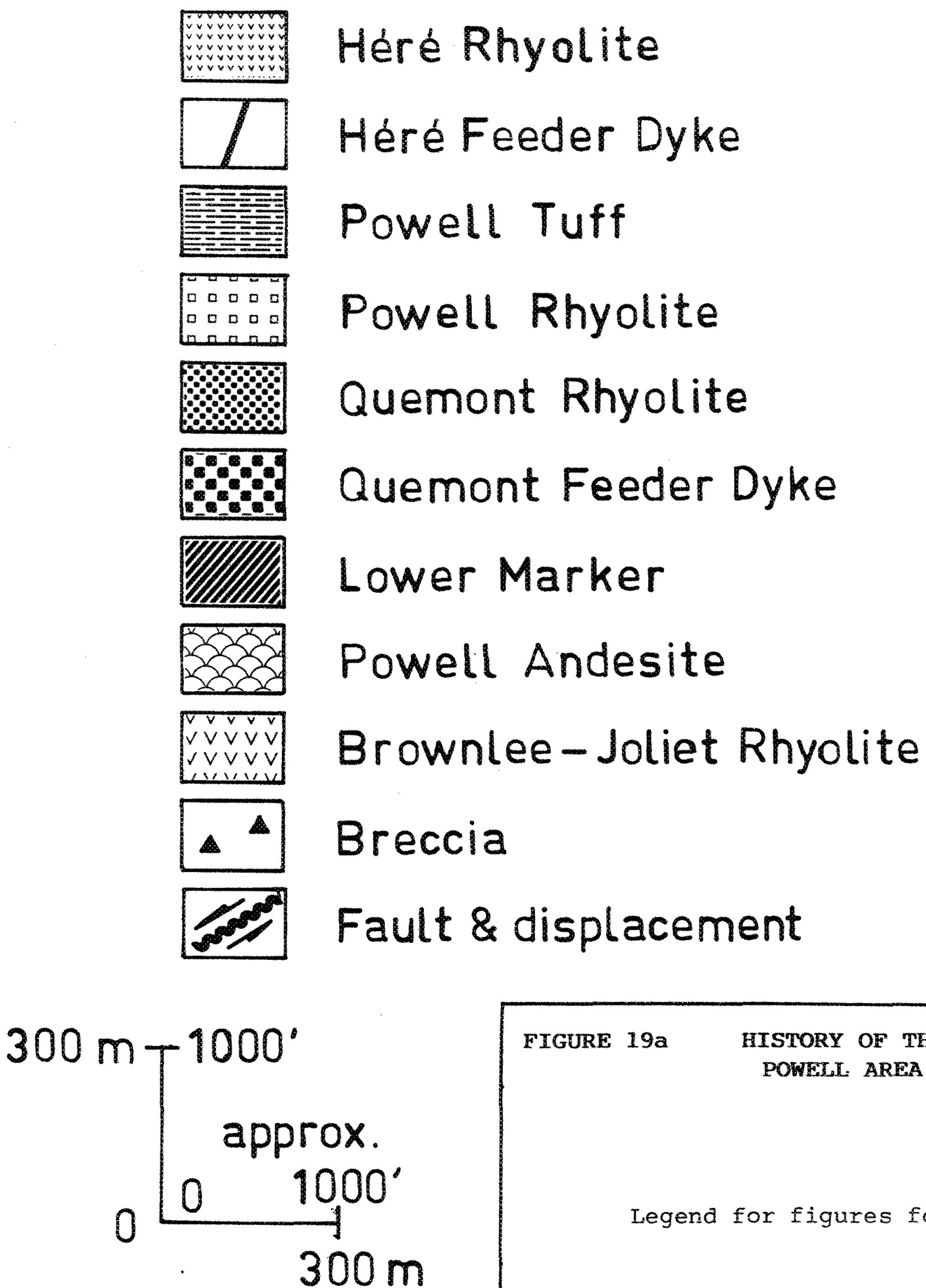


FIGURE 19a HISTORY OF THE POWELL AREA

Legend for figures following.

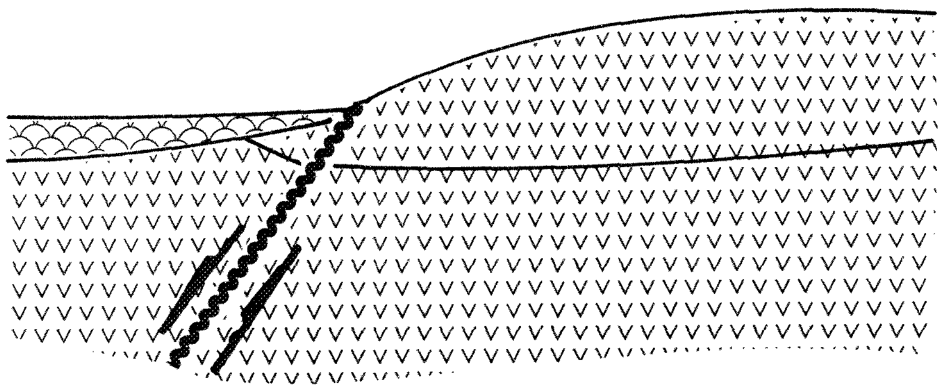


FIGURE 19b

Substrate of Joliet/Brownlee Rhyolite, in part overlain by Powell Andesite. Synvolcanic faulting enhances topographic relief.

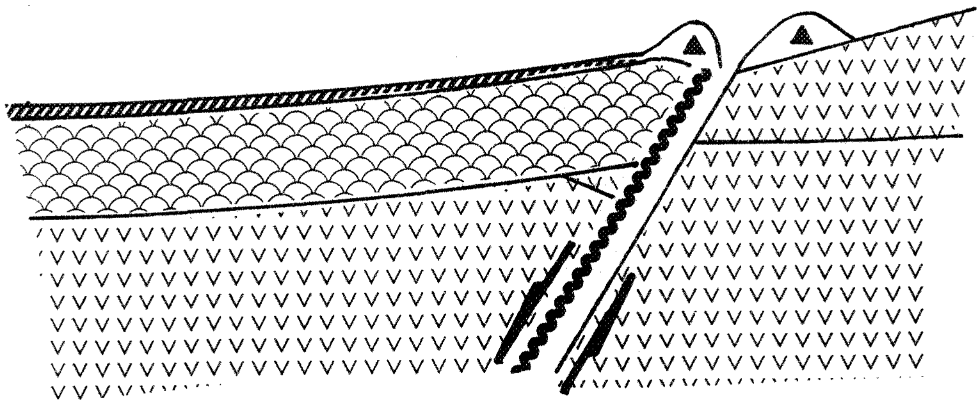


FIGURE 19c

Joliet Rhyolite capped by Quemont Breccia I; Lower Marker Horizon overlies Powell Andesite within basin.

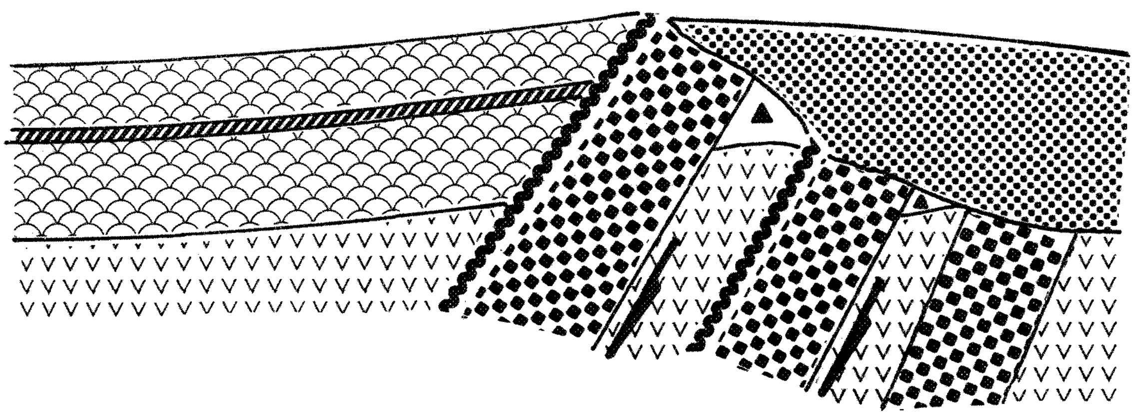


FIGURE 19d

Intrusion of Quemont Feeders and extrusion of Quemont Flows. Continued in-filling of basin by Powell Andesite.

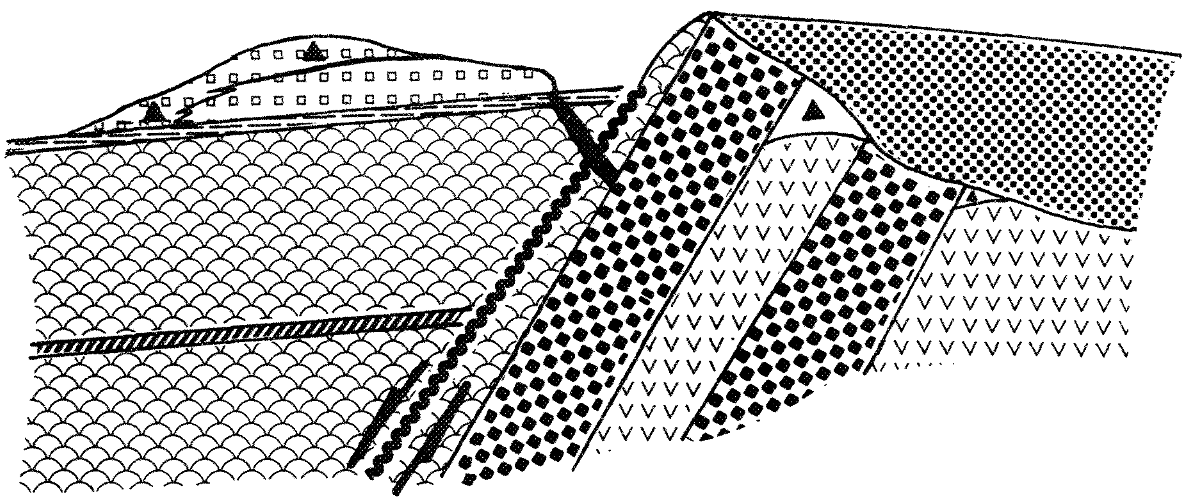


FIGURE 19e

Extrusion of Powell Rhyolite after short pyroclastic interval. Continued subsidence of basin.

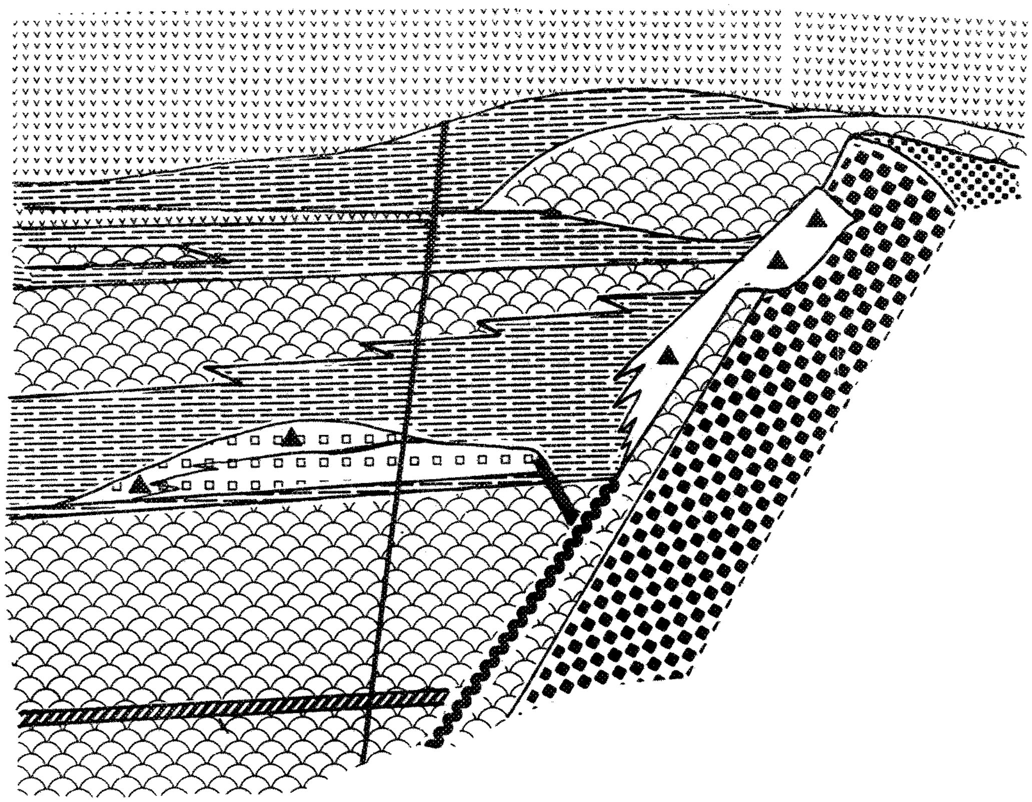


FIGURE 19f

Further subsidence, followed by burial of Powell Rhyolite by Powell Tuff. Formation of Upper Marker Horizon. Continued extrusion of Powell Andesites. Basin filled-in and capped by Héré Rhyolite (fed by dyke shown in solid black).

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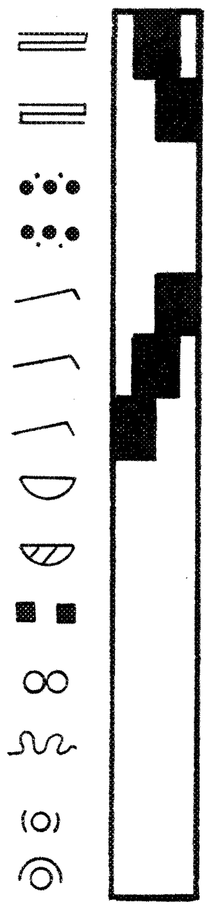
APPENDIX I

LEGEND FOR THE STRATIGRAPHIC SECTIONS

(adapted from BOUMA, 1962)



Parallel lamination: finely laminated

Parallel lamination: coarsely laminated

Normal grading

Inverse grading

Ripple lamination (less than 5cm height); wavelength less than 10cm

.. .. 10-20cm

.. .. +20cm

Scouring

Scour filled with trough cross-beds

Bed pulled apart

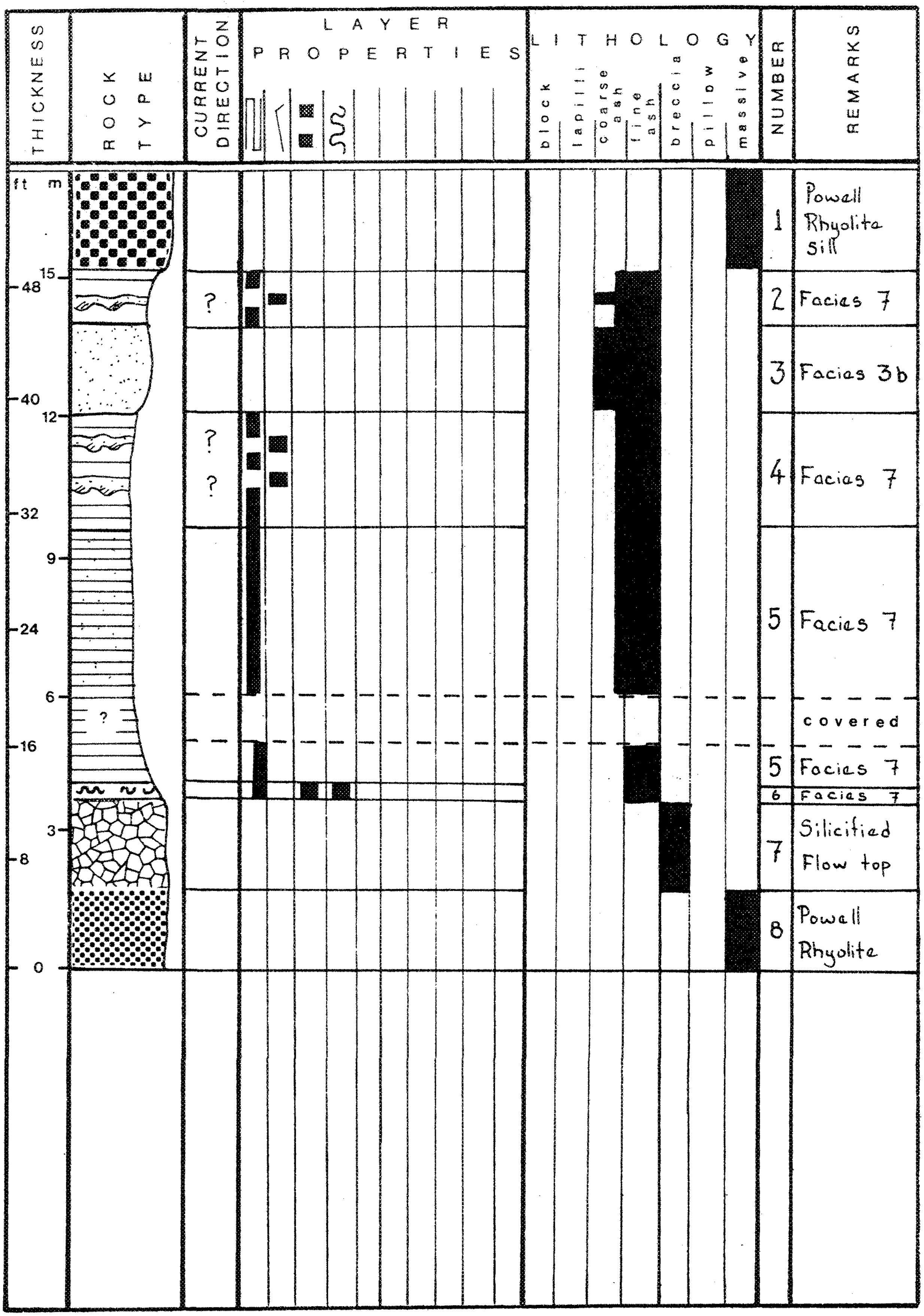
Lenticular layer (1-5m long)

Convoluted bedding

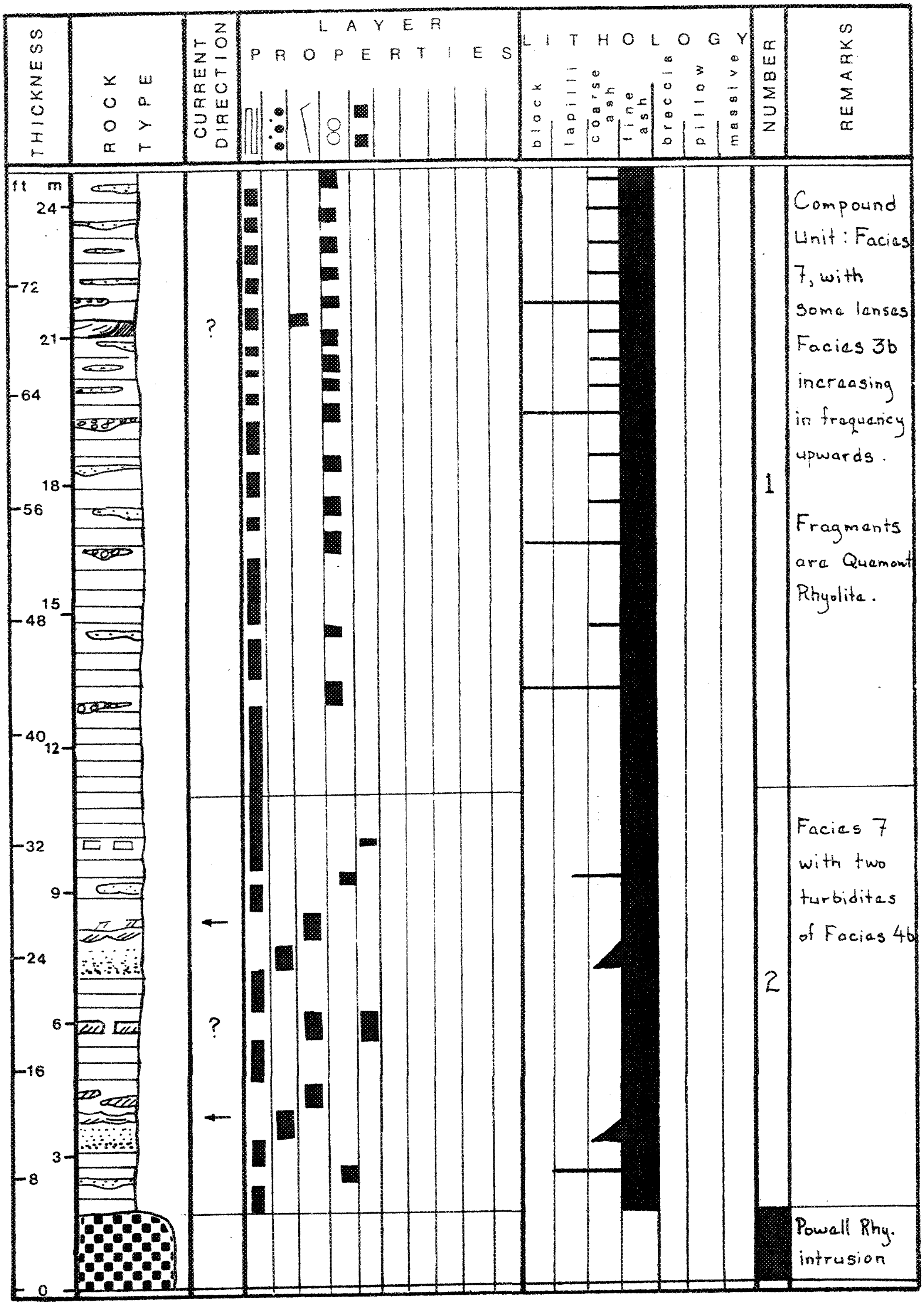
Pseudo-nodule

Sediment draping

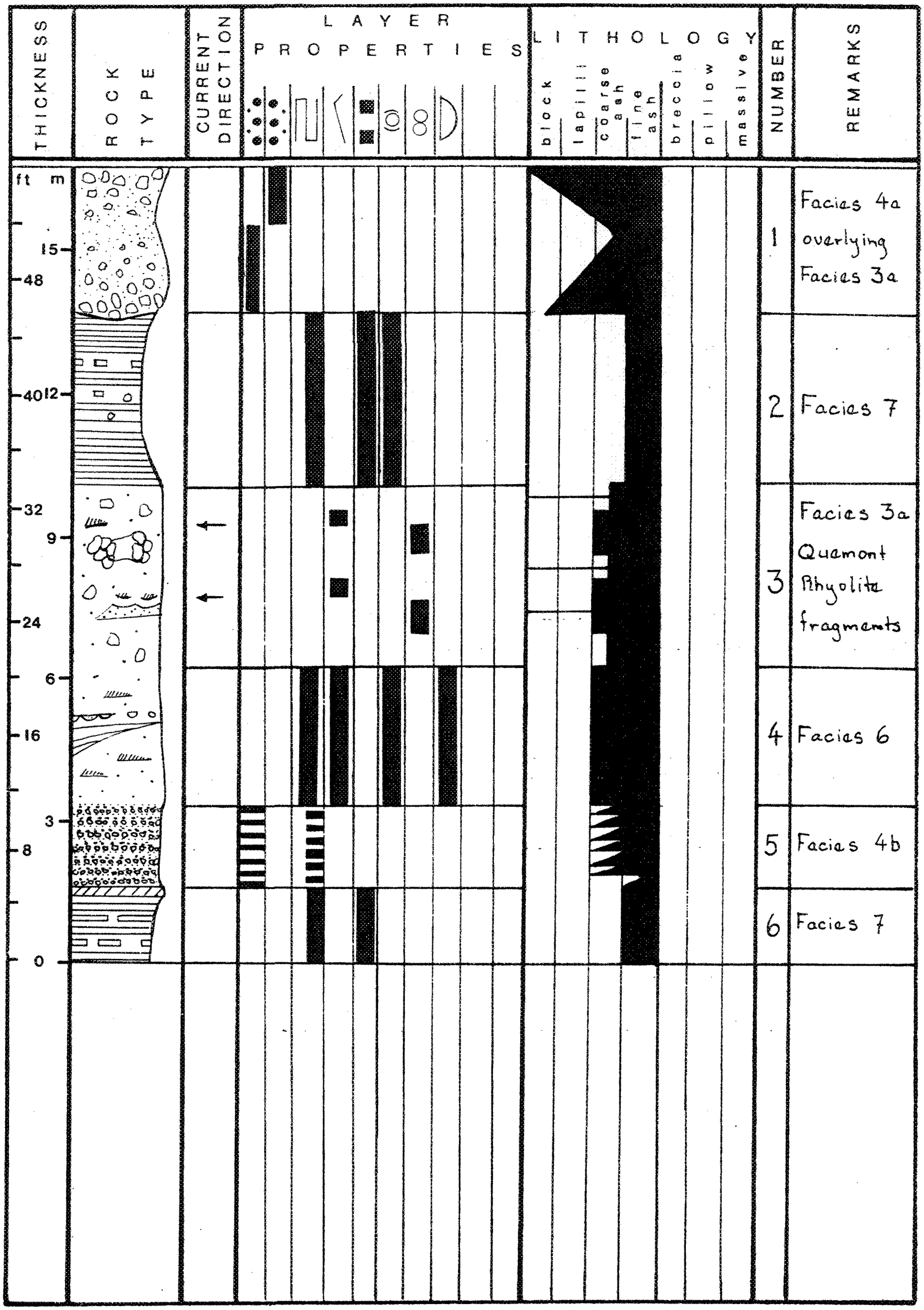
SECTION 2A


THICKNESS
ROCK TYPE
CURRENT DIRECTION
LAYER PROPERTIES
LITHOLOGY
block
lapilli
coarse ash
fine ash
breccia
pillow
massive
NUMBER
REMARKS
ft m
15
48
40
12
32
9
24
6
16
3
8
0
?
1 Powell Rhyolite Sill
2 Facies 7
3 Facies 3b
4 Facies 7
5 Facies 7
covered
5 Facies 7
6 Facies 7
7 Silicified Flow top
8 Powell Rhyolite

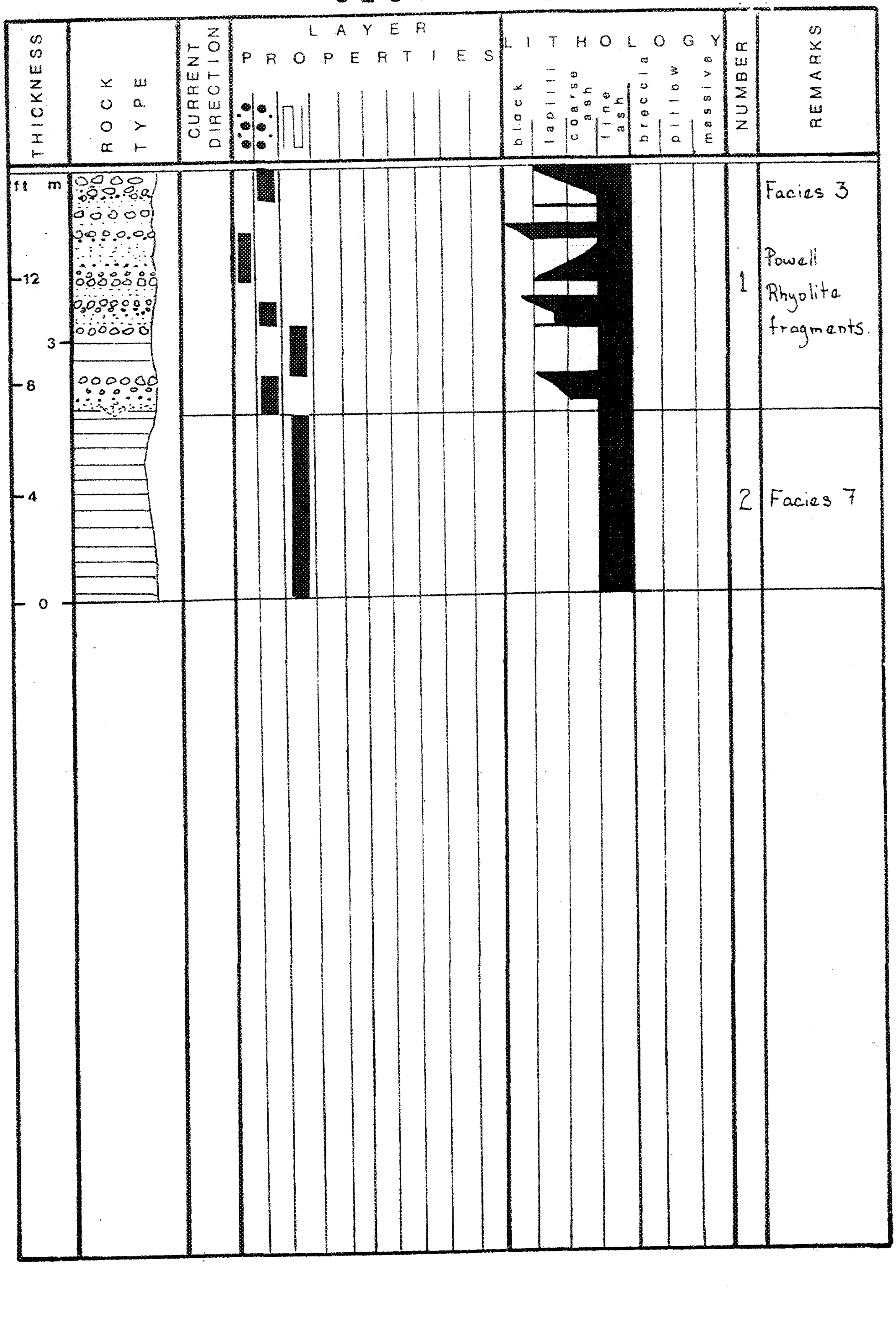
SECTION 2B


THICKNESS
ROCK TYPE
CURRENT DIRECTION
LAYER PROPERTIES
LITHOLOGY
block
lapilli
coarse ash
fine ash
breccia
pillow
massive
NUMBER
REMARKS
ft m
24
72
21
64
18
56
15
48
40
12
32
9
24
6
16
3
8
0
?
?
1
2
Compound Unit : Facies 7, with some lenses Facies 3b increasing in frequency upwards.
Fragments are Quemont Rhyolite.
Facies 7 with two turbidites of Facies 4b
Powell Rhy. intrusion

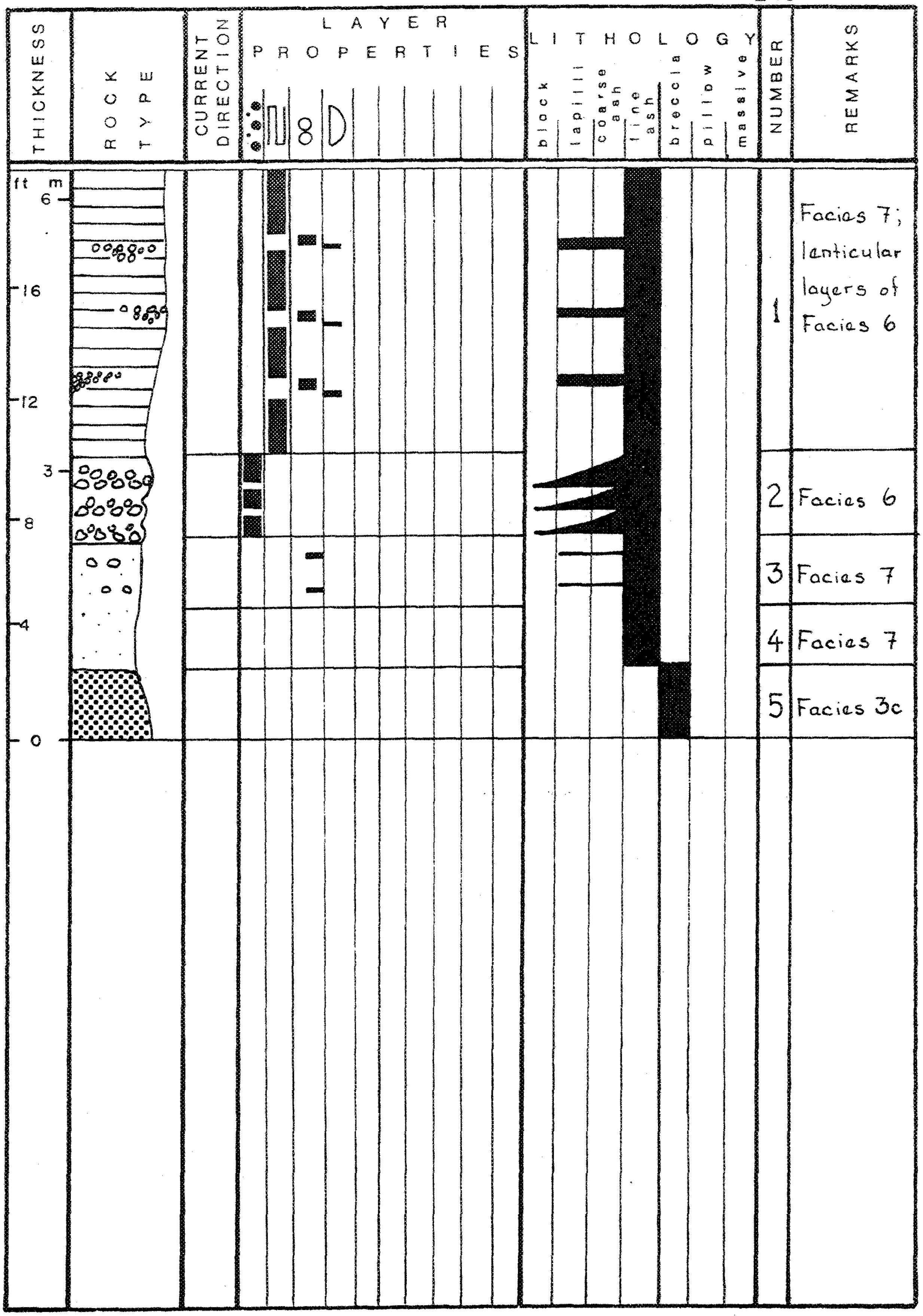
SECTION 2C


THICKNESS
ROCK TYPE
CURRENT DIRECTION
LAYER PROPERTIES
LITHOLOGY
block
lapilli
coarse ash
fine ash
breccia
pillow
massive
NUMBER
REMARKS
ft m
15
48
40 12
32
9
24
6
16
3
8
0
1 Facies 4a overlying Facies 3a
2 Facies 7
3 Facies 3a Quemont Rhyolite fragments
4 Facies 6
5 Facies 4b
6 Facies 7

SECTION 3A

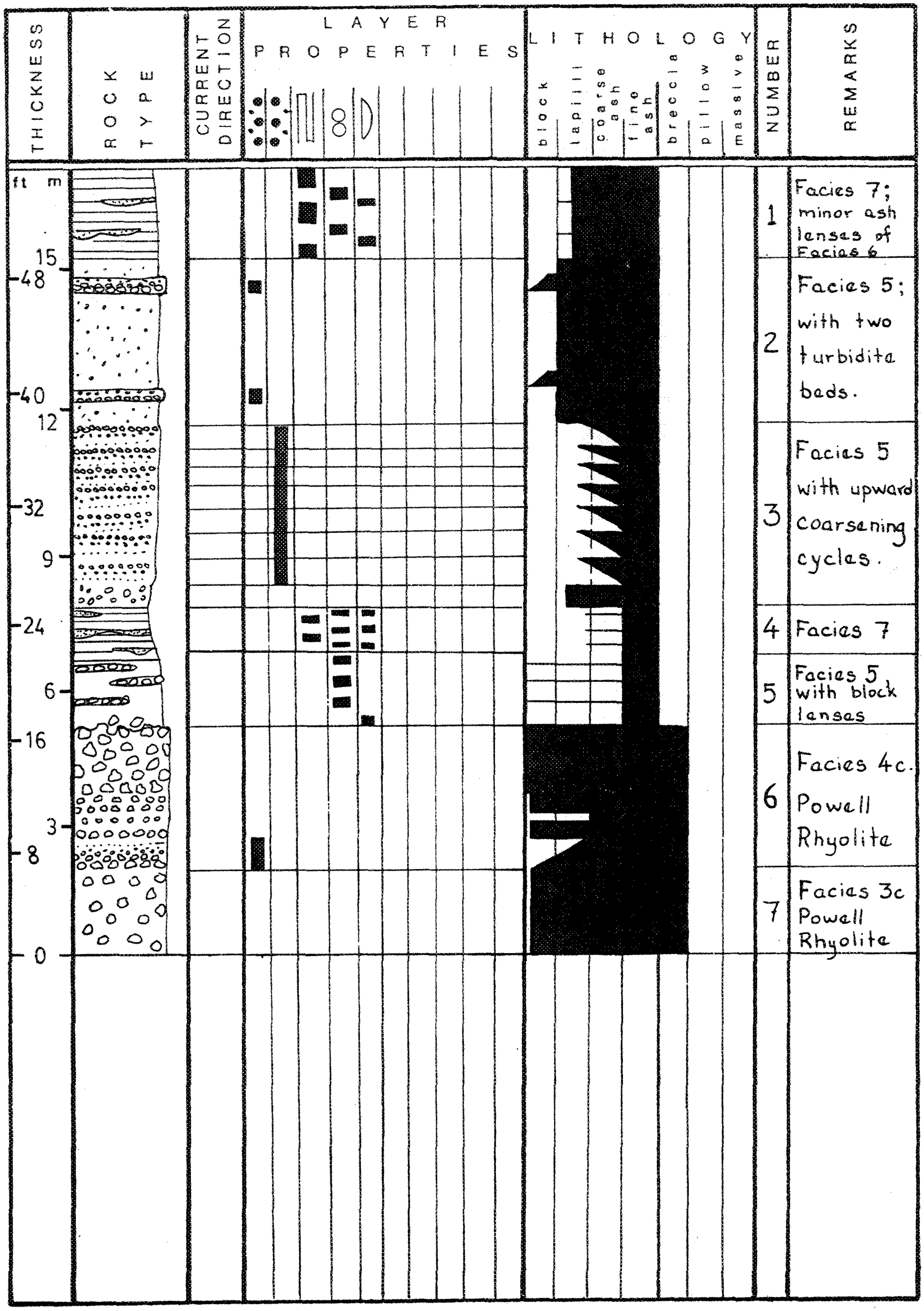

THICKNESS
ROCK TYPE
CURRENT DIRECTION
LAYER PROPERTIES
LITHOLOGY
block
lapilli
coarse ash
fine ash
breccia
pillow
massive
NUMBER
REMARKS
ft m
12
3
8
4
0
1
Facies 3
Powell Rhyolite fragments.
2
Facies 7

SECTION 4A

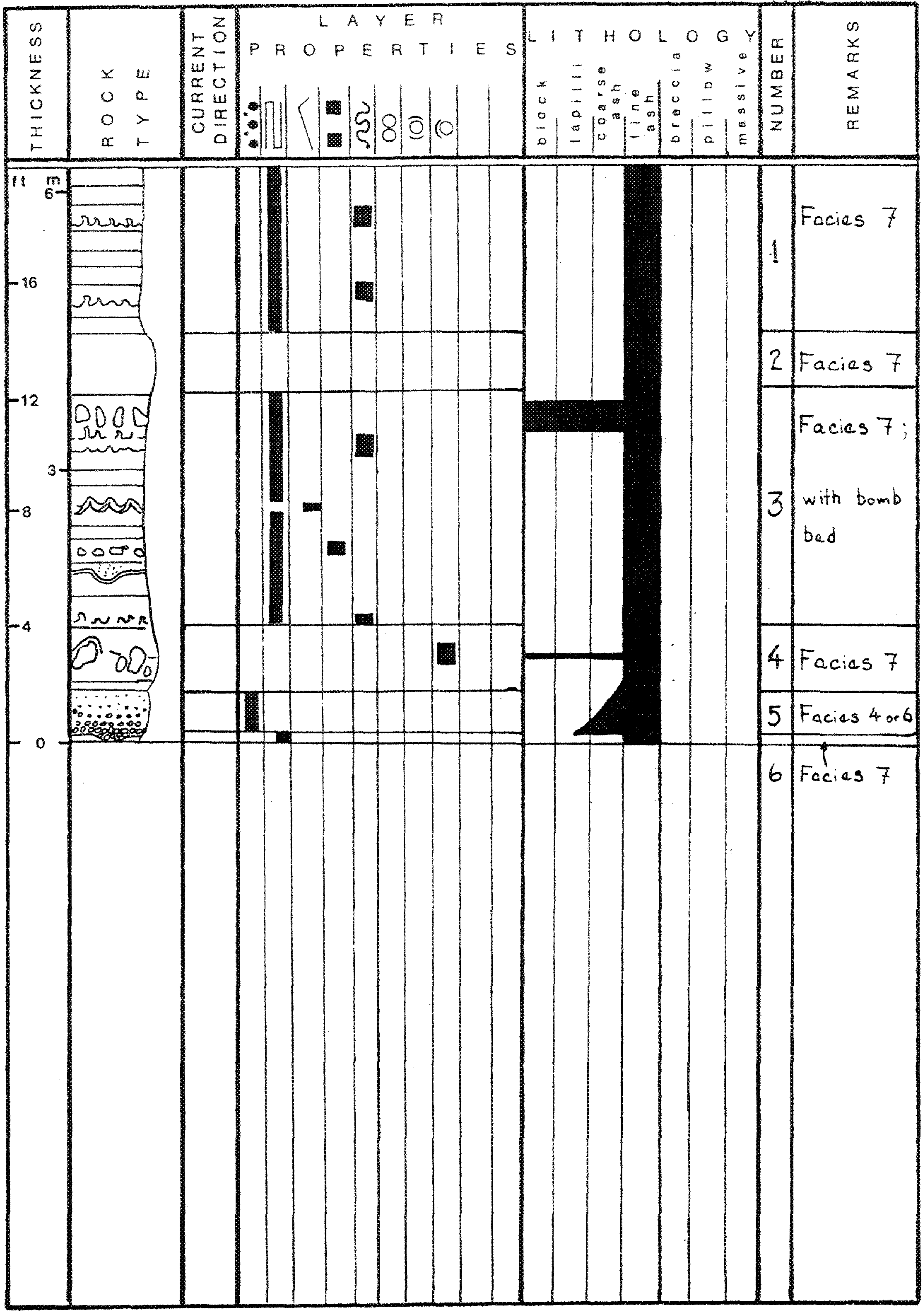


THICKNESS
ROCK TYPE
CURRENT DIRECTION
LAYER PROPERTIES
LITHOLOGY
block
lapilli
coarse ash
fine ash
breccia
pillow
massive
NUMBER
REMARKS
ft m
6
16
12
3
8
4
0
1 Facies 7; lenticular layers of Facies 6
2 Facies 6
3 Facies 7
4 Facies 7
5 Facies 3c

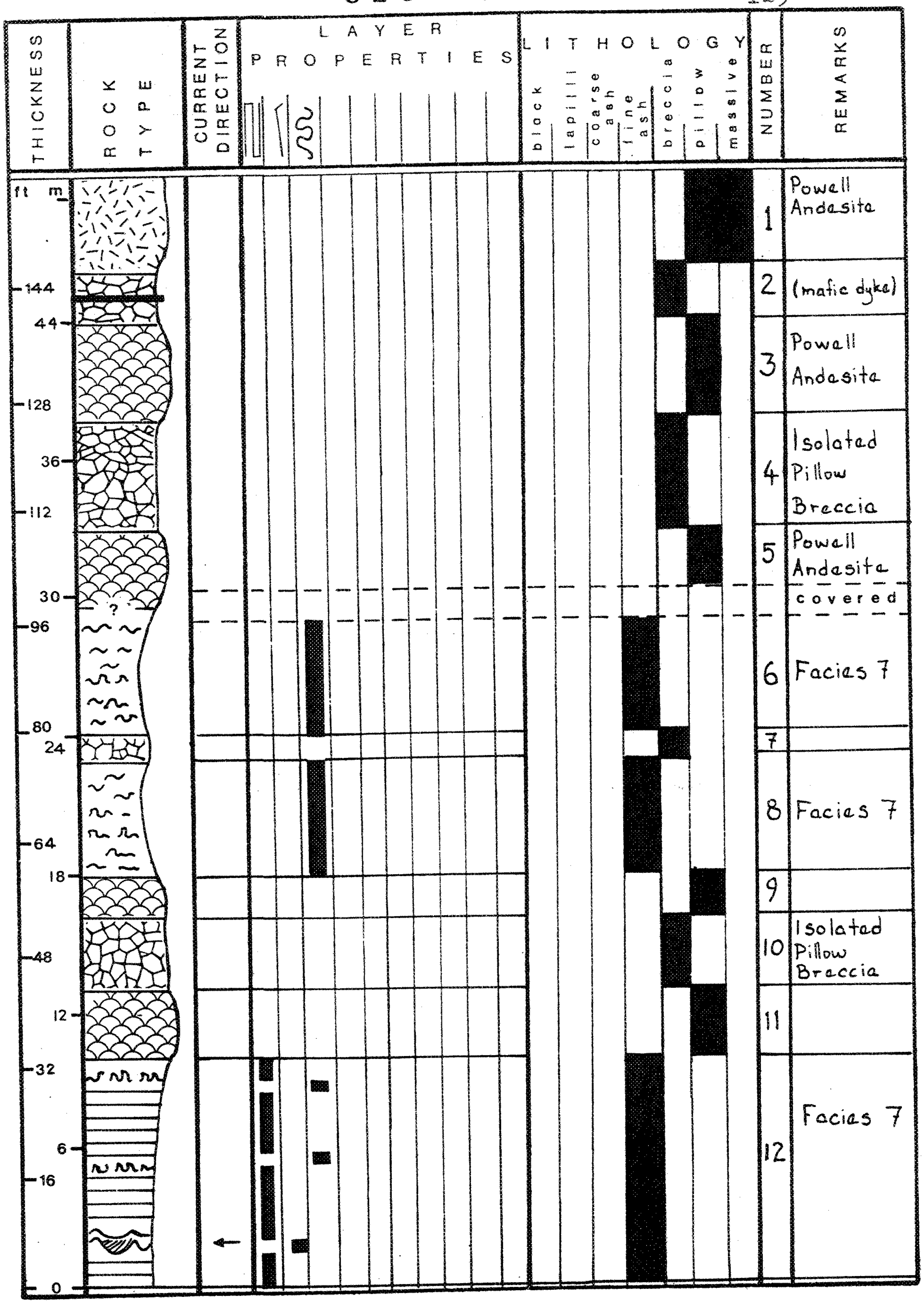
SECTION 4B


THICKNESS
ft m
ROCK TYPE
CURRENT DIRECTION
LAYER PROPERTIES
LITHOLOGY
block
lapilli
coarse ash
fine ash
breccia
pillow
massive
NUMBER
REMARKS
15
48
40
12
32
9
24
6
16
3
8
0
1 Facies 7; minor ash lenses of Facies 6
2 Facies 5; with two turbidite beds.
3 Facies 5 with upward coarsening cycles.
4 Facies 7
5 Facies 5 with block lenses
6 Facies 4c. Powell Rhyolite
7 Facies 3c Powell Rhyolite

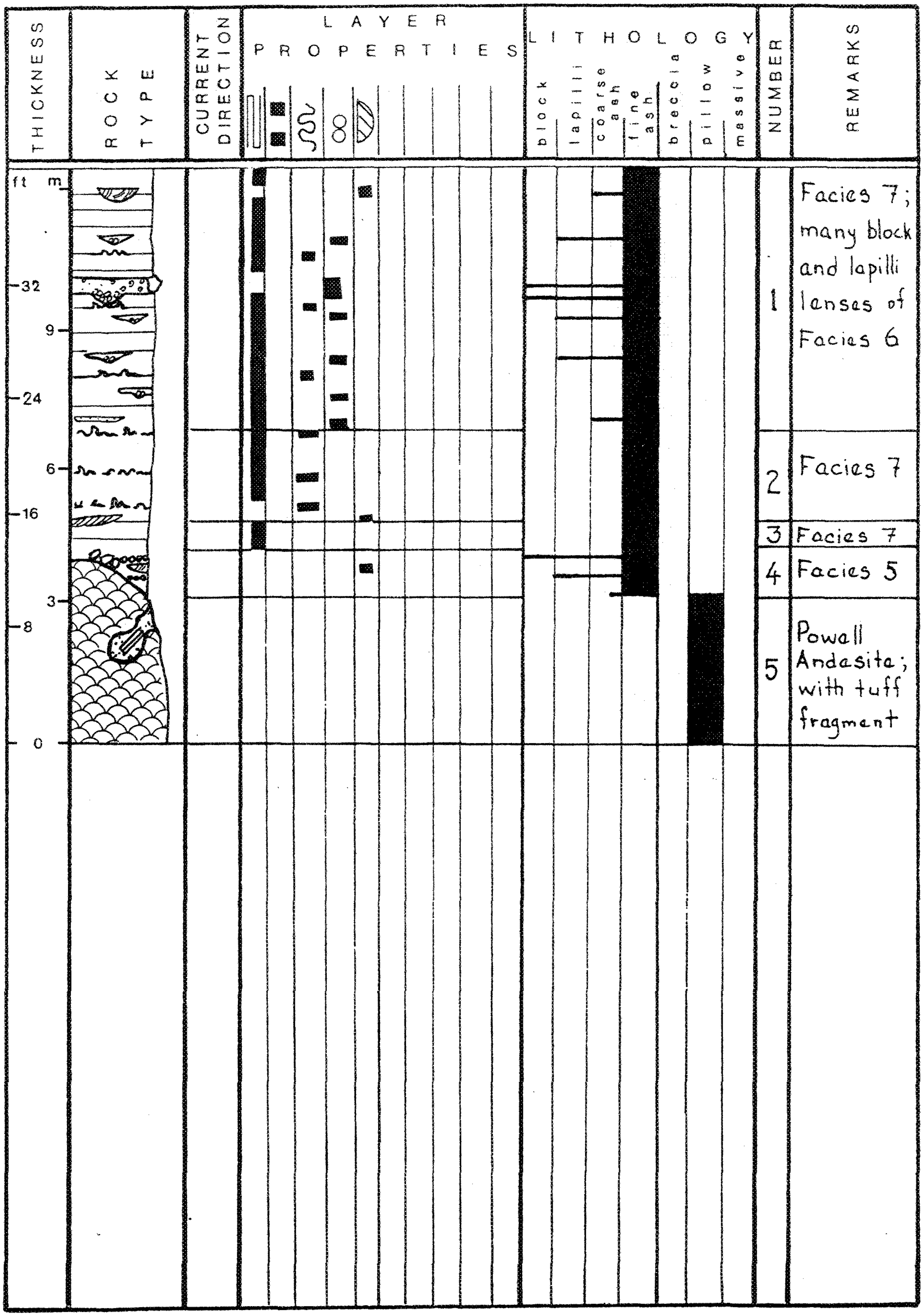
SECTION 4C


THICKNESS
ROCK TYPE
CURRENT DIRECTION
LAYER PROPERTIES
LITHOLOGY
block
lapilli
coarse ash
fine ash
breccia
pillow
massive
NUMBER
REMARKS
ft m
6
16
12
3
8
4
0
1 Facies 7
2 Facies 7
3 Facies 7; with bomb bed
4 Facies 7
5 Facies 4 or 6
6 Facies 7

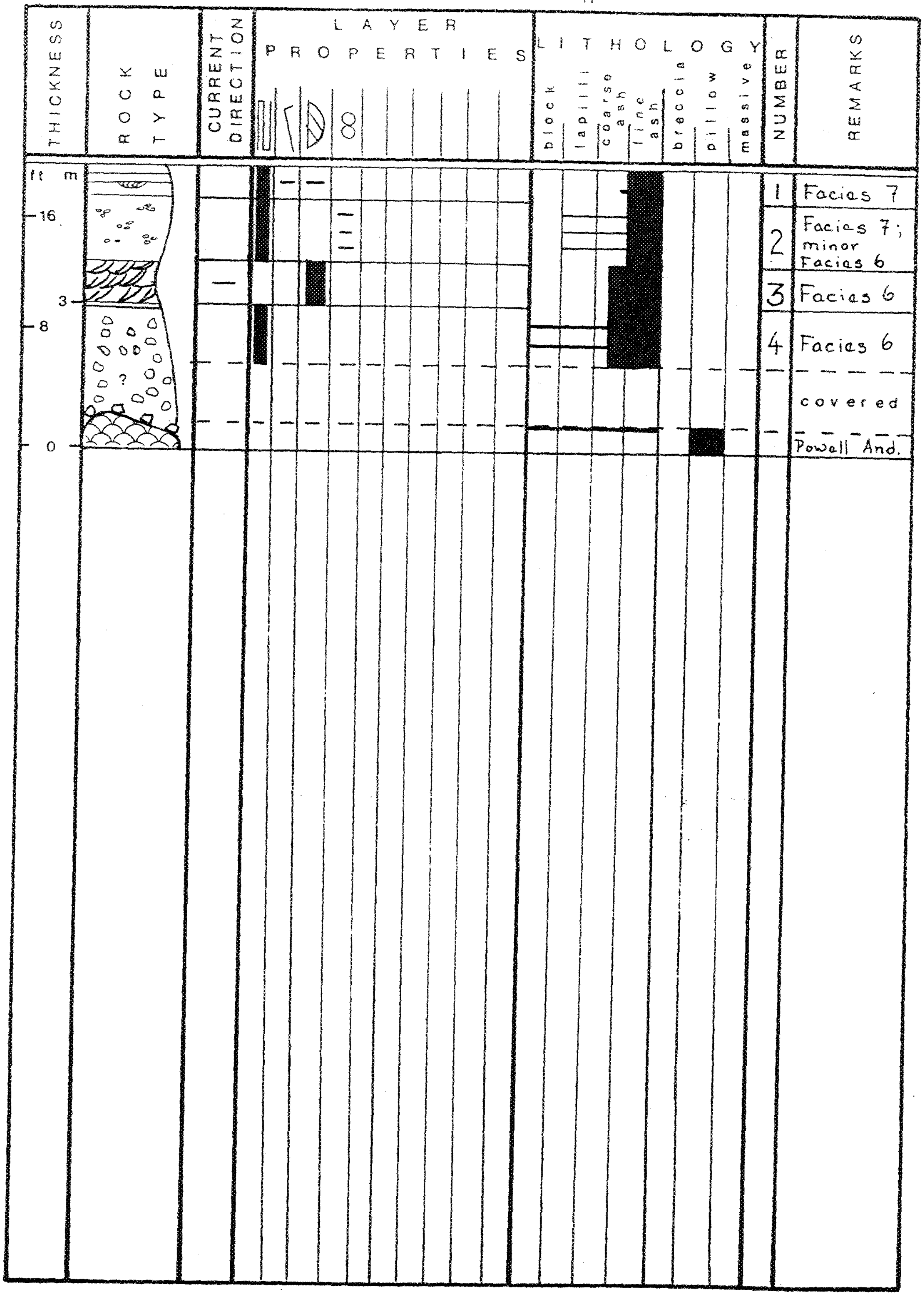
SECTION 4D


THICKNESS
ROCK TYPE
CURRENT DIRECTION
LAYER PROPERTIES
LITHOLOGY
block
lapilli
coarse ash
fine ash
breccia
pillow
massive
NUMBER
REMARKS
ft m
144
44
128
36
112
30
96
80
24
64
18
48
12
32
6
16
0
1 Powell Andesite
2 (mafic dyke)
3 Powell Andesite
4 Isolated Pillow Breccia
5 Powell Andesite
covered
6 Facies 7
7
8 Facies 7
9
10 Isolated Pillow Breccia
11
12 Facies 7

SECTION 4E

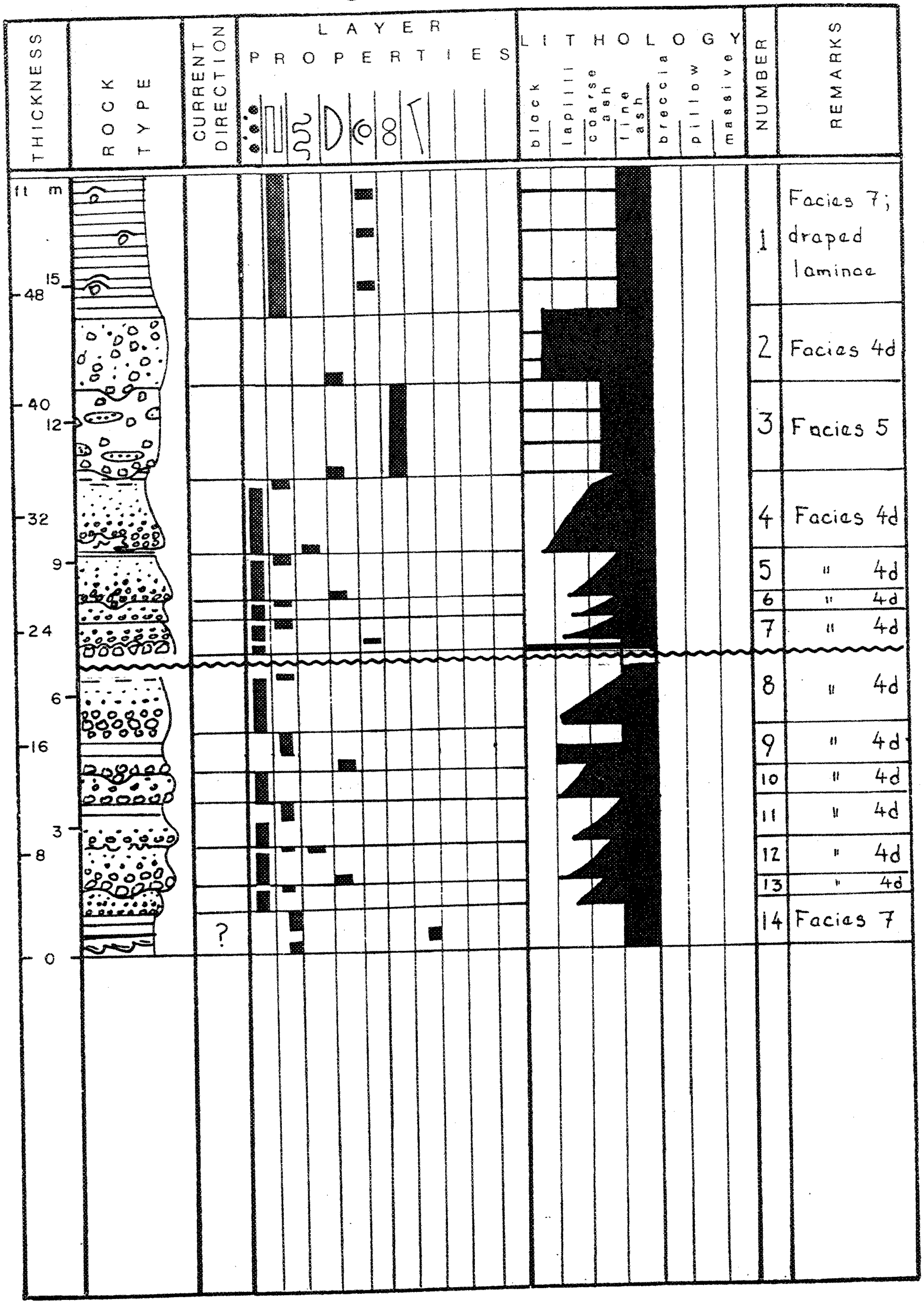

THICKNESS
ROCK TYPE
CURRENT DIRECTION
LAYER PROPERTIES
LITHOLOGY
block
lapilli
coarse ash
fine ash
breccia
pillow
massive
NUMBER
REMARKS
ft m
32
9
24
6
16
3
8
0
1
Facies 7; many block and lapilli lenses of Facies 6
2
Facies 7
3
Facies 7
4
Facies 5
5
Powall Andesite; with tuff fragment

SECTION 4F

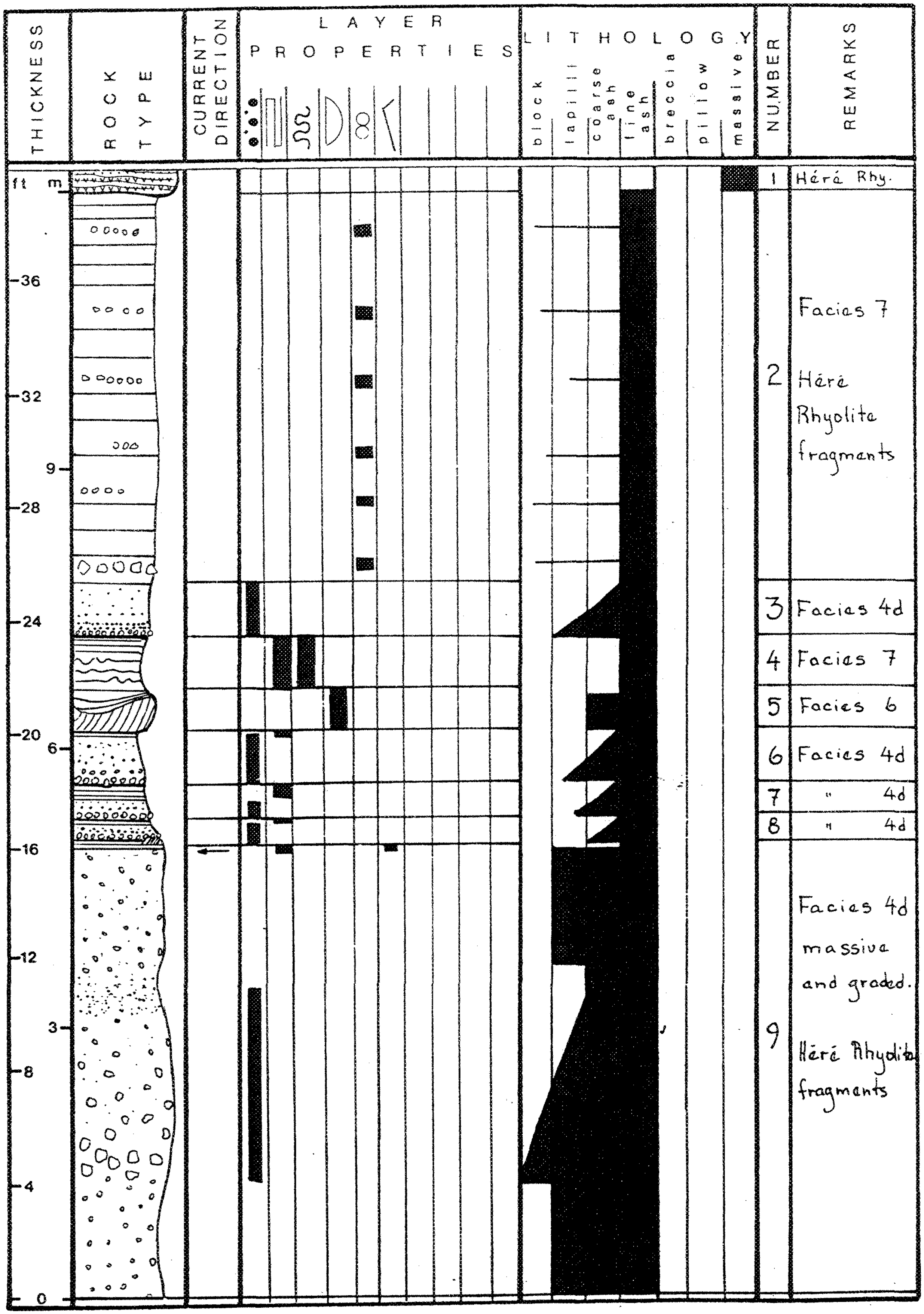


THICKNESS
ROCK TYPE
CURRENT DIRECTION
LAYER PROPERTIES
LITHOLOGY
block
lapilli
coarse ash
fine ash
breccia
pillow
massive
NUMBER
REMARKS
ft m
16
3
8
0
?
1 Facies 7
2 Facies 7; minor Facies 6
3 Facies 6
4 Facies 6
covered
Powell And.

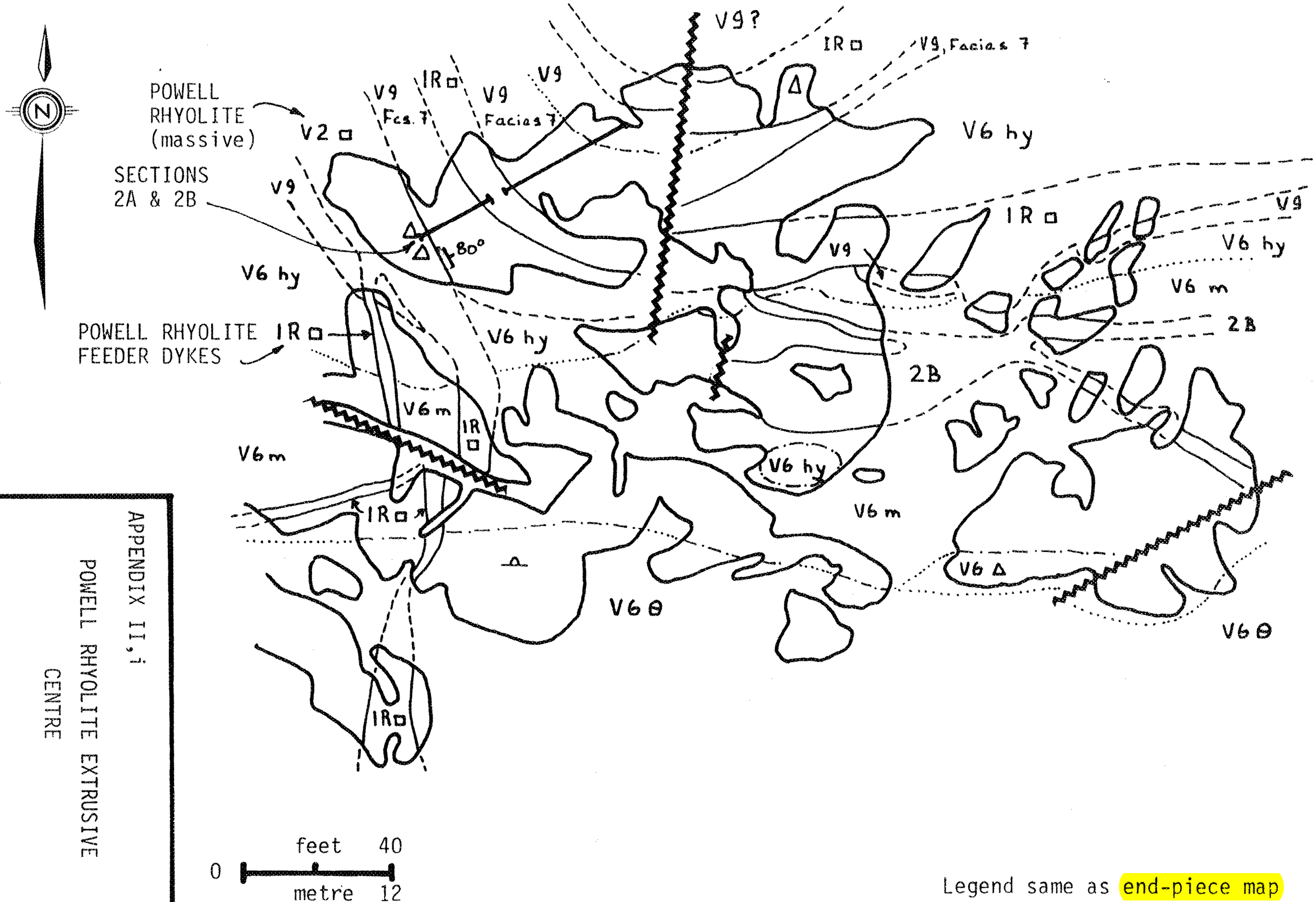
SECTION 4G


THICKNESS
ROCK TYPE
CURRENT DIRECTION
LAYER PROPERTIES
LITHOLOGY
block
lapilli
coarse ash
fine ash
breccia
pillow
massive
NUMBER
REMARKS
ft m
48
15
40
12
32
9
24
6
16
3
8
0
?
1 Facies 7; draped laminae
2 Facies 4d
3 Facies 5
4 Facies 4d
5 " 4d
6 " 4d
7 " 4d
8 " 4d
9 " 4d
10 " 4d
11 " 4d
12 " 4d
13 " 4d
14 Facies 7

SECTION 4H


THICKNESS
ROCK TYPE
CURRENT DIRECTION
LAYER PROPERTIES
LITHOLOGY
block
lapilli
coarse ash
fine ash
breccia
pillow
massive
NUMBER
REMARKS
ft m
36
32
9
28
24
20
6
16
12
3
8
4
0
1 Héré Rhy.
2 Facies 7 Héré Rhyolite fragments
3 Facies 4d
4 Facies 7
5 Facies 6
6 Facies 4d
7 " 4d
8 " 4d
9 Facies 4d massive and graded. Héré Rhyolite fragments

APPENDIX II



Legend same as end-piece map

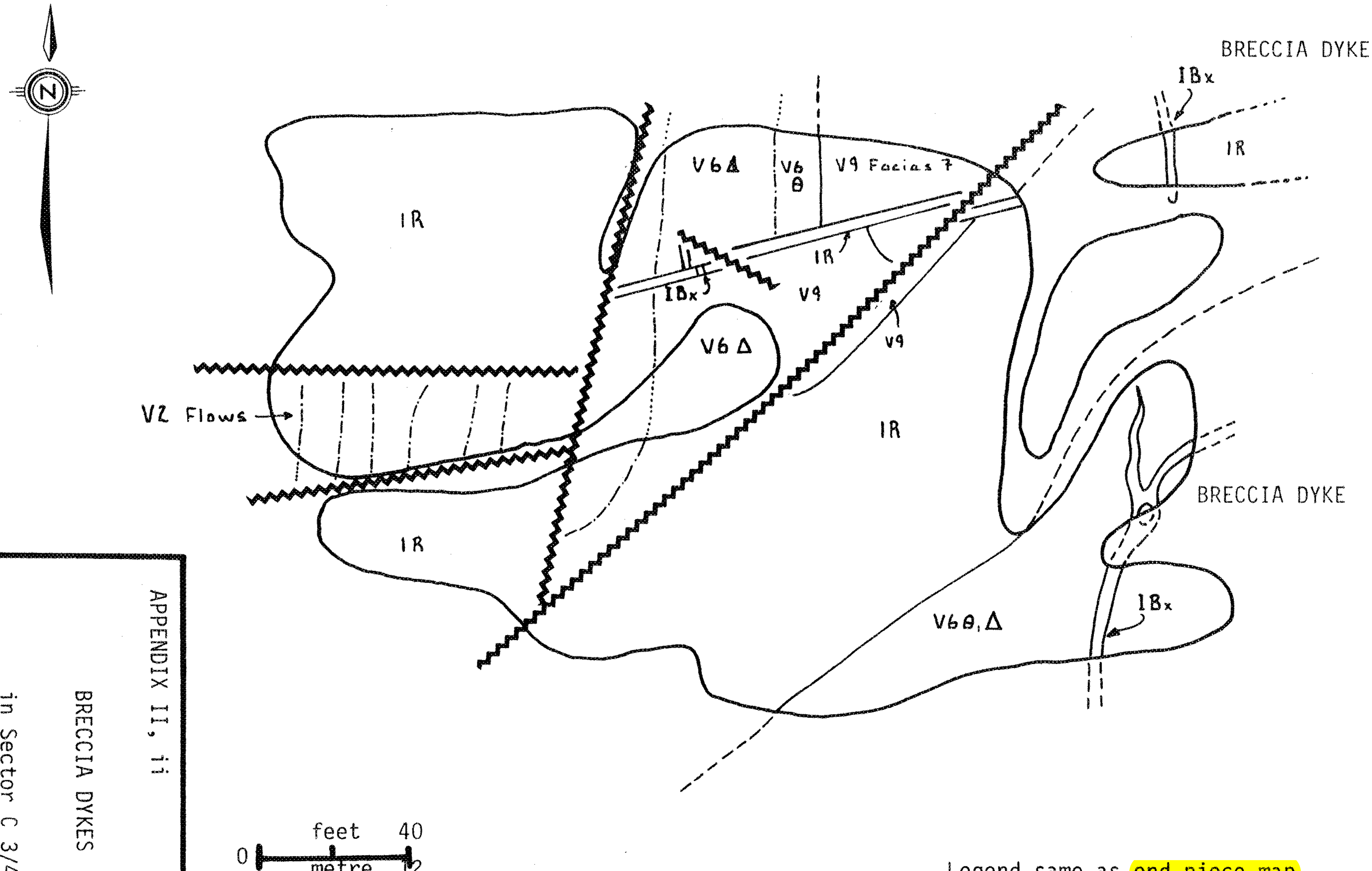
APPENDIX II,i

POWELL RHYOLITE EXTRUSIVE CENTRE

APPENDIX II, ii

BRECCIA DYKES

in Sector C 3/4



Legend same as end-piece map