Geological Report GR86-1

Geology of the Southern Part of the Rusty Lake Volcanic Belt

By D.A. Baldwin

Manitoba
Energy and Mines
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INTRODUCTION

The Ruttan Lake, Karsakuwigamak Lake, Muskayk Lake area covers approximately 435 km^2 and includes parts of National Topographic Series map sheets 64B/5, 64B/6, 64B/11 and 64B/12. The geology of the area was mapped at a scale of 1:20 000 and is displayed at 1:50 000 (Map GR86-1-1, in pocket). The area is bounded on the north by the 23rd Base Line and in the south by latitude 56°20'45". The east and west boundaries are longitudes 99°15' and 99°45' respectively. The location and boundaries of the area are shown in Figure 1. The area is accessible by road from Winnipeg, Thompson, Lynn Lake and Leaf Rapids. Leaf Rapids is also accessible by air from Winnipeg, Lynn Lake and Thompson. An all-weather road that connects Southern Indian Lake with Leaf Rapids passes through the map area and a winter road connects this all-weather road to Karsakuwigamak Lake. A network of drill roads and trails, that can be traversed with an all terrain vehicle, are present in the central and south-central parts of the area and are connected to the winter road and a Government Survey cut line.

Bedrock exposures are sporadic making up less than 10% of the surface area. Outcrop is all but absent on lake shorelines and inland is covered with lichen and/or a thin (up to 10 cm) layer of moss and organic material. This layer can be peeled from the outcrops, and generally provides the cleanest and best quality outcrop.

PRESENT WORK

Alcock (1921) made a track survey along the Rat River and subsequently the area, or parts of it, have been mapped, or investigated, by Wright (1953), Burwash (1962), Milligan (1964), Pearse (1964), Bristol (1966), Steeves and Lamb (1972) and Gilbert (1974).

Exploration for mineral deposits began in the 1950s, and the first recording of assessment work on a mining claim in the area was made in 1959. The discovery of the Ruttan Lake Cu-Zn deposit by Sherritt Gordon Mines Ltd., in 1969, and the release of an airborne INPUT electromagnetic and magnetic survey (Questor Surveys Ltd.) of the Southern Indian Lake region by the Manitoba Mines Branch in June, 1969, resulted in a staking rush and exploration activity in most of the Rusty Lake greenstone belt. Baldwin (1982) compiled data on the area and described and classified the known mineral deposits and occurrences. The Quaternary geology and sand and gravel resources in the area have been reported by Ringrose and Large (1977).

The remapping of part of the Rusty Lake greenstone belt was a spin-off of a project designed to describe, document and evaluate Precambrian massive sulphide deposit potential in Manitoba (Gale et al., 1980), a joint Federal-Provincial project under the Non-Renewable

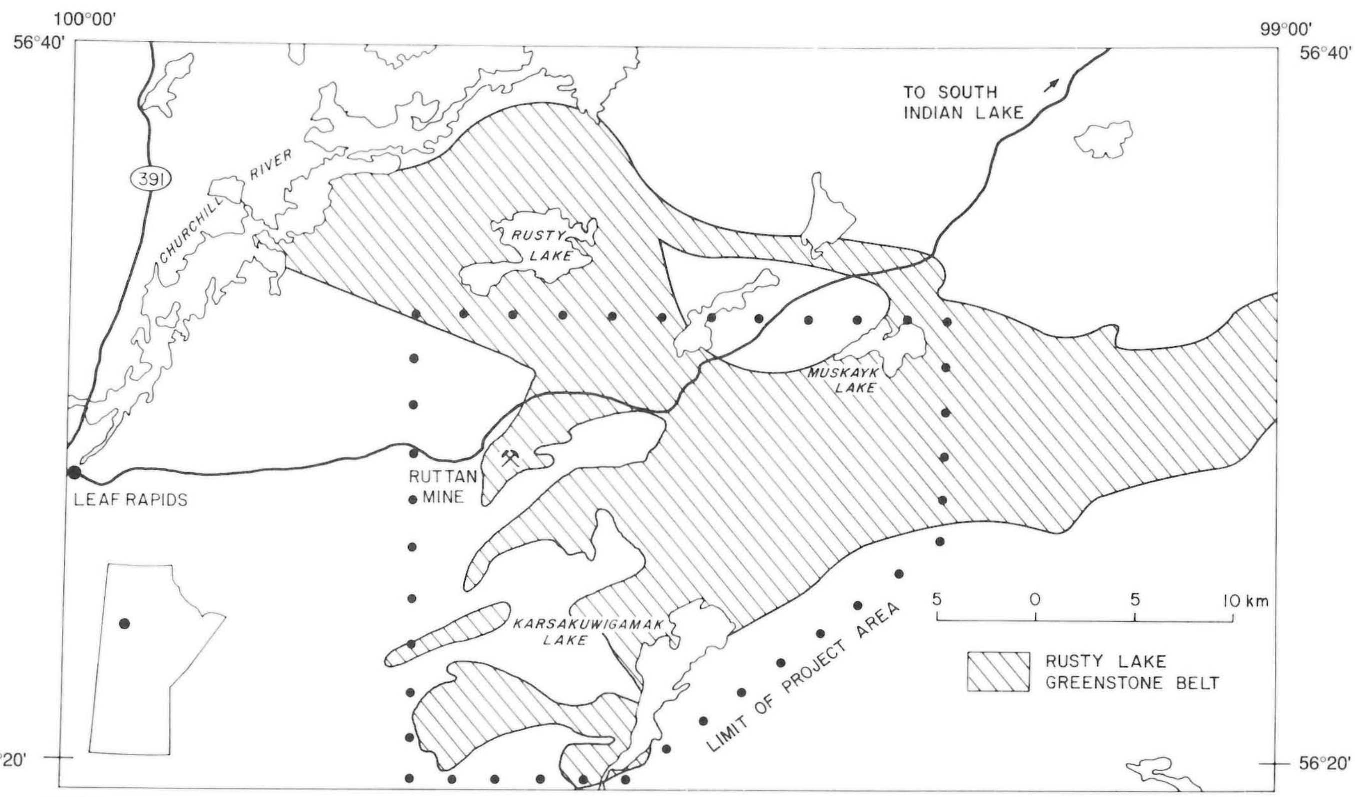

Figure 1: Geographic location of the Rusty Lake metavolcanic belt, its boundaries and the limits of the project area.

Resources Evaluation Program (NREP). During the course of this original project it was recognized that the existing geological data base was not sufficient for detailed mineral deposit studies. Furthermore, documentation of the stratigraphy of the volcanic rocks, and the interpretation of depositional environments and transport mechanisms of the volcanic and volcanic derived rocks had not been attempted by previous workers.

Mineral deposit documentation began in 1978 and continued to 1980 (Baldwin, 1982). Geological reconnaissance mapping started part way through the 1978 field season and from 1979 to 1981 mapping at 1:20 000 was carried out concurrently with mineral deposit investigations.

In most of the northwestern, eastern and central parts of the area traversing is facilitated by geophysical grids. Elsewhere standard pace and compass methods were used and helicopter support was employed to gain access to otherwise inaccessible parts of the area.

This report focusses on the stratigraphy of the volcanic and volcanic-derived rocks, their environment of deposition, mode of transport and genesis. Accordingly, many more lithologic units appear on the accompanying geological map (GR86-1-1) than on maps prepared by previous workers. The lithologies and their outcrop appearance are described in detail. The geology is described with respect to four subareas (fault blocks). Intrusive rocks, other than sills and dykes, are not discussed in this report and the reader is referred to Steeves and Lamb (1972) for lithological descriptions. Contact relationships between some of the intrusive rocks (quartz diorite) and the greenstones are described.

The metamorphic grade in the area is low, except at the margins of the greenstone belt, and as a result primary structures and textures are generally well preserved. Therefore, the terminology that is used in this report is that of primary rock types. Volcanic breccia terminology is after Fisher (1966a) and Parsons (1969). Grain size is according to the Wentworth scale and classification of epiclastic rocks is after Pettijohn (1975).

AVAILABLE MAPS, AERIAL PHOTOGRAPHS AND GEOPHYSICAL AND GEOLOGICAL REPORTS

The map area is within the Uhlman Lake sheet (64B) of the National Topographic Series at a scale of 1:250 000. The area also includes parts of the 1:50 000 scale series (64B/5, 64B/6, 64B/11 and 64B/12). These maps are available from the Manitoba Surveys Branch or from the Map Distribution Office in Ottawa.

Vertical aerial photographs at scales of one mile to the inch, one-half mile to the inch and 1:50 000 are available from the National Air Photo Library in Ottawa. The most recent aerial photographs are 1:50 000 scale and include changes in topography that resulted from hydroelectric development in the Southern Indian Lake area as well as all-weather and winter roads developed in conjunction with the hydroelectric project.

Claim maps of the area can be obtained from the Mining Recorder's office in either Winnipeg or The Pas.

The magnetic signature of bedrock in the area is displayed on Aeromagnetic Series maps 2388, 2389, 2396 and 2397 produced jointly by the Geological Survey of Canada and the Manitoba Mines Branch. An airborne INPUT electromagnetic and magnetic survey of the Southern Indian Lake region was flown by Questor Surveys Ltd. under contract to the Manitoba Mines Branch in 1968 (Manitoba Mines Branch, 1969). Sheets 7 and 10 from this survey cover the map area. A gradiometer survey that included the Rusty Lake metavolcanic belt was flown in 1985 and maps showing the results of this survey were published in 1986 as Geological Survey of Canada, Geophysical Series Maps C41100G, C41101G, C41102G and C41103G.

A compilation of geophysical data from non-confidential assessment files for the eastern part of the Lynn Lake greenstone belt (including the Rusty Lake greenstone belt) has been prepared by Hosain (1980).

The Aeromagnetic Series maps, the airborne INPUT survey maps, gradiometer survey maps and the geophysical compilation by Hosain (1980) are all available from Exploration Services, Manitoba Energy and Mines, Winnipeg. Copies of the geological reports and maps by Burwash (1962), Milligan (1964), Pearse (1964), Bristol (1966), Steeves and Lamb (1972) and Ringrose and Large (1977) are available at this same address. The reports by Alcock (1921) and Wright (1953) were published by the Geological Survey of Canada, Ottawa. These reports and the gradiometer maps are available from the Geological Survey of Canada, Ottawa.

ACKNOWLEDGEMENTS

M. Fedikow, D. Filteau and I. Trinder took part in the mapping program. Their careful field work has contributed much to the project. At various times during the project the following people assisted in the field: L. Paquin, R. Holm, B. MacGregor, D. Johnson, J. Parker, D. Stone, J. Harvey, J. Horvath, K. Kowalchuk, M. Benoit, and L. Cumming.

Thanks are due to Sherritt Gordon Mines Ltd. for access to their properties and for logistical support on numerous occasions and, in particular, to P.J. Chornoby for several field trips in, and numerous discussions about the geology of, the Rusty Lake metavolcanic belt.

Thin sections and etched slabs were prepared by the staff of the Rock Preparation Laboratory. E. Stockwell of Cartographic Services drafted the geological map and many of the figures that appear in the report. L. Chudy typed the tables and the staff of the Word Processing Centre typed the manuscript.

GENERAL GEOLOGY

REGIONAL SETTING

The Churchill Structural Province of northern Manitoba and northeastern Saskatchewan includes two main and several smaller metavolcanic belts that partially surround a large area of recrystallized and complexly deformed metasedimentary rocks (Fig. 2). The Lynn Lake metavolcanic belt, the Rusty Lake metavolcanic belt, the Flin Flon metavolcanic belt, and the metavolcanic rocks in the Scimitar Lake area discontinuously surround the Kisseynew metasedimentary gneiss belt. Collectively these belts of metavolcanic rocks have been termed the circum-Kisseynew volcanic belt (Sangster, 1978). Radiometric ages indicate that the supracrustal rocks are between 1800 and 1900 Ma old, and were deformed and metamorphosed prior to about 1750 Ma (Clark, 1980; Sangster, 1978). Basement rocks have not been recognized in the Lynn Lake and Rusty Lake metavolcanic belts, nor in the Kisseynew metasedimentary gneiss belt. Although late Archean to early Proterozoic strata were identified at Hanson Lake at the west end of the Flin Flon belt (Coleman, 1970), these volcanic rocks have now been dated at 1888 Ma (Van Schmus and Bickford, 1984). Felsic volcanic rocks from the Scimitar Lake area and the Lynn Lake metavolcanic belt yield U/Pb zircon ages of between 1910 and 1876 Ma (Van Schmus et al., 1987; Baldwin et al., 1987). The stratigraphically youngest rhyolite flow in the Karsakuwigamak Block in the Rusty Lake metavolcanic belt yielded a U/Pb zircon age of 1876 Ma (Baldwin et al., 1987).

In the Lynn Lake belt, Zwanzig (1976) suggested that metasediments that underlie a thick metavolcanic succession correlate with paragneisses of the Kisseynew belt. Subsequently, Gilbert et al. (1980) have traced metavolcanic units from the west end of the Lynn Lake metavolcanic belt into the upper parts of the Kisseynew belt. This suggests that volcanism in the Lynn Lake metavolcanic belt was coeval with sedimentation in the Kisseynew belt.

The Rusty Lake metavolcanic belt is 35 Ma younger than the Lynn Lake belt (Baldwin et al., 1987). It is physically separated from the Lynn Lake metavolcanic belt by 10 km of apparently older plutonic orthogneisses and it is bordered on the east, west, and south by younger Aphebian granitoid plutonic rocks.

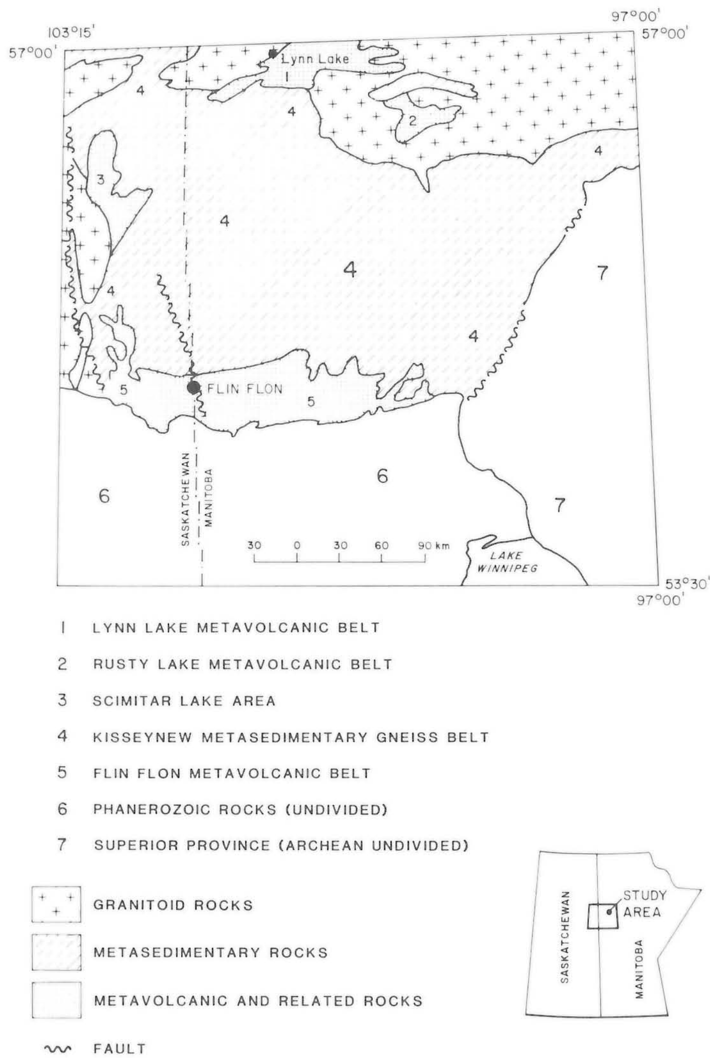

Figure 2: *Geological setting of the metavolcanic belts in the southwestern part of the Churchill Structural Province of northern Manitoba and northeastern Saskatchewan.*

Geological Framework

The Rusty Lake metavolcanic belt is typical of many Precambrian metavolcanic belts in that it comprises folded, faulted and metamorphosed basaltic and rhyolitic flows, pyroclastic deposits, volcanic derived sedimentary rocks and subvolcanic plutons. The rocks are regionally metamorphosed to greenschist and/or middle amphibolite facies. The metavolcanic belt is surrounded by batholithic plutonic terranes and metasedimentary gneiss belts.

The main structural elements in the Rusty Lake metavolcanic belt are three major faults identified as Fault 1, Fault 2 and Fault 3 (Fig. 3; Baldwin, 1982) that divide the metavolcanic belt into four fault blocks: Karsakuwigamak Block, Northern Block, Eastern Block and Ruttan Block. Position of the faults is inferred from local shearing, discontinuous stratigraphy, lithological contrasts, opposing facing directions and bedding dips, and from discontinuities in aeromagnetic and gradiometric trends. Strata in all fault blocks are steeply dipping. In the Northern, Eastern and Ruttan Blocks, stratigraphy can be traced within block boundaries but attempts to correlate stratigraphic units from one fault block to another have been largely unsuccessful.

Fault 4 divides the Karsakuwigamak Block into two segments (Fig. 3). Both segments contain a high proportion of felsic volcanic rocks but in the southeastern segment there is less than 1 per cent outcrop. Consequently the geology of the southeastern segment has been only grossly subdivided and stratigraphy has not been correlated across Fault 4. In the northwest segment of the fault block, stratigraphy can be traced across the area bounded by Faults 1, 3 and 4 (Fig. 3, Map GR86-1-1).

There appears to have been a 1 km left lateral displacement on Fault 1 following pluton emplacement, but the total displacement and true sense of displacement are unknown. Since stratigraphic units cannot be correlated from block to block, pre-pluton emplacement fault displacement must have been large. The sense and amount of displacement on

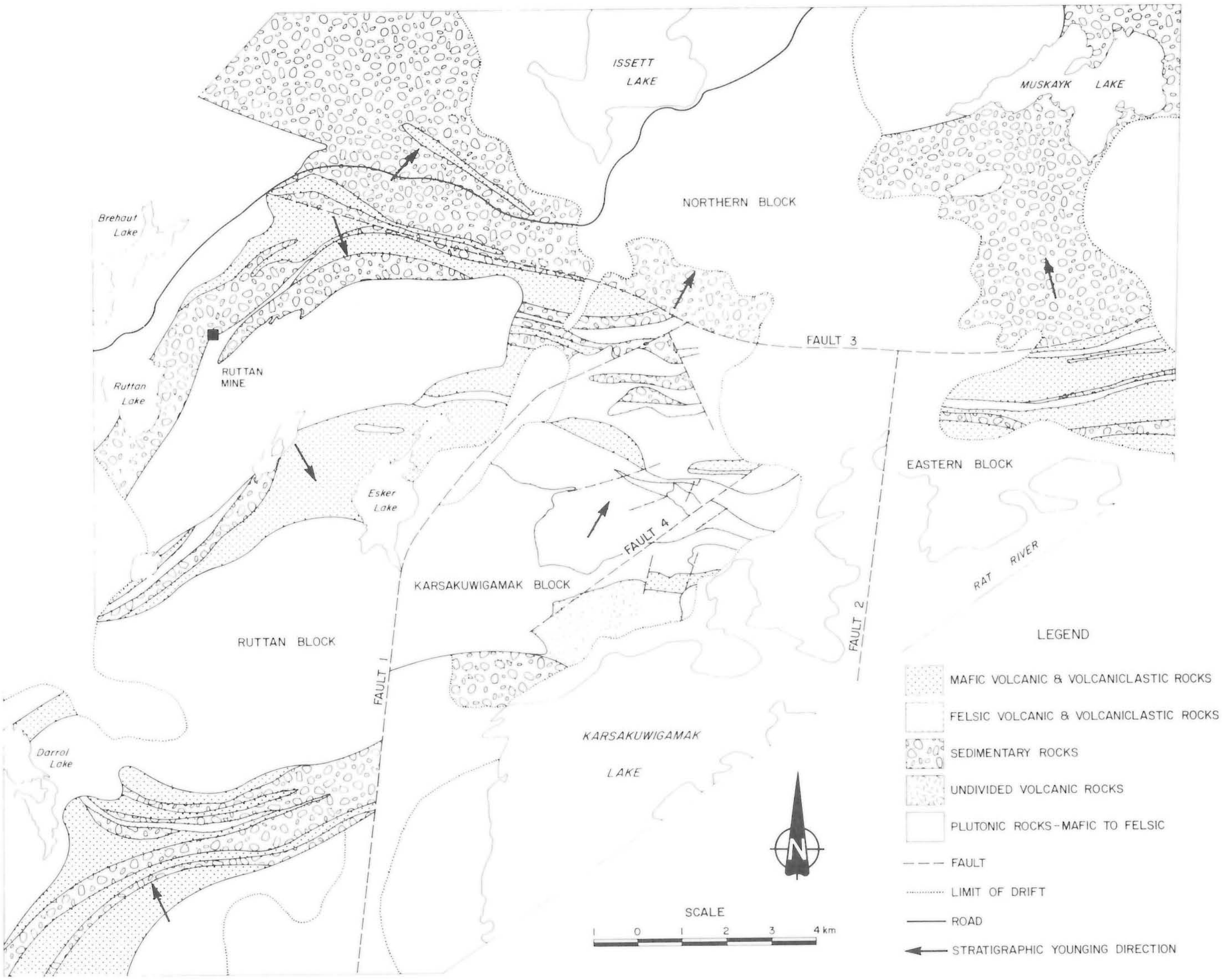

Figure 3: Simplified geological map of the southern part of the Rusty Lake metavolcanic belt.

Faults 2, 3 and 4 are unknown. Fault 3 apparently postdates Faults 1 and 2, and probably postdates Fault 4.

Younging directions in the Northern, Ruttan and Karsakuwigamak blocks have been determined from numerous primary volcanic and sedimentary structures. The Northern Block and the Karsakuwigamak Block each consist of a northerly facing homoclinal succession, but the Northern Block is overturned toward the north (Fig. 3, Map GR86-1-1). The Ruttan Block comprises two opposite facing homoclinal successions that are separated by a composite pluton. Reliable top indicators in the Eastern Block are scarce. However, top indicators that are present suggest that the block consists of a north-facing homoclinal succession.

Although all of the fault blocks are composed largely of volcanic and volcaniclastic rocks each block is lithologically diverse from neighbouring fault blocks (Fig. 4, Tables 1, 2, 3, 4 and 5). Rocks in the Northern Block are mainly sedimentary rocks formed from redeposition of volcanic material; basaltic flow rocks and sedimentary rocks composed of mixed volcanic and plutonic material are subordinate to the volcanic-derived sedimentary rocks. Both homoclinal sequences in the Ruttan Block are dominated by basaltic flow rocks. Volcanic-derived sedimentary rock units in the southern homoclinal succession are thinner and generally finer grained than those in the northern homoclinal succession. Felsic volcanic rocks make up a small proportion of both the northern and southern successions, but are thicker and more abundant in the northern of the two homoclinal successions. The Karsakuwigamak Block is almost totally composed of felsic flow rocks and felsic pyroclastic rocks. The remainder comprises mafic flow rocks, mafic pyroclastic rocks and felsic sedimentary rocks. The Eastern Block succession is largely mafic flow rocks with lesser mafic fragmental rocks and felsic volcanic rocks.

Regional metamorphic grade within the Rusty Lake metavolcanic belt is, for the most part, greenschist facies. Primary sedimentary structures, angular fragments, pillow shapes, bedding plane relationships, phenocryst shapes and spherical amygdules are commonly preserved and pronounced schistosity is absent in most areas, suggesting that penetrative deformation was slight. Middle amphibolite facies mineral assemblages occur at the margins of the metavolcanic belt, where fragments, amygdules and phenocrysts are flattened in the plane of a

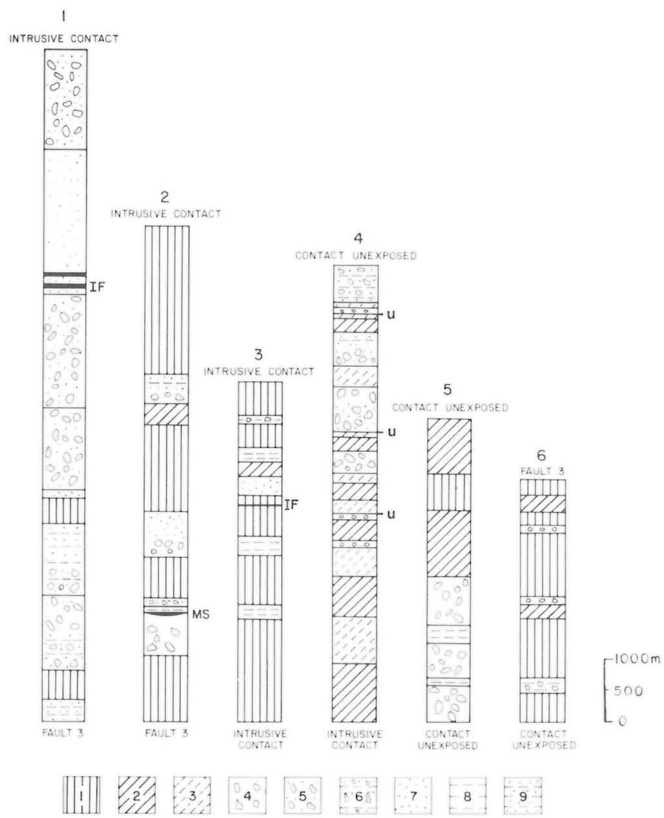

Figure 4: *Stratigraphic sections of the four fault blocks in the southern part of the Rusty Lake metavolcanic belt. Stratigraphic sections are: 1) Northern Block; 2) Ruttan Block, north domain; 3) Ruttan Block, south domain; 4) Karsakuwigamak Block, northwest segment; 5) Karsakuwigamak Block, southeast segment; 6) Eastern Block. Lithology symbols are: 1) mafic volcanic flows; 2) felsic volcanic flows; 3) felsic pyroclastic rocks; 4) volcanic conglomerate or heterolithic breccia; 5) volcanic conglomerate or volcanic and plutonic derived conglomerate, and sandstone; 6) volcanic conglomerate or volcanic and plutonic derived conglomerate, and sandstone and siltstone; 7) sandstone; 8) siltstone; 9) sandstone and siltstone; MS) massive sulphide; IF) iron formation; U) unconformity.*

pronounced schistosity; primary textures, sedimentary structures and bedding planes are destroyed or obscured.

Intrusive rocks include granite, quartz monzonite, granodiorite, gabbro and diorite. Plutonic bodies composed of granite, quartz monzonite and/or granodiorite are most abundant in the Ruttan and Karsakuwigamak blocks. Gabbro bodies are most abundant in the Karsakuwigamak Block and Northern Block. Gabbro and diorite sills and dykes occur in the Northern and Karsakuwigamak blocks. Diorite dykes are also present in the Ruttan and Eastern blocks.

LITHOLOGIES

INTRODUCTION

Supracrustal rocks in the Ruttan Lake, Karsakuwigamak Lake, Muskayk Lake area comprise volcanic and sedimentary rocks. The volcanic rocks include mafic and felsic extrusive rocks, pyroclastic rocks, and volcaniclastic rocks composed of redeposited pyroclastic material that had been subjected to little if any erosion prior to redeposition. Sedimentary rocks are for the most part volcaniclastic, but prior to and/or during secondary transport and redeposition the volcanic material was subjected to erosional processes. Other sedimentary rocks contain a mixed population of volcanic, plutonic and sedimentary detritus.

In the following lithologic descriptions, the text for each rock type is accompanied by a descriptive table that summarizes the features of each unit of that rock type according to stratigraphic order in each of the fault blocks where that rock type occurs, and by a figure that shows the stratigraphic distribution of that rock type in each fault block. The alphabetical identifier for each lithologic unit, located to the left of the stratigraphic columns in each of these figures, corresponds to the description of that unit in that fault block, which is similarly identified in the corresponding descriptive table.

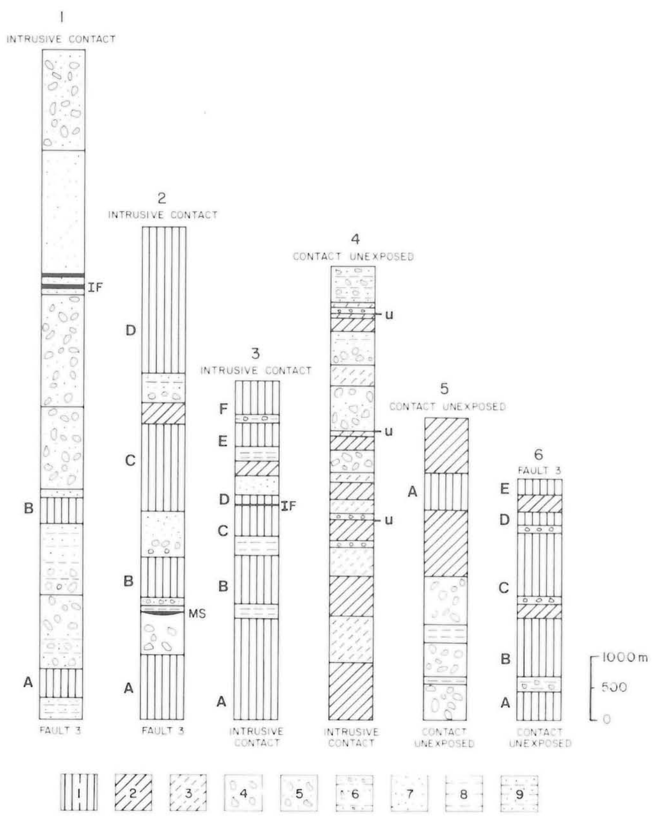

Figure 5: Stratigraphic distribution of units comprising basalt flows. Stratigraphic columns and symbology are the same as for Figure 4.

BASALT FLOWS

General Statement

Lithologic units that are composed of a sequence of basalt flows are present in all fault blocks, but they are most abundant in the Ruttan Block and the Eastern Block (Map GR86-1-1, in pocket). The maximum thickness of basalt flow sequences ranges from 100 to 2000 m, but most are between 100 and 875 m (Fig. 5; Table 6). The thickest units occur in the Ruttan Block and the Eastern Block, but those in the Ruttan Block are generally thicker than those in the other fault blocks. The thickness of individual flows ranges from 1 to 30 m, but most commonly maximum flow thickness is 6 to 15 m and rarely exceeds 20 m. Basalt flows are fine grained and can have aphyric, plagioclase-phyric, plagioclase- and hornblende-phyric, or hornblende-phyric texture. Flow facies include massive, pillowed, brecciated and interflow tuff, or the flows are differentiated. Flow breccia is associated with massive and pillowed facies in flows. Commonly lateral variations in the abundance of massive, pillowed and breccia facies indicate transport directions. The distribution and the relationships between textures and structure of basalt flows in each fault block are shown in Figure 5 and summarized in Table 6.

Aphyric flows occur in the Northern, Ruttan and Karsakuwigamak blocks. Plagioclase- and hornblende-phyric flows occur in the Ruttan Block and the Eastern Block. Plagioclase-phyric flows are present in only the Northern Block and the Karsakuwigamak Block. Hornblende-phyric flows occur in only the Ruttan Block where they are more common in the south domain than in the north domain (Table 6). Most commonly the flows in a flow sequence have similar texture (Table 6). For example, the flow sequences in the Eastern Block are plagioclase- and hornblende-phyric and most flow sequences in the Ruttan Block are hornblende-phyric. Less commonly flow sequences contain flows with different textures (Table 6). For example, the flow sequences in the Northern Block and the Karsakuwigamak Block contain both aphyric and plagioclase-phyric flows, and some sequences in the Ruttan Block contain aphyric and plagioclase- and hornblende-phyric flows (Table 6).

Massive, and massive to brecciated flows are present in all fault blocks whereas pillowed flows are absent in the Eastern Block; differentiated flows are present in only the south domain of the Ruttan Block (Table 6). Breccia and interflow tuff are nearly ubiquitous with massive and pillowed flow facies. Most commonly basalt contains less than 10% vesicles but in the Eastern Block flows with 20 to 40% vesicles are common. Pillowed flows are most commonly plagioclase-phyric. Pillows do not occur in hornblende-phyric flows. Aphyric flows are predominantly massive, but pillowed flows in aphyric basalt are common (Table 6). Differentiated flows are hornblende-phyric.

Basalt flow sequences may be composed entirely of massive, massive to brecciated or differentiated flows, but never of pillowed flows only, although pillowed flows can be the most abundant flow type in a basalt unit (Table 6).

Flow Morphology

Variations in the internal structure of massive, and massive to brecciated basalt flows are shown in Figure 6. Rarely are flows totally composed of massive basalt. Most commonly a 2 to 6 m thick lower zone of massive basalt is gradational upward into a 15 cm to 1.5 m thick zone of flow breccia. The flow breccia is in turn overlain by a zone of basaltic tuff that ranges from zero to 20 m thick, although most commonly it is less than

Figure 6: *Schematic diagram of flow morphologies in massive and brecciated basalt flows in the southern part of the Rusty Lake metavolcanic belt.*

40 cm. Flow breccia most commonly comprises monolithic angular, or angular to subrounded blocks, or blocks and lapilli, that are mineralogically and texturally the same as basalt in the massive zone, supported in a fine grained, mafic, granular, tuffaceous matrix. In some flows, flow breccia contains pillows that have amoeboid shapes in addition to angular breccia fragments. Block and lapilli abundance in breccia zones ranges from 15 to 50%; however, it is consistent within any one flow. Basaltic tuff is characterized by 10 to 20% angular to subrounded basalt fragments, 0.3 to 2.5 cm diameter, that are supported in a matrix similar to the matrix of flow breccia in the underlying breccia zone. One or more of the structural divisions may be absent in a flow. Flow contacts are commonly defined by a basal 2 to 5 cm thick layer of aphanitic and aphyric basalt that has a sharp lower contact and a gradational upper contact. This layer is interpreted to be a chilled flow contact. Interflow tuff is similar to the matrix of flow breccia and basaltic tuff. Interflow tuff is common in some basalt flow sequences (Table 6) but it is not present between all flows. Where it does occur it forms 1 to 7 cm thick, massive layers that have sharp contacts with adjacent flows.

Massive flows in basalt units A and B in the Northern Block have a basal massive zone, a central breccia zone composed of basalt blocks and lapilli, and an upper basaltic tuff zone. In the Karsakuwigamak Block, massive basalt flows have a thin layer of the mafic fine grained granular mosaic, overlying and in sharp contact with a central block and lapilli breccia zone (Fig. 7). They do not have a basaltic tuff zone.

Massive flows in basalt units A and B in the north domain of the Ruttan Block are similar to those in the Northern Block. Small size and scarcity of outcrops, as well as local lichen cover on outcrops, in the remainder of the Ruttan Block (north and south domains) does not permit documentation of flow morphology. However, locally all structural zones have been observed but not in a single outcrop, nor in adjacent outcrops that could be the outcrop of a single flow. In the Eastern Block exposure is sparse and outcrops of basalt units exhibit only the massive structural zone.

Locally lateral variations in the proportion of massive basalt, flow breccia and basaltic tuff can be determined. In basalt unit B in the Northern Block there is an eastward decrease in the thickness of massive basalt zones and a concomitant increase in thickness and abundance of flow breccia. This same variation occurs in a westward direction in basalt unit

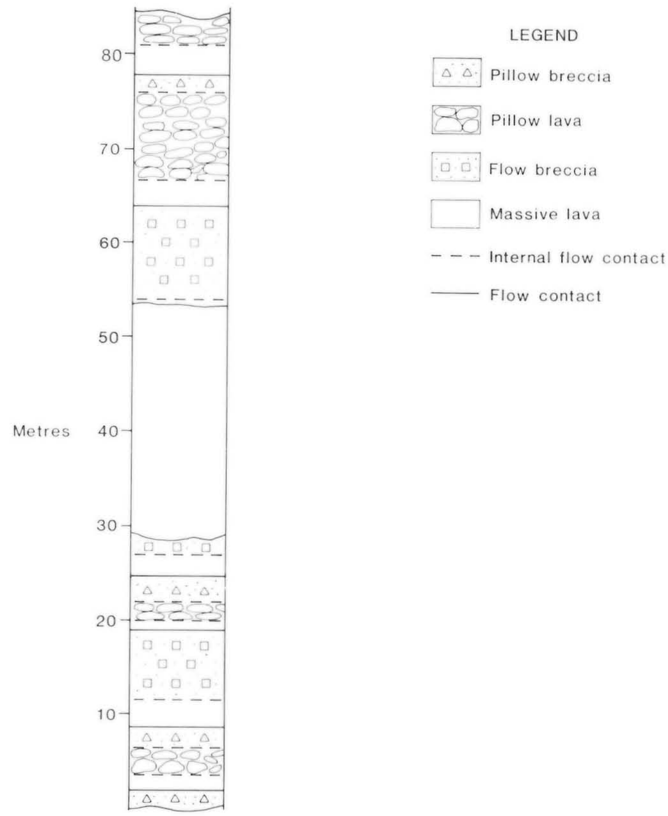

Figure 7: *Measured section of unit comprising basalt flows in southeast segment of the Karsakuwigamak Block, Rusty Lake metavolcanic belt.*

B in the north domain of the Ruttan Block. Local variations in facies abundance also occur in basalt units D in the north domain of the Ruttan Block and in basalt units A, C and D in the south domain of the Ruttan Block. However, outcrop abundance is not sufficient to determine the significance of these facies variations.

The general organization of structural zones in basalt pillowed flows is shown in Figure 8. Massive basalt, 40 cm to 3 m thick, is overlain by a 5 to 20 m thick zone of densely packed pillows; it is overlain by 2 to 7 m of breccia comprising intact pillows and fragments of pillows, supported in mafic tuff. Amoeboid pillows are present in some of these breccia zones. Breccia zones are overlain by a zero to 50 cm thick zone of basaltic tuff comprising angular to subrounded fragments 0.3 to 1.5 cm in diameter that are lapilli supported in fine grained tuffaceous mafic material. Rarely are all structural zones present in a single flow. Most commonly the massive and basaltic tuff zones are absent. Flow contacts are commonly defined by a chilled zone between massive or pillowed basalt and underlying breccia or basaltic tuff. A basal chilled zone is apparently not present where pillows overlie flow breccia or basaltic tuff. Here, pillows have flat bottoms and bulbous tops. Some flow contacts can be inferred from adjacent outcrops that have different phenocryst populations or different structural zones present in the same stratigraphic order as in completely exposed flows. Interflow tuff is similar to that associated with massive flows.

Pillows in aphyric flows are generally elliptical and 15 to 50 cm across. They rarely exceed 75 cm and may decrease in size upward in a flow. Pillow selvages are less than 1 cm wide and commonly 0.5 cm. Internally, pillows are massive and amygdules occur within a few centimetres of the selvage. Breccia zones associated with aphyric pillowed flows contain elliptical pillows and/or amoeboid pillows and angular basalt

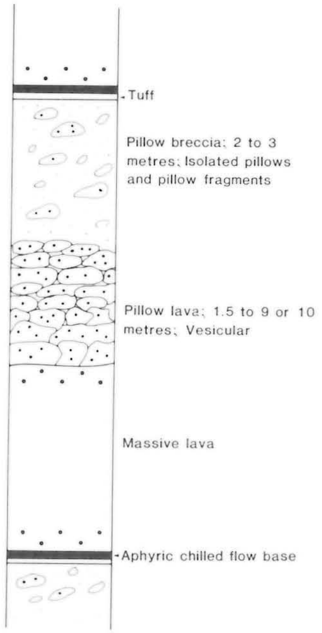

Figure 8: *Schematic diagram of flow morphology in basalt pillowed flows, southern part of the Rusty Lake metavolcanic belt.*

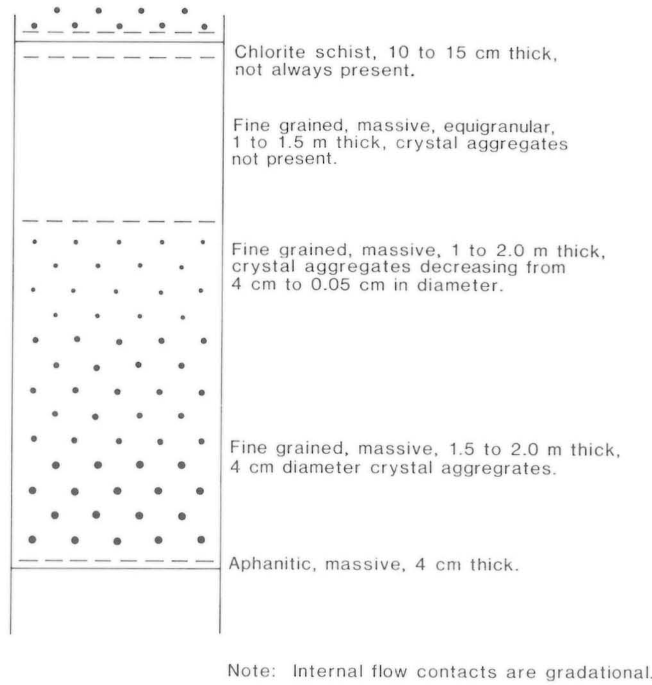

Figure 9: *Schematic diagram of flow morphology in differentiated basalt flows.*

fragments. Individual pillows are 5 to 20 cm across; amoeboid pillows are elongate parallel to flow contacts and are 6 to 30 cm long. Angular fragments are generally lapilli-size and rarely up to 15 cm across. Breccia containing fragments of pillows are not present in aphyric flows.

In plagioclase-phyric and plagioclase- and hornblende-phyric pillowed flows, pillows are generally bun-shaped and less commonly elliptical. The long dimension of these pillows is 30 to 60 cm. Selvages are up to 2 cm wide, and concentric and/or radial cooling fractures are locally a common feature in these pillows. Amygdules are concentrated in the tops of pillows within a few centimetres of the selvage, and decrease in abundance toward pillow interiors. Breccia zones in these pillowed flows comprise pillows similar in shape but generally half as large as those in densely packed pillowed zones, broken pillows, and angular to subrounded basalt fragments supported in a fine grained basaltic tuffaceous matrix.

Lateral variations in the abundances of structural zones in pillowed flows are known for two basalt units. In basalt unit A in the Northern Block, thicknesses of densely packed pillow zones decrease and thicknesses of breccia zones increase eastward. In the west, breccia composes about 30% of the unit thickness, whereas in the east it composes 75%. Locally in the east, basaltic tuff zones are up to 20 cm thick; in the west they are less than 5 cm thick. Although basalt unit A in the north domain of the Ruttan Block thins rapidly westward, breccia is more abundant in the west. Elsewhere in the area outcrop is sparse or units are truncated by faults and intrusions (e.g. Karsakuwigamak Block) and lateral variations are unknown.

Differentiated flows are hornblende-phyric and occur in only the southern domain of the Ruttan Block where they are the only flow type present in basalt units C, D and F. In units A and B they are the most abundant flow type (Table 6). Differentiated flows comprise a lower porphyritic zone overlain by and in gradational contact with a fine grained, massive, equigranular generally aphyric zone that is in turn overlain by and in gradational contact with a chlorite schist (Fig. 9). The chlorite schist is not always present. Flow contacts are defined by a basal chilled layer that is generally 4 cm thick and consists of very fine grained aphanitic massive basalt. Contacts between the chilled layer and porphyritic zone are generally gradational over a few millimetres but locally they are sharp.

The porphyritic zone contains hornblende phenocrysts that decrease in size and abundance upward. Most commonly phenocrysts range in size from 5 to 21 mm, but in some flows the maximum size is 8 mm. In the lower 50 to 70 m of basalt unit C porphyritic zones have glomeroporphyritic textures. Glomerocrysts are hornblende 0.05 to 4 cm in diameter, and decrease in size upward in porphyritic zones. In some of these flows, 2 to 5% of 0.5 to 1 mm hornblende phenocrysts commonly occur in the fine grained zones that overlie porphyritic zones.

Amygdules

Amygdules occur in aphyric, plagioclase-phyric and plagioclase- and hornblende-phyric basalt. Amygdules are round to oval and comprise quartz, quartz + plagioclase, quartz + plagioclase + carbonate, or quartz + plagioclase + epidote ± disseminated iron oxide (magnetite). In aphyric basalt amygdules are typically 1 to 2 mm in diameter, rarely 4 mm, and most commonly their mineralogy is quartz or quartz + plagioclase. In porphyritic flows in the Northern, Ruttan and Karsakuwigamak blocks, amygdules are less than 5 mm in diameter, most commonly between 2 and 3 mm, and most contain only quartz. Except for basalt units in the Eastern Block, basalt units in the area contain less than 10% amygdules. Flows in the Eastern Block contain 10 to 40% amygdules. Most commonly these amygdules are 5 to 7 mm in diameter but locally they are 1.5 cm diameter and all contain quartz, plagioclase and carbonate.

Alteration

Epidote alteration is a common characteristic of many basalt breccia and basaltic tuff zones in aphyric, plagioclase-phyric and plagioclase- and hornblende-phyric flows in the Northern Block and the Ruttan Block. The epidote alteration comprises a granoblastic mosaic of epidote, quartz and amphibole. Most commonly this alteration occurs in the upper

15 to 70 cm of flows where it forms an alteration blanket in flow breccia and basaltic tuff zones. Contacts between the alteration and the "unaltered" parts of flows are sharp to gradational. Less commonly the alteration occurs as elongated pods 10 to 20 cm wide and 1 to 10 m long at the top of or in the upper 1 m of flow breccia and basaltic tuff zones. Breccia matrix is more intensely altered than breccia fragments and the original brecciated nature of the altered rock is preserved as a mottled texture composed of these differing degrees of alteration. In addition, from place to place in some flows breccia fragments are partially replaced by epidote alteration and the co-existing breccia matrix appears not to be epidotized. In flow sequences the epidote alteration is not present in all flows. In some flows that are composed of only massive basalt the epidote alteration occurs in and adjacent to fractures in flow tops.

Genesis of Flow Breccia and Alteration

In all breccia facies in basalt flows the original nature of the breccia matrix has been destroyed by metamorphic recrystallization. In basalt flows composed of massive and/or pillowed basalt and associated breccia the breccia is monolithic, and breccia fragments are angular to subrounded and have the same mineralogy and texture as the associated massive and/or pillowed basalt; the contacts between the different structural zones in the flows are gradational. Therefore, it is assumed that the original components of the breccia matrix had the same composition as the associated breccia fragments and that these components were comminuted glassy basaltic particles. Because fragments of 0.3 cm in diameter can be recognized in some breccia zones the glassy particles were probably mainly ash-size.

The structural relationships of breccia composed of angular to subrounded blocks and lapilli and the nature of these particles are consistent with an autoclastic origin (Parsons 1969). On the other hand, the features of pillow breccia and the structural relationships of pillow breccia to pillow basalt are consistent with a hyaloclastic origin for pillow breccia (Dimroth et al., 1978). In addition the finer grained basaltic tuff zones that overlie coarser grained breccia zones, and in some flows overlie massive basalt or pillow basalt, have a grain size similar to hyaloclastic breccia. Thus, hyaloclastic fragmentation may be in part responsible for breccia formation in non-pillow breccia as well as in pillow breccia.

The thin tuff layers that occur between and in sharp contact with some flows in flow sequences are composed of very fine grained mafic material. It is suggested that these tuff layers are composed of hyaloclastically fragmented material that was suspended in and settled through a water column above the flows.

Epidote alteration is confined to the upper parts of and the very tops of breccia zones in basalt flows as well as in and adjacent to fractures at the tops of flows composed of only massive basalt. These features suggest chemical alteration at flow tops during or shortly after flow emplacement by reaction of fragmented and fractured basalt with seawater and/or by the circulation of fluids through fissure systems and permeable zones in flows. However, it may be expected that alteration caused by the circulating fluids in flows would occur at various stratigraphic positions in flows. Because of the confined distribution of the epidote alteration in the basalt flows, it appears more likely that the alteration in the basalt flows resulted from the interaction of fragmented and fractured basalt and seawater.

RHYOLITE AND DACITE FLOWS

General Statement

Lithologic units comprising rhyolite and/or dacite flows occur in the Ruttan, Karsakuwigamak and Eastern blocks; they are thickest and most

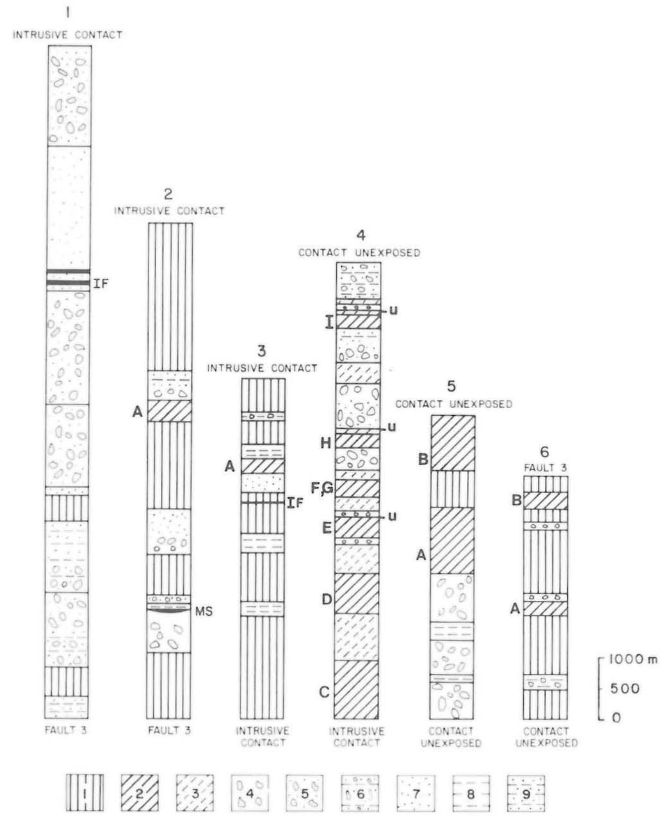

Figure 10: *Stratigraphic distribution of rhyolite and dacite flows in the southern part of the Rusty Lake metavolcanic belt. Stratigraphic columns and symbology are the same as for Figure 4.*

abundant in the Karsakuwigamak Block (Fig. 10; Table 7). Thickness of individual flows ranges from 0 to 250 m and phyric flows are generally thicker than aphyric flows. A lateral extent of 2 to 4 km for the units is a minimum because of truncations by faults and plutonic rocks. However, in the Eastern Block units composed of dacite and/or rhyolite flows can be traced discontinuously for up to 50 km. In the Ruttan Block (north domain) and the Karsakuwigamak Block some units composed of dacite and/or rhyolite flows can be traced laterally into rhyolite pyroclastic flow deposits.

Rhyolite and dacite flows are fine grained and show aphyric, plagioclase-phyric and plagioclase- and quartz-phyric textures. In units comprising several flows, phenocryst abundance is variable. However, in a single flow phenocryst content is uniform. Phenocryst abundance rarely exceeds 10% (Table 7). In units containing aphyric and phyric flows, aphyric flows tend to occur in the upper part of the unit and phyric flows in the lower; however, this vertical variation is not ubiquitous (unit D, Karsakuwigamak Block). Aphyric flows have a maximum thickness of 125 m, whereas phyric flows are up to 250 m thick. Aphyric and phyric flows display autobrecciation but it is more common in phyric flows (Table 7).

Rhyolite and dacite flows comprise massive, flow layered and breccia facies. Massive rhyolite is common to all flows except for a flow in unit G in the Karsakuwigamak Block that is entirely composed of breccia fragments (Fig. 10, Table 7). Massive parts of flows compose 80% to 100% of flow thickness. Flow layered zones are generally 0.5 to 1.5 m thick and several zones may occur in a single flow. Breccia facies typically occur as flow top and/or flow bottom breccia but in some flows a central massive zone is enveloped by breccia and in one flow the breccia is marginal to massive rhyolite.

Massive Rhyolite

Massive rhyolite is white, light beige, light pink, salmon, light to medium grey, fine grained, aphyric, plagioclase-phyric or plagioclase- and quartz-phyric and breaks with conchoidal fracture. Aphyric flows are most commonly light beige or light to medium grey and contain 2 to 4% elliptical, 1 to 2 mm diameter quartz amygdules. Less commonly aphyric flows are light pink. On fresh surface the rock is typically aphanitic and in some a fine grained granular texture can be identified. Microscopically the rock comprises a granular mosaic of feldspar and quartz with random to subparallel oriented micaceous minerals. Some aphyric flows contain randomly oriented plagioclase microphenocrysts.

Plagioclase-phyric flows are most commonly light grey but can be light beige and, least commonly, are light pink. Plagioclase- and quartz-phyric rhyolite flows are white, light pink, salmon and light beige. On weathered surface plagioclase is white. Phenocrysts are set in a fine grained granular mosaic of feldspar and quartz with random to subparallel oriented flakes of micaceous minerals. Plagioclase phenocrysts are randomly oriented, euhedral, 1 to 4 mm long, have equant cross-sections and are carlsbad-albite twinned. Quartz phenocrysts are equant, euhedral to subhedral and less than 2 mm in diameter; locally they show a pale blue coloration.

Microscopically plagioclase phenocrysts are generally fresh but some contain individual or coalesced patches of quartz, quartz + carbonate, quartz + epidote, or epidote. Minute opaque (oxide) grains are a common accessory mineral in these patches. Quartz phenocrysts are single crystals, rarely recrystallized to a polycrystalline aggregate and rarely surrounded by a monocrystalline quartz rim that may or may not be in optical continuity with the phenocryst. Quartz phenocrysts commonly show sharp, smooth sided embayments and oval inclusions. Embayments are filled with a granular mosaic that has the same grain size and mineralogy as groundmass in the rock. Inclusions are occupied by a very fine grained granular mosaic that appears to be feldspar and quartz or by cryptocrystalline material.

In the Ruttan and Karsakuwigamak blocks the massive parts of rhyolite flows vary little in thickness laterally. In the Eastern Block massive rhyolite occurs as pods, ranging in width from 5 to 15 m and in length from 25 to 130 m, surrounded by breccia. Flow layering is a common feature in massive rhyolite (Table 7).

Flow Layering

Flow layered zones are 0.5 to 2 m thick and are interlayered with unlayered zones one to tens of metres thick. Flow layered zones comprise 2 mm to 1 cm thick light and dark coloured layers that alternate with 5 mm to 40 cm thick layers that are similar to unlayered zones. Flow layers are commonly slightly coarser grained and more feldspathic than unlayered rhyolite; some have a lower phenocryst abundance than associated rhyolite. Most commonly flow layering parallels flow contacts. Where flow contacts have been identified, flow layering generally occurs only in the lower half of a flow. However, flow layering can occur at various positions within the massive parts of flows. Rhyolite unit F in the Karsakuwigamak Block comprises a single flow that is flow layered throughout nearly its entire thickness, and flow layered blocks occur in the flow top breccia. Locally in this flow, flow layering is inclined at 25° to 35° to the flow boundaries. This implies that ramp structure developed during the emplacement of the flow. Flow-top breccia containing flow layered blocks also occurs in rhyolite units D and I in the Karsakuwigamak Lake Block. In the Eastern Block flow layering occurs in the larger pods of massive rhyolite. Locally this flow layering is highly contorted. Locally the 2 mm to 1 cm thick layers in flow layered zones are spherulitic. Spherulites occur as white, 1 to 3 mm circular to slightly oval structures within these layers. Flow layered breccia fragments are non-spherulitic.

Flow Breccia

Flow breccia in the Karsakuwigamak Block and the Ruttan Block is characterized by 40 to 65% angular-to-subrounded blocks and lapilli that are identical in composition and texture to associated massive rhyolite. Breccia fragments are both framework-supported and matrix-supported. The matrix is fine grained and is generally more siliceous than the blocks and lapilli. Breccia zones can occur at the bottom and top of flows and range in thickness from 4 to 100 m, and where flow thicknesses are known the flow breccia can equal the thickness of massive flow material. Generally the breccias are less than 20 m thick. Rhyolite unit G in the Karsakuwigamak Block (Fig. 10) is entirely composed of breccia fragments and is interpreted to be a flow breccia at the margin of a rhyolite flow in which the massive portion is unexposed. Well exposed examples of rhyolite flow breccia in the area are described below.

The stratigraphically lowest flow in rhyolite unit H, Karsakuwigamak Block, consists of an 80 m thick aphyric rhyolite that is continuously exposed for about 300 m along strike and can be traced discontinuously for another 300 m. It varies little in thickness and is brecciated at the base and top. At the base there are 5 to 10 m of 60 to 65%, 15 to 35 cm, equant to rectangular, angular to subangular rhyolite blocks that are framework-supported to matrix-supported. The blocks have the same composition and texture as the overlying massive rhyolite. In the stratigraphically lower 2.5 to 3 m of this breccia zone the blocks are matrix-supported; in the upper 2.5 to 7 m blocks are framework-supported. The matrix in the breccia is fine grained and more siliceous than either the blocks or the massive rhyolite. Fractures oriented sub-perpendicular to the contact between massive and brecciated rhyolite penetrate 50 to 80 cm upward into the massive rhyolite. They are 0.5 to 5 mm wide and are filled with the fine grained siliceous material that forms the breccia matrix. Breccia at the top of the flow is up to 10 m thick and comprises 40 to 60% chaotically arranged, 8 to 20 cm diameter, subangular to subrounded, equant rhyolite blocks supported in a fine grained siliceous matrix. The blocks have the same composition and texture as the massive rhyolite and blocks in the basal breccia. The contact between this flow-top breccia and the underlying massive rhyolite is sharp to gradational over 1 to 25 m. Locally at this contact V-shaped fractures to 5 cm wide, spaced 10 to 40 cm apart, penetrate 1 to 3 m downwards into massive rhyolite. These fractures are filled with the same siliceous material that surrounds the rhyolite blocks in the flow-top and basal breccias. The massive rhyolite is internally structureless.

Flow-top breccia also occurs at the top of the stratigraphically higher flow in rhyolite unit H, Karsakuwigamak Block. The breccia is 0 to 6 m thick and consists 60% of equant, 4 to 10 cm, angular to subangular, dacite fragments that have the same mineralogical composition and texture as the underlying massive dacite. The fragments are supported in a fine grained dacitic matrix that contains 1 mm rounded fragments that appear to have the same composition as both the larger breccia fragments and the underlying massive dacite. Massive dacite is locally spherulitic but the breccia fragments are structureless.

Flows in rhyolite unit 1, Karsakuwigamak Block are incompletely exposed; however, contacts between flows are locally well exposed. At one locality a quartz- and plagioclase-phyric rhyolite flow is overlain by a sparsely plagioclase-phyric rhyolite flow. The contact exhibits local relief of 1 to 2 m. In the lower flow massive rhyolite grades upward into 3 to 4 m of flow-top breccia. This breccia contains 30 to 55% irregularly distributed, rounded to oval 12 to 25 cm blocks of pumiceous quartz- and plagioclase-phyric rhyolite of the same mineralogical composition (except for vesicle fillings), phenocryst size and phenocryst abundance as the underlying massive rhyolite. The breccia matrix is aphyric, and is more siliceous than, and weathers with positive relief relative to, either the pumiceous blocks or the massive rhyolite. Blocks increase in abundance upward and their long axis is oriented parallel or subparallel to the contact zone between breccia and massive rhyolite, and also to flow unit contacts. Vesicles in the blocks are elliptical, generally 1 to 3 mm long (rarely to 7 mm long), are elongate parallel to the long dimension of the blocks and are filled with quartz. Blocks generally contain several 1 cm oval vesicles filled with quartz + carbonate + muscovite. These large amygdules also occur in the massive rhyolite in a 2 to 4 m thick zone directly below the flow-top breccia. Elsewhere in this rhyolite unit there is flow-top breccia similar to that described from rhyolite unit H; locally fragments in this breccia are spherulitic.

Rhyolite unit D, in the northwest segment of the Karsakuwigamak Block, comprises two massive dacite lenses that are wholly or partially enveloped by dacite breccia, and one massive- to flow-layered rhyolite lens. The rhyolite flow forms the base of the unit; it does not have an exposed associated breccia. The combined thickness of the breccias at the top and bottom of the massive dacite lenses can be equal to or greater than the thickness of the associated massive lens. The breccias are mainly dacite tuff-breccias with subordinate dacite lapilli-tuff, and consist of angular to subrounded dacite blocks and lapilli supported in a fine grained matrix that is more siliceous than the fragments. The blocks, lapilli and massive dacite lenses have the same phenocryst population and texture.

The breccia fragments are chaotically arranged and adjacent to the massive dacite lenses flow breccia is composed almost entirely of blocks that are largely framework-supported or separated by less than 1 cm. Both vertically and laterally from the massive lenses the proportion of lapilli-sized fragments and matrix increases and locally the rock is lapilli-tuff. The degree of rounding of breccia fragments increases laterally from the massive lenses.

Monolithic breccia comprising tuff-breccia and/or lapilli-tuff, composed of angular to subrounded fragments that are similar in composition, texture and phenocryst population to associated massive rhyolite or dacite, also occur in many other rhyolite units in the Karsakuwigamak Block and in the northern domain of the Ruttan Block. These units are generally poorly exposed; however, the outcrop distribution of massive, flow-layered and breccia facies in these units suggests that the breccias are associated with massive rhyolite or dacite. These breccias display thicknesses, grain size, grain shape and fragment distribution similar to the better documented breccias in the map area.

In the Eastern Block breccia associated with massive rhyolite pods consists of 40 to 55%, angular, 0.3 to 2 cm diameter fragments of rhyolite set in a very fine grained siliceous matrix. Breccia envelops massive rhyolite. Breccia matrix comprises a very fine grained feldspar and quartz granular aggregate, sub-millimetre rhyolite fragments and, where the associated massive rhyolite is phyric, rare phenocrysts. These breccias are considered to be hyaloclastite whereas rhyolite breccias associated with massive rhyolite in the Karsakuwigamak and Ruttan blocks are coarser grained, contain polygonal breccia fragments, and are considered to form from the autoclastic fragmentation of congealed tops and bottoms of the flows. The pumiceous breccia associated with a flow in rhyolite unit I in the Karsakuwigamak Block probably formed by disruption of an extremely vesicular flow top during emplacement of the flow.

RHYOLITE AND DACITE PYROCLASTIC ROCKS

General Statement

Rhyolite and dacite pyroclastic rocks occur in the Karsakuwigamak Block and also form one thin unit (not shown on map) that occurs between two rhyolite flows in the north domain in the Ruttan Block. Pyroclastic rocks include pyroclastic flow and air-fall deposits and related surge deposits. The following descriptions are for pyroclastic units in the Karsakuwigamak Block. The pyroclastic unit in the Ruttan Block comprises lapilli-tuff interpreted to be pyroclastic flow deposit of the ash-flow tuff type.

Ignimbrites

Most pyroclastic flow deposits in the Karsakuwigamak Block comprise rhyolite and dacite lapilli-tuff but some are composed of rhyolite tuff and others rhyolite tuff-breccia. They form all or parts of eight units in the block (Fig. 11). Pyroclastic flow deposits range in thickness from 4 to 375 m and individual flows (flow unit) are 2 to 60 m thick (Table 8). The majority of flow units are internally stratified. Fragments are size and/or density and abundance graded and locally stratification is defined by concentrations of pyrogenic crystals and/or fragments. Within the flow deposits, flow units have sharp and planar upper and low contacts.

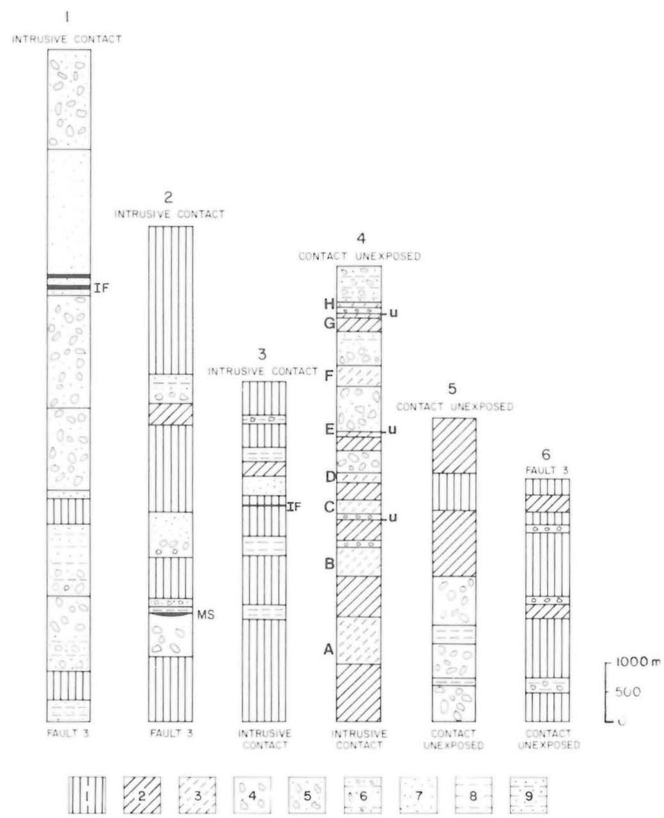

Figure 11: Stratigraphic distribution of rhyolite and dacite pyroclastic rocks in the southern part of the Rusty Lake metavolcanic belt. Stratigraphic sections and symbology are the same as for Figure 4.

In the map area, pumice fragments are rarely identified by vesicularity because of primary compaction in pyroclastic flow units and superimposed deformation and metamorphism. However, pumice fragments in these deposits can be identified indirectly. In any one pyroclastic flow unit pumice fragments are the most abundant fragment type; they are commonly reversely size graded, are monolithic and, where they contain phenocrysts, the phenocrysts are the same mineral species that occur as pyrogenic crystals in the matrix of the deposit. The largest phenocrysts in the fragments and pyrogenic crystals in the matrix are the same size. However, pyrogenic crystals in the matrix are more abundant than phenocrysts in fragments.

Pumice fragments are present in 53% of the deposits and range in size from 0.3 to 7 cm; however, in any one flow unit the range in pumice size is less than 6 cm and most commonly less than 4 cm (Table 8). The maximum pumice content of a flow unit is 35% and the average is 15 to

20%. Pumice fragments generally have an elliptical shape but in some flow units they are subrounded and equant. The phenocryst content of pumice fragments ranges from 0 to 5% but is most commonly between 2 and 4%.

Cognate fragments are present in 38% of the ignimbrites (Table 8). Where present they generally form less than 40% of the rock but can be present in amounts up to 60%. They are non-vesicular to poorly vesicular, angular to subrounded, up to 15 cm across but generally less than 5 cm, and are phyric to aphyric (Table 8).

Phenocryst assemblages in pumice and cognate fragments are plagioclase, or quartz and plagioclase. Plagioclase is idiomorphic, lath-shaped, 1 to 3 mm across, randomly oriented and of albite composition (optical determination). Plagioclase occurs as single phenocrysts and rare glomerocrysts. Quartz is idiomorphic to subrounded, equant and 1 to 2 mm in diameter. It can be embayed, and always occurs as individual phenocrysts. Quartz phenocrysts are rarely recrystallized to an equigranular mosaic of polycrystalline quartz. Phenocrysts, particularly plagioclase, are commonly fractured. These fractures are occupied by an equigranular, fine grained, granoblastic mosaic displaying the same grain size as the groundmass in the fragments.

Accessory fragments occur in 23% of the pyroclastic deposits. They are angular, non-vesicular, dacite to rhyolite in composition, phyric to aphyric, 1 to 4 cm in diameter and compose 5 to 15% of the rocks in which they occur (Table 8).

Pyrogenic crystals in the pyroclastic flow deposits are plagioclase and quartz and their abundance is up to twice the phenocryst abundance in associated pumice (Table 8). These crystals have the same size and display the same morphological features as associated phenocrysts in pumice; fragments of crystals are common in the matrix of the deposits. The distribution of crystals in the matrix is not uniform. Estimated crystal contents from several rock slabs, from a single outcrop and from the same deposit, yield results that differ by +75% of the minimum estimated crystal content. Similar analysis of pumice and cognate fragments yield results that differ by less than 30% of the minimum estimated value. The matrix in the pyroclastic flow deposits generally has the same mineralogical composition as contained juvenile fragments. In some deposits, however, the matrix is more siliceous than juvenile fragments; the monolithic nature of the fragments, and the presence of phenocrysts and pyrogenic crystals that are the same mineral species, suggest that prior to silicification the matrix and the juvenile fragments had the same composition.

The pyroclastic flow deposits form tabular and wedge-shaped units. Several units can be traced discontinuously for 1.5 to 3 km along strike and display little variation in thickness, grain size or internal organization. Well exposed features of the deposits and flow units are described in detail below.

There are two types of ignimbrites in the stratigraphic succession: ash-flows and block-and-ash flows (Table 8). The ash-flow ignimbrites consist of lapilli-tuff and tuff comprising rhyolitic or dacitic pumice, lithic fragments and recrystallized vitric ash. Block-and-ash flow ignimbrites consist of interlayered tuff-breccia, lapilli-tuff and tuff composed of non-vesiculated dacite blocks, lapilli, recrystallized ash and, rarely, accessory lithic fragments.

Ash-Flow Ignimbrites

Rhyolite and dacite ash-flows most commonly occur as single flow units that are overlain and underlain by rocks of a different genesis, but two composite ash-flow ignimbrites (unit D and unit B) account for more than 50% of the total ignimbrite thickness in the stratigraphic succession. Ash-flow units are associated with other ash flow units, air-fall and surge deposits, debris flows and lava flows.

Ash-flow ignimbrites range in thickness from 0 to 350 m, including minor associated air-fall deposits, and can be traced laterally for 1.2 to 4.0 km. Flow units are 2 to 60 m thick, but most are less than 25 m thick. Most flow units can be traced for only 100 to 400 m, but some are exposed discontinuously for up to 1.5 km. Where examined, flow unit boundaries are sharp and planar or gradational.

Ash-flow ignimbrite is mainly lapilli-tuff, and locally it is tuff. It consists of 5 to 50% recognizable pumice 0.3 to 7 cm across, 0 to 10% lithic fragments 0.2 to 3 cm across, and 0 to 20% pyrogenic crystals in 35 to 85% fine grained, recrystallized, quartzofeldspathic aggregate. In most flow units the pumice content is between 20 and 45%, the abundance of lithic fragments is generally less than 5%, and the combined abundance of recrystallized vitric ash and pyrogenic crystals is 50 to 75%. Because of the size of the pyrogenic crystals and the abundance of recrystallized vitric ash and pyrogenic crystals, 50% or more of the components in the ash-flow units are ash size material. Pumice is commonly reverse size and abundance graded, whereas lithic fragments show normal grading in some flows. In a few flow units, pumice is concentrated in thin zones in the upper part of the flow unit, and in other flow units pumice forms concordant layers 0.2 to 2.5 m thick that generally occur in the upper half of flow units. In all but one of the ignimbrites, the abundance of pyrogenic crystals is 2 to 4 times the abundance of phenocrysts in associated pumice. Pyrogenic crystals are commonly broken.

The ash-flow ignimbrite in unit H is a single, 3 to 4 m thick, flow unit that can be traced nearly continuously along strike for 225 m in the eastern part of the area and, after a 1 km gap without exposure, it can be traced for an additional 150 m in the west. The ignimbrite is overlain by an air-fall deposit and underlain by a surge deposit. Pumice is well preserved (Fig. 12) and density grading is defined by upward increases in the size and abundance of pumice (Fig. 13). In the lower 5 to 7 cm of the unit, pumice fragments are rare and are about 0.5 cm long. The unit grades upward into a central 2 to 3 m thick zone in which pumice abundance increases upward from 10 to 50% and size increases from 0.5 to 3 cm. The central zone grades in turn into a 25 cm thick upper zone in which pumice size and abundance decrease upwards from 3 to 1.5 cm and 50 to 30% respectively. Angular, 0.2 to 0.4 cm, lithic fragments are confined to the lower 1.5 m of the unit where they decrease in abundance upwards from about 15 to 0%, but they are not size graded. Pyrogenic crystals, some of which are broken, are randomly distributed throughout the unit, but are rare in the lower 5 to 7 cm.

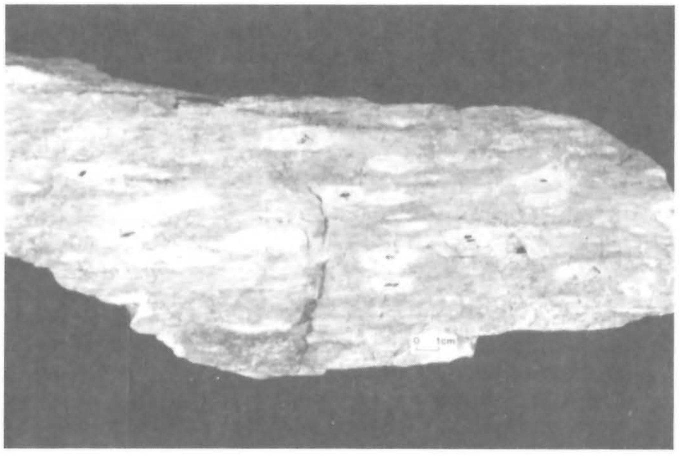

Figure 12: *Weathered surface of pumiceous rhyolite lapilli-tuff (ash-flow ignimbrite), pyroclastic unit H. The centres of some lapilli contain several 1-2 mm cavities whereas others contain one or two larger cavities. The cavities may be weathered out pits because vesicles of this size are not observed in thin section.*

In pyroclastic unit B there is a 170 to 360 m thick sheet that is composed almost entirely of ash-flow ignimbrite that has a lateral extent of 4.0 km; individual flow units have been mapped only in the uppermost

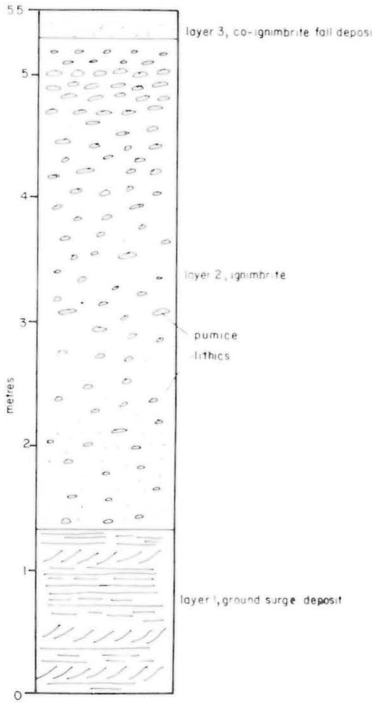

Figure 13: *Stratigraphic section of ash-flow tuff in pyroclastic unit H.*

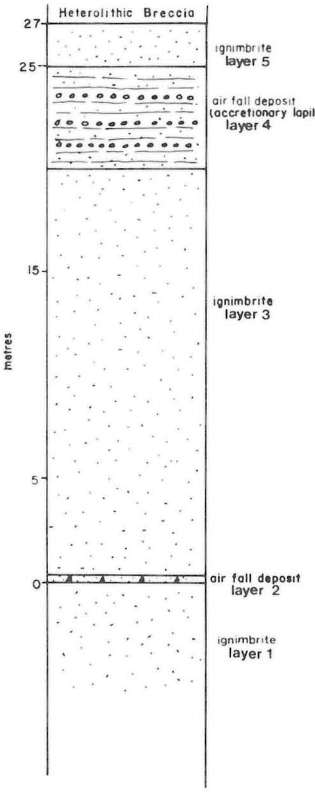

Figure 14: *Stratigraphic section of the upper part of pyroclastic unit B.*

part of the unit where there are discrete flow units (Table 9; Fig. 14). In the lower 150 to 350 m of the unit, 1 to 25 m thick flow units are present but could not be defined precisely because stratification is only locally exposed. Observed stratification in this part of the unit is defined by changes in the proportion of pumice and lithic fragments, and by local pumice concentrations that form layers 20 to 50 cm thick. For example, in several outcrops the lithic fragment/pumice ratio changes from about 2 to 0.25 across a stratigraphic distance of 1 to 25 m; locally, in 1 to 2 m thick poorly defined zones, a few layers have a pumice concentration that is double that of adjacent parts of the ignimbrite. Size grading has not been observed in this part of the pyroclastic unit.

In the upper part of the unit, flow units have lateral extents of 1.8 and 1.0 km respectively. They are completely exposed for 100 m in the eastern part of the unit and are discontinuously exposed westward without any apparent change in thickness. A lower flow unit ignimbrite is 23.3 m thick and an upper flow unit is 2 m thick. In both, slight changes in pumice abundance occur (Table 9) but without variation in the distribution of pumice sizes.

The lower flow unit in pyroclastic unit C is a single, 27 to 60 m thick, flow composed of lapilli-tuff. It has a lateral extent of 700 m, but the upper contact is not exposed and thus the shape of the unit is unknown. In the lower 10 to 25 m of the unit pumice is subrounded, and shows an upward increase in size from 1 to 7 cm and in abundance from 5 to 20%; ungraded, 0.5 to 3 cm, angular lithic fragments compose 7% of this part of the unit. The lower zone grades upward over 1.7 m into the 17 to 35 m thick upper zone that contains 10 to 15%, 1 to 4 cm, homogeneously distributed pumice. Relative to other ash-flow ignimbrites in the stratigraphic succession, this flow unit contains the largest pumice fragments and has one of the lowest pumice contents (Table 9).

In pyroclastic unit E, a 3 to 7 m thick ignimbritic tuff unit that occurs between, and has sharp contacts with, dacite flows can be traced laterally for 50 to 100 m in the easternmost outcrops of the formation. The unit comprises 0.5 to 2.5 m thick layers of pumice-bearing tuff interlayered with 0.1 to 0.5 m thick layers of pumice-free tuff. The layers are planar, and layer contacts are generally gradational although some are sharp. Pumice-bearing layers are poorly sorted and ungraded.

At the top of the easternmost exposures of pyroclastic unit C, a 10 m thick pyroclastic unit comprises 2 ignimbrite flow units, each of which is overlain by an air-fall deposit. The flow units are 4 to 4.5 m thick and have sharp lower contacts, but the upper contacts of both flow units are gradational with the overlying air-fall deposit. Pumice is reversely graded in the lower 3 m and normally size graded in the upper 1 to 1.5 m of the units, but abundance grading is absent. The pumice content of 15% is among the lowest of any of the ash flow ignimbrite units in the stratigraphic succession (Table 9).

Pyroclastic unit D has a lateral extent of 2.8 km and is composed of ignimbrites and minor, thin, coarse grained air-fall deposits, but the number of flow units has not been identified. Exposures are sparse in the eastern and western parts of the unit but are more plentiful in the central part. There, two flow unit boundaries have been identified by abrupt changes in the abundance of pumice. At a few localities, where there are 5 to 10 m continuous sections across clean outcrop, pumice abundance doubles and the cognate lithic abundance changes inversely relative to pumice from 10 to 3% northward. Flow units are estimated to be 10 to 20 m thick.

Pyroclastic flow rocks in pryoclastic unit F consist of a single 45 to 50 m thick ignimbrite flow unit that has a lateral extent of 500 m; however, the south, east and west boundaries of the unit are a younger intrusion. Pumice is reversely to normally graded and ranges in abundance from 5 to 25% and in size from 0.5 to 3 cm; the change from reverse to normal grading takes place at about 15 m from the top of the unit. Locally in the upper 3 m, the ignimbrite contains pumice swarms that form 0.3 to 0.5 m thick layers composed of 35 to 40% pumice, 1.5 to 3 cm across. The pumice swarms have gradational boundaries with the remainder of the ignimbrite. Lithic fragments are normally graded and are most abundant in the lower 10 m of the flow unit.

At the top of pyroclastic unit C there is a 5 to 15 m thick ignimbrite flow unit that occurs between air-fall deposits. It forms a westward thinning layer that has a lateral extent of about 2.0 km. Exposures are small and, in the eastern part of the formation, exposures are rare. However, in scattered exposures between the well identified air-fall deposits, there is an apparent reverse vertical gradation in pumice size from 0.3 to 1 cm and in abundance from 5 to 30%.

Block-and-Ash Flow Ignimbrites

Block-and-ash flow ignimbrites occur in the lower and upper parts of the Karsakuwigamak Block stratigraphic succession. They form parts of pyroclastic units A, B and F. All of the block-and-ash flow ignimbrites are dacite and are associated with dacite flows.

Block-and-ash flow ignimbrite sequences range in thickness from 0 to 400 m (Table 9). Flow units are generally poorly defined, but abrupt changes in fragment size suggest a thickness range of 0 to 35 m for flow units, although most flow units appear to be less than 25 m thick (Table 9). Flow sequences can be traced laterally for 1 to 3 km, but flow units cannot be traced for more than 300 m because of outcrop distribution.

The block-and-ash flow ignimbrites comprise 20 to 65% monolithic, angular to subangular and rarely subrounded, non-vesiculated blocks and lapilli in a fine-grained, recrystallized, quartzofeldspathic, granoblastic mosaic that represents the ash portion of the flows (Fig. 15, Table 9). In most units the average content of blocks and lapilli is about 50% although in one unit the average is about 30%; blocks and lapilli range in size from 0.2 to 15 cm. Pyrogenic crystals and cognate lithic fragments, which differ in composition and size range from the more abundant juvenile monolithic

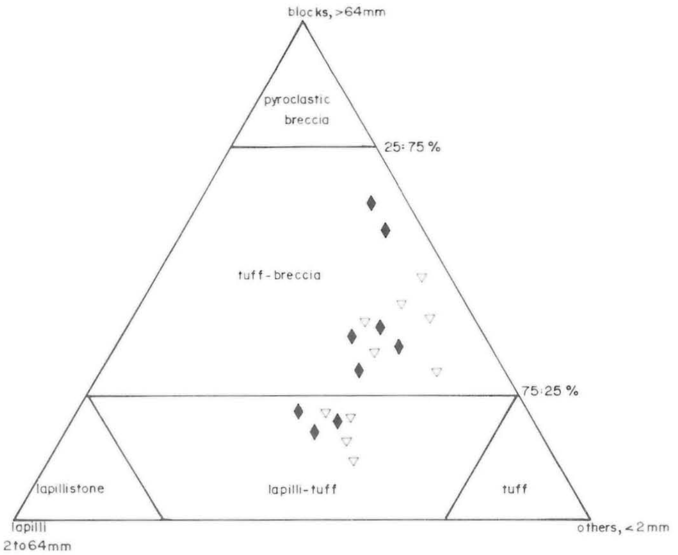

Figure 15: *Proportions of components in tuff-breccia and lapilli-tuff of block-and-ash flow ignimbrites; pyroclastic unit F (▽) and pyroclastic unit B (◆). Data for pyroclastic unit A are similar to pyroclastic unit B. Others include the fine grained recrystallized granoblastic mosaic. Data determined from point counting 2, 1 x 1 m areas on outcrop (200 points). Classification is after Fisher and Schmincke, 1984.*

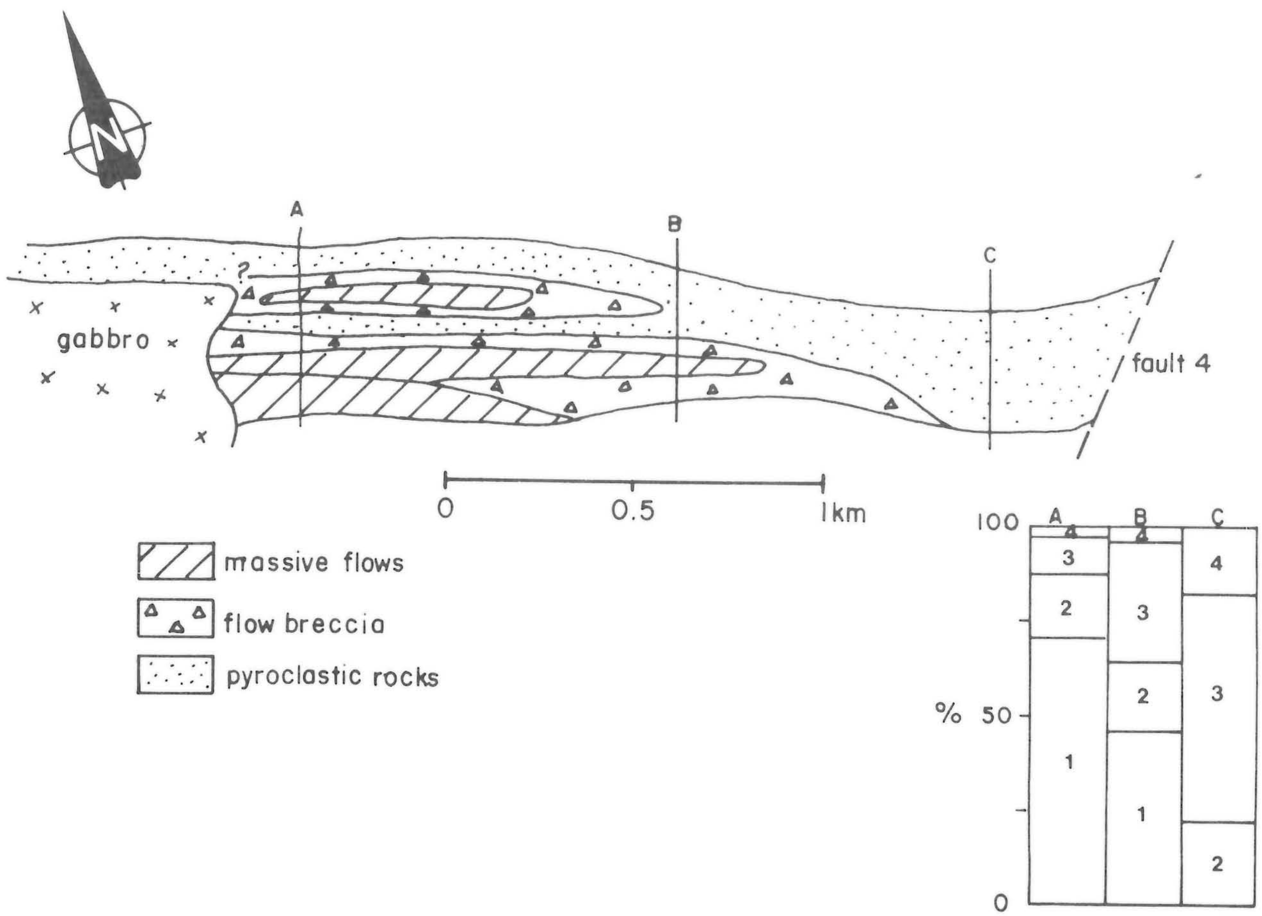

Figure 16: *Distribution of facies and comparative abundances of rock types in pyroclastic unit B and flow unit D in the Karsakuwigamak Block; gabbro sills have been removed. 1 - massive flows plus flow breccia; 2 - tuff-breccia; 3 - lapilli tuff; 4 - tuff.*

blocks and lapilli, are rare. The vertical sequence in a flow unit is tuff-breccia, overlain by lapilli-tuff, which is locally overlain by minor tuff.

The lower 100 to 200 m of pyroclastic unit F comprises interlayered tuff-breccia and lapilli-tuff units (Table 9) that on outcrop surface appear to have a disrupted framework. The units are lateral stratigraphic equivalents of massive dacite flows, but the pyroclastic rocks and the flows are separated laterally by an 800 m gap in which there is no exposure. The tuff-breccia and lapilli-tuff units have a lateral extent of 1.3 km. The number of flow units is unknown, but, based on distribution of lithologies at a few localities where outcrop is plentiful, the thickness of flow units is estimated to be 12-15 m (Table 9). This would imply 8 to 13 flow units. Juvenile blocks and lapilli are monolithic, massive aphyric dacite that differ from the associated flows which contain 1% plagioclase phenocrysts and, in places, are flow layered. Cognate fragments, on the other hand, which form 2 to 5% of the ignimbrite, appear to be similiar to the associated lava flows.

Where outcrop is most plentiful, tuff-breccia layers, 9 to 12 m thick, are interlayered with lapilli-tuff layers, 3 to 5 m thick. Where lapilli-tuff overlies tuff-breccia the contact is gradational, but where tuff-breccia overlies lapilli-tuff contacts are sharp and planar. These contact relations suggest that flow units comprise a lower tuff-breccia zone that grades upward into a lapilli-tuff zone with lapilli-tuff composing about one-third of flow unit thicknesses. The gradational contact between tuff-breccia and lapilli-tuff is 0.4 to 1 m thick. In tuff-breccia zones the abundance of blocks can vary by about 15% and locally variations in block abundances define a crude stratification. Lapilli-tuff is generally massive but locally it shows normal abundance grading; size grading is apparently absent.

In pyroclastic unit B interlayered, compositionally identical, tuff-breccia, lapilli-tuff and tuff (Fig. 15), overlie and are locally interbedded with compositionally similar flows of the dacite flow sequence; tuff-breccia and lapilli-tuff have a disrupted framework. The pryoclastic sequence thickens eastward and can be traced laterally for 3.0 km although individual tuff-breccia, lapilli-tuff and tuff units can be traced for only 75 to 200 m. The juvenile blocks and lapilli form 30 to 65% of the deposit, are monolithic and non-vesicular, and have the same phenocryst population and texture as the dacite flows. Cognate lithic fragments, which form 5% of the deposit comprise aphyric, non-vesicular clasts, that appear to be similar to massive dacite in Flow 1 (Table 8), and minor chert; cognate fragments are uniformly distributed through the tuff-breccia and lapilli-tuff but are rare in tuff. In the west tuff-breccia is the dominant pyroclastic rock. Eastward the total thickness of tuff breccia remains uniform but the relative abundance decreases and the amounts of interlayered lapilli-tuff and tuff increase as the pyroclastic sequence thickens (Fig. 16).

The number of flow units in pyroclastic unit B is unknown but, from some good exposures, flow unit thickness is estimated to be 5 to 35 m. Contact relationships between tuff-breccia and lapilli-tuff are similar to those in pyroclastic unit F. In addition, contacts between underlying lapilli-tuff and overlying tuff are gradational over 0.25 to 0.75 m, whereas contacts between underlying tuff and overlying lapilli-tuff or tuff-breccia are sharp. As in pyroclastic unit F these lithologic variations appear to define flow units consisting of a lower tuff-breccia zone that grades upward into lapilli-tuff and, in places, tuff. In the west flow units range in thickness from 14 to 35 m with the lower tuff-breccia zone being 10 to 25 m thick, and the upper lapilli-tuff zone, 4 to 10 m thick; where present, the capping tuff is 5 to 10 cm thick. In the east, the lower part of the unit is poorly exposed and flow unit thicknesses are unknown. However, at the top of the unit flow units are 5 to 13 m thick and comprise either 1) a lower tuff-breccia zone 5 to 10 m thick, a central lapilli-tuff zone 2 to 3 m thick, and an upper tuff zone 20 to 30 cm thick, or 2) a lower lapilli-tuff zone 5 to 10 m thick and an upper tuff zone 20 to 30 cm thick. In some tuff-breccia and lapilli-tuff zones, there is normal vertical size and abundance grading of blocks and lapilli, but grading has not been observed in tuff zones.

In places tuff-breccia zones are superficially similar to flow breccia associated with flows of the dacite flow sequence. The two units have similar sized blocks and lapilli and particle abundance (Tables 8, 9). However, the flow breccias differ from the tuff-breccia in three aspects: 1) maximum block size is larger, 2) flow breccia has a lower zone of intact framework whereas the pyroclastic rocks have only a disrupted framework, and 3) the pyroclastic rocks contain cognate and accidental lithic fragments.

Pyroclastic unit A, which is poorly exposed in the west and central parts of the fault block and is unexposed in the east, comprises compositionally identical lapilli-tuff and tuff. Blocks and lapilli are monolithic and non-vesicular to very poorly vesicular; they appear to be similar to underlying massive dacite flows. The number of flow units is unknown, but in the western part of the unit, sharp and gradational contacts between lapilli-tuff and tuff suggest flow unit thicknesses of 17 to 25 m. Lapilli-tuff zones are 12 to 20 m thick and tuff zones are about 5 m thick. Some lapilli-tuff zones show normal size grading of the largest lapilli.

Interpretation

The pumice-bearing units are poorly sorted, depositional units composed entirely or largely of juvenile pumice, pyrogenic crystals and recrystallized vitric ash; lithic fragments generally compose less than 5% of the components in the rock and are thought to be cognate. Pumice is commonly reversely or reversely to normally graded whereas lithic fragments are normally graded, although grading is absent in a few units. Pyrogenic crystals and phenocrysts are the same mineral species but pyrogenic crystals are more abundant than phenocrysts. Broken crystals compose part of the pyrogenic crystal population. Depositonal units have sharp upper and lower boundaries and comprise a single pumice-bearing layer 2 to 60 m thick or form 0 to 350 m thick deposits composed of several depositional units. Pumice-bearing units that have these features are the deposits of pumice-bearing pyroclastic flows (Fisher, 1966b; Fisher and Schmincke, 1984; Smith, 1975, 1976; Sparks et al., 1973). Because these Karsakuwigamak Block pumice-bearing units contain 50% or more ash-size material and have a median grain size of less than 2 mm, they are classified as ash-flow ignimbrites.

Except for the ash-flow ignimbrite in pyroclastic unit E, the ash-flow ignimbrites were produced from the collapse of eruption columns associated with Plinian eruptions. The ash-flow ignimbrite of pyroclastic unit E apparently formed from collapse of a low height, short-lived eruption column or from a pyroclastic flow that issued directly from a vent. The details that resulted in these conclusions are discussed at length in Baldwin (1987).

The non-vesicular monolithic breccias of pyroclastic layers A, B and F form fragmental sequences composed of well defined depositional units. The depositional units consist of a coarser grained lower zone and a finer grained upper zone, suggesting gravitational separation of particle sizes during emplacement of flows. These monolithic breccias consist of abundant poorly sorted, angular to subangular, blocks and lapilli and the fragmental sequences are spatially associated with lithologically similar dacite flows. Baldwin (1987) suggests that these rocks are block-and-ash flows and because the thickness of the accumulated breccia is equal to or larger than associated lava flows, the fragmental material in the breccias was largely dense juvenile material and not simply fragmental dome or plug material. Thus it appears that the eruptions that produced the block-and-ash flows were magmatic and the flows result from collapse of vertical eruption columns.

TEPHRA FALL DEPOSITS

General Statement

In the northwest segment of the Karaskuwigamak Block air fall deposits of rhyolite and dacite lapilli-tuff and tuff compose 6% of the stratigraphic succession; they do not occur in the other three fault blocks. They form parts of pyroclastic units A, B, C, D, G and H. Deposits range in thickness from 0 to 400 m, but, except for those in pyroclastic unit A, they are all less than 50 m thick (Table 9). They are tabular to wedge-shaped and can be traced laterally for 0.3 to 1.8 km.

Tephra fall deposits occur as single beds of lapilli-tuff, interbedded sequences of lapilli-tuff and tuff, sequences of well bedded lapilli-tuff interlayered with sequences of well bedded tuff, and single tuff layers. With the exception of pyroclastic unit A all tephra fall deposits are associated with ignimbrites. Pryoclastic unit A is underlain and overlain by massive and brecciated flow sequences. The upper and lower boundaries of tephra fall deposits are sharp and planar. Graded bedding and lateral decrease in grain size, deposit thickness and bed thickness are common.

The tephra fall deposits are the products of block-and-ash fall, lapilli-and-ash fall, pumice-rich fall, and ash fall. Unusual hot air fall deposits, that are unlike reported Cenozoic deposits, occur in pyroclastic unit C.

Block-and-Ash Fall

In sharp and planar contact with underlying and overlying ignimbrites of pyroclastic unit B, there is 20 to 30 cm of poorly sorted, coarse, monolithic, lapilli-tuff (Table 9, Fig. 14). Locally, the unit can be traced continuously for 40 to 100 m and because of outcrop distribution, discontinuously for 1.8 km. The lapilli-tuff consists of 35 to 45% lapilli and 10 to 15% blocks of non-vesicular, plagioclase-phyric, angular to subrounded, generally polygonal, dacite that form a disrupted to locally intact framework and 40 to 50% fine grained recrystallized, granoblastic, quartzofeldspathic mosaic. The phenocryst content of blocks and lapilli is similar to that of pumice in the underlying ignimbrite but differs from the phenocryst content and population in the overlying ignimbrite. The recrystallized, granoblastic mosaic consists of 10 to 20%, recognizable, submillimetre, angular, dacite fragments, rare 1 to 2 mm long plagioclase crystals and 80 to 90% recrystallized plagioclase and quartz in about a 2:1 ratio.

In the easternmost outcrops where the unit is 30 cm thick, lapilli are ungraded in the lower 20 cm and show coarse-tail grading in the upper 10 cm. In addition, many lapilli in the lower 15 cm of the unit are in mutual contact (Fig. 17). Block size fragments are randomly distributed through

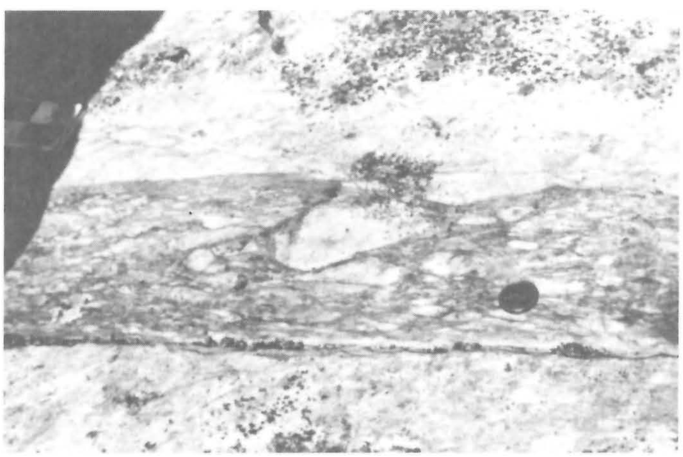

Figure 17: *Poorly sorted lapilli-tuff in pyroclastic unit B in sharp contact with overlying and underlying ignimbrite. Stratigraphic top is toward top of page. The black patchy material is lichen. Lens cap is 6 cm in diameter.*

the unit and have a maximum size of 24 cm. In the westernmost outcrops where the unit is 20 cm thick, blocks are rare and have a maximum size of 8 cm; lapilli have the same size distribution as in the east.

On the basis of fragment size the unit can be divided into a 15 to 30 cm thick coarse grained lower division and a 0 to 7 cm thick finer grained upper division (Fig. 17). The boundary between divisions is defined by a break in the distribution of large lapilli. Rarely the lower division composes the entire thickness of the unit. The lower division contains all of the large lapilli and block-size fragments; it is ungraded and locally lapilli are in mutual contact (Fig. 17). The upper division has a maximum grain size of 1 cm and is generally ungraded although locally coarse-tail grading is present; it has a disrupted framework (Fig. 17).

At one locality in the easternmost outcrops there is a 6 cm depression at the top of the unit occupied by overlying ignimbrite (Fig. 17). Below the depression there is a 20 cm long rectangular block at the top of the lower division, and between the block and the base of the depression there is 2 cm of upper division. On one side of, and adjacent to the block the upper division thickens, whereas on the other side the upper division is very thin or absent, but it thickens again within 30 cm laterally. This suggests that the variation in thickness of the upper division is due to erosion prior to or accompanying the emplacement of the overlying ignimbrite.

The granoblastic mosaic is mineralogically similar to the blocks and lapilli but its grain size is about twice the grain size of the groundmass in blocks, lapilli and identifiable ash-size fragments. Because the mineralogical composition of all components is similar, the granoblastic mosaic is probably the metamorphic equivalent of dust and fine ash particles from the same precursor as the other components in the rock. Therefore, the coarse lapilli-tuff appears to be monolithic and probably originally had a unimodal grain size distribution.

Lapilli-and-Ash Fall

Pyroclastic unit A contains 200 to 400 m of well bedded lapilli-tuff and tuff. The formation thickens eastward and changes from largely lapilli-tuff with lesser interlayered tuff in the west to a bipartite unit consisting of a lower lapilli-tuff with lesser interlayered tuff and an upper tuff with lesser lapilli-tuff in the east (Fig. 18). Both the lapilli-tuff and tuff form discrete units composed of a sequence of similar beds. Lapilli-tuff units range in thickness from 5 to 27 m and beds are 0.15 to 5 m thick. Both units and beds are generally thinner in the eastern part of the formation than in the western part. Tuff units and beds range in thickness from 0 to 60 m and 0.03 to 1.2 m respectively and are generally thinner in the western part of the formation than in the eastern part. Bedding planes are generally sharp and are defined by abrupt changes in abundance of lapilli and recognizable ash-size particles and in grain size due to normal particle size grading. In tuff, bed to bed variations in the abundance of recognizable ash-size particles commonly results in colour changes at bed boundaries.

Lapilli-tuff consists of 35 to 65%, angular, blocky to serrate, monolithic lapilli and recognizable ash-size particles, 2 to 3%, 0.25 to 2 mm, euhedral and broken plagioclase and quartz crystals, and 32 to 63% fine grained recrystallized, quartzofeldspathic aggregate. Lapilli have a maximum size of 1.75 cm. The lapilli are porphyritic and slightly amygdaloidal with 2 to 4% combined plagioclase and quartz phenocrysts and 2 to 5%, quartz-filled, subspherical to elliptical vesicles, 0.3 to 1.2 mm across. The blocky nature of the lapilli suggests that they were resistant to flattening; thus the observed vesicle abundance is probably the original magmatic abundance. The groundmass of lapilli and recognizable ash size particles is a 0.003 mm equigranular, recrystallized quartzofeldspathic aggregate with accessory biotite, muscovite, and Fe-Ti oxide. Broken and euhedral crystals of plagioclase and quartz that are not contained in lapilli are considered to be pyrogenic because they have the same size as phenocrysts in lapilli.

The recrystallized, quartzofeldspathic aggregate surrounding the recognizable juvenile components consists of 50 to 55% quartz, 45 to 50% plagioclase and accessory biotite, muscovite and Fe-Ti oxide; it has a grain size of about 0.01 mm. Except for grain size it appears similar to the recrystallized groundmass of lapilli and recognizable ash-size particles and is considered to be recrystallized, vitric, fine grained ash.

Based on fragment shapes two types of lapilli-tuff units can be

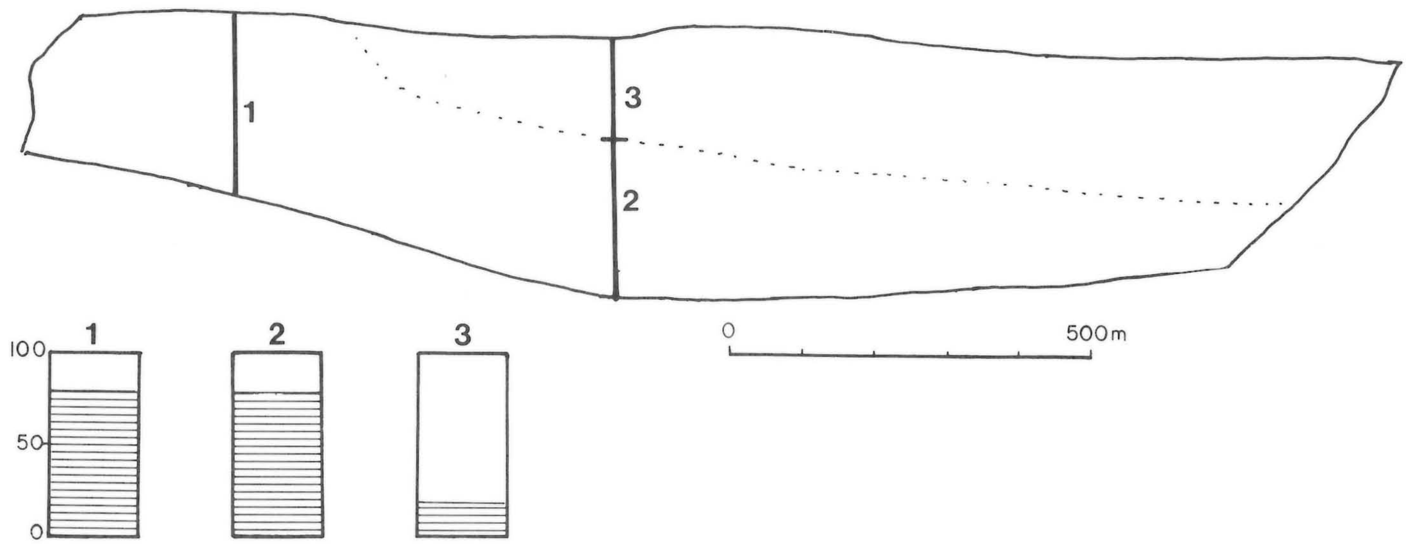

Figure 18: *Sketch map showing the abundance of lapilli-tuff (patterned) and tuff (unpatterned) in three stratigraphic sections in pyroclastic unit A in the Karsakuwigamak Block. The dotted line is the boundary between the lower section composed mainly of lapilli-tuff and the upper section composed mainly of tuff.*

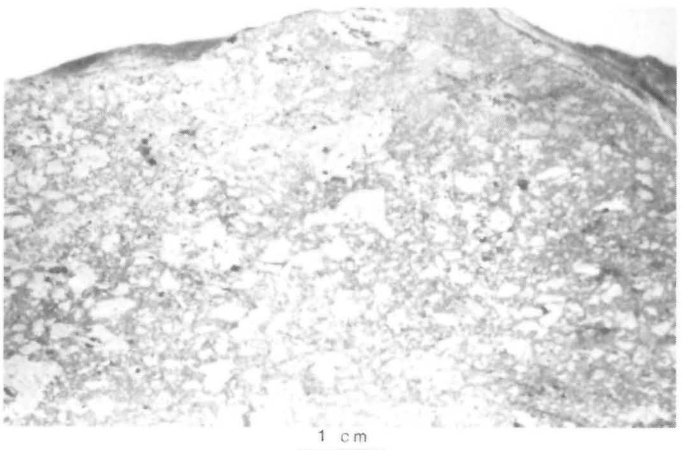

Figure 19: *Etched slab of Type 1 lapilli-tuff in tephra fall deposit in pyroclastic unit A. Most fragments (white) are angular and blocky but some are serrate and poorly vesicular. The euhedral 0.5 to 1 mm black specks are quartz crystals. The material enclosing the fragments is a fine grained quartzofeldspathic aggregate.*

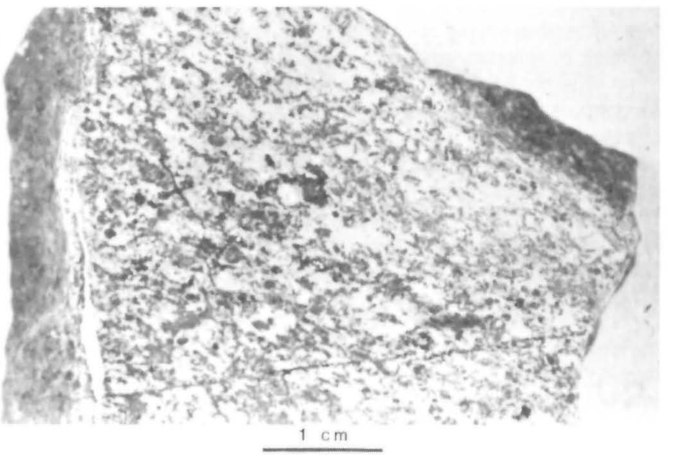

Figure 20: *Etched slab of Type 2 lapilli-tuff in tephra fall deposit in pyroclastic unit A. Fragments (white) are irregular to locally angular in shape, and are largely serrate or less commonly blocky. Fragments contain euhedral to subhedral quartz phenocrysts, and elliptical quartz-filled vesicles. The material enclosing fragments is a fine grained quartzofeldspathic aggregate.*

recognized (Fig. 19, 20). In Type 1 lapilli-tuff, the lapilli and recognizable ash-size particles are angular and blocky. In Type 2 lapilli-tuff there are subequal amounts of angular and blocky, and angular and serrate lapilli and recognizable ash-size particles. There does not appear to be any difference in amygdule or phenocryst abundance in the variously shaped fragments.

Most tuff is texturally similar to lapilli-tuff but the abundance of lapilli is less than 25%. Except for the 2 to 5% pyrogenic crystals, some tuff beds are totally recrystallized to a homogeneous, dense, uniformly coloured, fine grained aggregate similar in mineralogical composition and grain size to the quartzofeldspathic aggregate in lapilli-tuff.

The presence of phenocrysts and amygdules in the fragments suggests a magmatic source. The lapilli-tuff and tuff are pyroclastic rocks based on the similarity of recognizable fragments, angularity of the fragments, and presence of broken and unbroken pyrogenic crystals as well as developed bedding.

In sharp contact with two ash-flow ignimbrites near the top of pyroclastic unit B there is a 2 to 5 m thick unit of interbedded tuff (Fig. 14) and lapilli-tuff with lapilli-tuff composing about 65% of the unit thickness. The unit has a known lateral extent of about 1 km and thins westward but there is no lateral change in lapilli size.

Lapilli-tuff beds are 5 to 30 cm thick and contain 40 to 60%, circular to elliptical accretionary lapilli, 2 to 5 mm across, surrounded by tuff that contains 5 to 10%, broken and unbroken, 0.25 to 2 mm crystals of

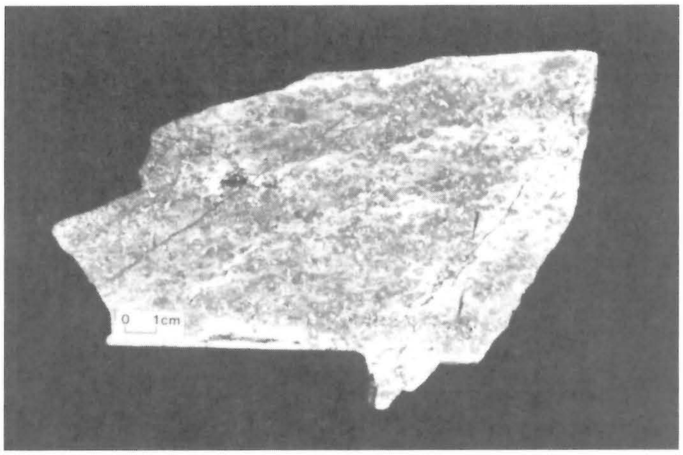

Figure 21: *Etched slab of lapilli-tuff from base of a tephra fall deposit near the top of pyroclastic unit B showing spherical to slightly elliptical accretionary lapilli (dark grey oval structures). The white tabular to equant specks are plagioclase crystals. A closer view of the sample is presented in Figure 22.*

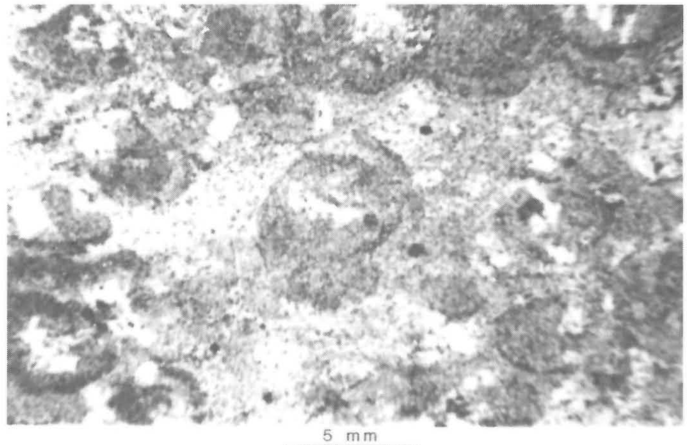

Figure 22: *Etched slab of accretionary lapilli in lapilli-tuff from the base of a tephra fall deposit near the top of pyroclastic unit B. Note concentric zonation and pyrogenic plagioclase crystals in the lapilli.*

plagioclase (Fig. 21, 22). Accretionary lapilli are commonly normally graded and in most beds there is a 0.5 to 4 cm thick, accretionary lapilli-free tuff zone at the top of lapilli-tuff beds; however, in beds less than 10 cm thick accretionary lapilli occur throughout the bed.

Tuff beds are 8 to 10 cm thick and generally consist of 3 to 5% randomly distributed, broken and unbroken, 0.25 to 2 mm, plagioclase crystals in a fine grained recrystallized, quartzofeldspathic mosaic composed of 95% combined quartz and plagioclase, subequal amounts of biotite and sericite, and rare Fe-Ti oxide granules. Some tuff beds, however, lack plagioclase crystals or contain several 1 to 3 mm parallel laminations defined by abrupt changes in plagioclase crystal abundance from 0 to 10%, and/or by changes in colour from pink to tan; microscopic differences were not observed between different coloured laminae.

Accretionary lapilli consist of concentric layers of recrystallized quartzofeldspathic mosaic that has the same grain size as the surrounding tuff. The concentric layers are defined by abrupt colour change but, as in laminated tuff, there is no apparent microscopic difference between layers. The observed cross sections of most of the largest accretionary lapilli contain one or two pyrogenic plagioclase crystals that are similar in size and shape to those in tuff beds and in tuff surrounding the lapilli.

Pumice-Rich Fall

Pyroclastic unit D is dominated by ash-flow ignimbrites, but it contains two coarse lapilli-tuff beds, 10 to 15 cm thick, that are stratigraphically separated by 25 m of ignimbrite and have sharp and planar boundaries with adjacent ignimbrite units. These lapilli-tuff beds have been identified only in the lower half of the eastern part of the pyroclastic unit.

Both beds have similar composition, grain size, grain shape, component abundance (Table 9) and texture. They consist of: (a) 65 to 70%, elliptical, 4 to 7 cm long lapilli that have a length:width ratio of 3:1; (b) 26 to 31% fine grained, recrystallized, quartzofeldspathic, granoblastic mosaic; (c) 4 to 5%, 0.25 to 1 mm randomly distributed quartz and plagioclase crystals, some of which are broken; and (d) rare 0.5 to 1.5 mm angular, dense, lithic particles (Table 9). The lapilli are normally separated by 3 to 4 mm of the granoblastic mosaic.

The lapilli have the same length:width ratio and contain the same abundance and size of euhedral quartz and plagioclase phenocrysts as pumice in the adjacent ignimbrites. There is no evidence that the elliptical shape of the lapilli is due to tectonic flattening and thus the lapilli are interpreted to be pumice.

The unbroken quartz and plagioclase crystals are the same size as phenocrysts in pumice (Table 9), and thus are pyrogenic; the granoblastic mosaic is recrystallized vitric ash.

Because of the restricted size of the pumice, it is not size graded, and the rock appears to have a bimodal grain size distribution.

Ash Fall

At the top of pyroclastic unit H there is 15 cm of rhyolite tuff that overlies, but is gradational with, ignimbrite (Fig. 13, Table 9). The top of the tuff is not exposed, and thus the true thickness of the unit is unknown. As exposed, the tuff comprises 3 zones of differing grain size that, from bottom to top, are 5, 6 and 4 cm thick respectively. The basal zone contains 25%, angular, non-vesicular, rhyolite lapilli, and 4 to 7%, broken and unbroken pyrogenic crystals that are homogeneously dispersed in a fine grained quartzofeldspathic aggregate that represents recrystallized vitric material. This grades upward into a central zone comprising 4 to 7% pyrogenic crystals in a fine grained quartzofeldspathic aggregate that represents recrystallized vitric material; in the upper 2 cm of this zone the abundance of pyrogenic crystals decreases to zero. The upper zone is composed entirely of a fine grained quartzofeldspathic aggregate representing recrystallized vitric material; it is parallel laminated with the laminations being defined by alternating, 1 to 2 mm thick, white and buff layers.

In pyroclastic unit G, two pumice-bearing ignimbrite units are each overlain by a 0.5 m thick, fine grained tuff bed. Contacts between ignimbrite flow units and overlying tuff are gradational. The contact between the lower tuff bed and overlying ignimbrite is sharp, but the top of the other tuff unit is not exposed and in part is interpreted to be at an unconformity. Other than the fine grained quartzofeldspathic aggregate that is interpreted to be recrystallized vitric material, the only identifiable components in the tuff are 2% pyrogenic quartz and plagioclase crystals (Table 9). The quartz and plagioclase crystals are present in about equal amounts, but they are considerably smaller and less abundant than in the associated ignimbrites (Tables 9 and 10).

In pyroclastic unit C, tuff layers composed of a number of beds are interlayered with lapilli-tuff layers that are interpreted to be hot air fall deposits; they compose two distinct depositional sequences separated by ignimbrite. These sequences thin rapidly westward. The tuff layers, 0.5 to 1.75 m thick, are thin bedded to laminated. Tuff beds consist of a fine grained, recrystallized, quartzofeldspathic mosaic that contains 2 to 3%, broken and unbroken, 0.25 to 0.5 mm crystals of plagioclase and quartz. Laminae in tuff layers are defined by abrupt colour changes from light pink to white; however, there is no apparent microscopic difference between laminae. The quartzofeldspathic mosaic consists of about 90% plagioclase and quartz in subequal amounts, 10% combined muscovite, biotite, chlorite, and rare Fe-Ti oxide and pyrite granules.

In the upper 10 to 20 cm of one of the tuff layers laminations locally pinch and swell, form dune-like structures with amplitudes of 3 to 8 cm (Fig. 23), and rarely define a low angle cross-stratification. Although these structures resemble features found in surge deposits, the rare and spatially confined occurrence of the structures suggests that they are more likely the result of water or wind reworking of the upper part of one tuff layer rather than surge deposition.

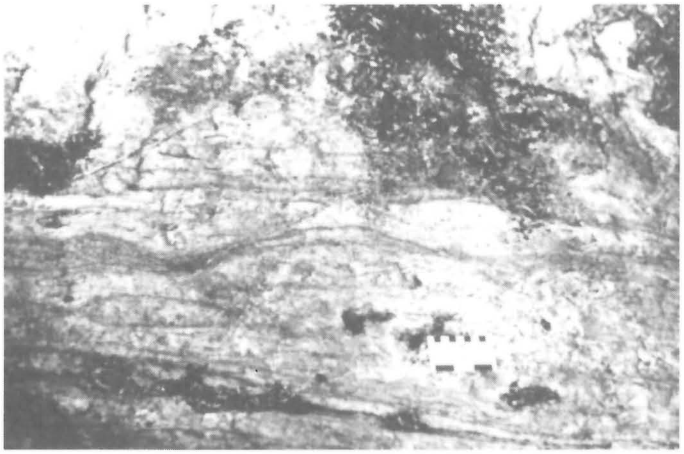

Figure 23: *Thin laminations and dune-like bedding in ash-fall tuff in pyroclastic unit C.*

Figure 24: *Etched slab of hot air fall lapilli-tuff, in pyroclastic unit C, showing the nature of the bedding, distribution of the lapilli in the beds, and distribution of pyrogenic quartz crystals (black specks) and plagioclase crystals (white specks). Plagioclase crystals are best seen in the lapilli; in the matrix they are masked because of the the similarity in tone of the etch on the matrix and plagioclase crystals. The dashes to the right of the photograph mark the position of bedding planes.*

Hot Air Fall

In the two distinct depositional sequences of tuff and lapilli-tuff in pyroclastic unit C unusual, bedded, white, light pink or light red lapilli-tuff, is characterized by 20 to 60%, well rounded, oblate to spherical, concentrically zoned lapilli, 0.2 to 10 cm long, in a fine grained matrix (Table 9; Fig. 24). The lapilli-tuff and tuff sequences thin westward. One of the sequences decreases in thickness from 30 to 0 m over a lateral distance of 800 m and the other decreases in thickness from 50 to 0 m in 2 km of strike length. Thus, both sequences have a high aspect ratio (average thickness:length); this ratio in one sequence is 1:53 and in the other it is 1:80. Lapilli-tuff is the dominant rock type forming 65 to 70% of the sequences in layers 0.1 to 18 m thick.

Based on field observations and examination of etched slabs and thin sections, structures, textures and composition are generally similar in both sequences although pyrogenic crystals are more abundant in one of them (Table 9). Lapilli-tuff in the stratigraphically lower sequence is not as well exposed as lapilli-tuff in the stratigraphically higher sequence and thus this presentation will concentrate on the better exposed sequence, particularly a 50 m continuously exposed section in the eastern part of the unit. There, 4 lapilli-tuff layers are interlayered with 5 tuff layers (Fig. 25) that are interpreted to be tephra fallout deposits (Table 9) and described previously in this section of the report.

Superficially the lapilli resemble normal accretionary lapilli (Moore and Peck, 1962). However, they have variable composition that differs from that of the matrix, and appear to represent the accretion of hot pyroclasts.

Lapilli-tuff comprises 20 to 60% rhyolite lapilli and 1.5 to 13% pyrogenic quartz and plagioclase crystals in a fine grained, recrystallized, quartzofeldspathic, granoblastic mosaic (Table 9); the lapilli also contain pyrogenic quartz and plagioclase crystals. On outcrop, lapilli-tuff has a pebbled surface. Variations in lapilli size and abundance can be identified, but sharp breaks or bedding planes were not discerned. However, on the surface of some etched rock slabs, bedding planes were recognized and complete beds occur in a few slabs. These beds are 5 to 15 cm thick and are defined by abrupt changes in the abundance of lapilli (Fig. 24). Based on the size of etched slabs and the number of samples that do not show bedding and variation in lapilli abundance in outcrop, it is estimated that the possible range of bed thickness is 5 cm to 1 m. In outcrop, variations in lapilli size and abundance parallel layer boundaries. Thus, bedding is probably parallel to layer boundaries. Lapilli are generally concentrated in the lower 2/3 to 3/4 of beds. Within layers, lapilli progressively increase or decrease in size and abundance upward.

Oblate spheroidal lapilli are most common in lapilli-tuff layer 1 and in layers 2 and 3 spherical lapilli are most abundant. From observation in outcrop and measurements of the largest dimension of the lapilli on etched slab surfaces, oblate spheroidal lapilli are larger and have a larger standard deviation in size compared to spherical lapilli. However, trends in size distribution and variation in size are similar for both lapilli types (Baldwin, 1987). Size data for spherical lapilli are presented in Figure 26. In layers 2 and 3 the mean size of the largest lapilli decreases upward but in layer 2 it increases upward. This pattern is the same as that shown by lapilli abundance in these layers (Baldwin, 1987).

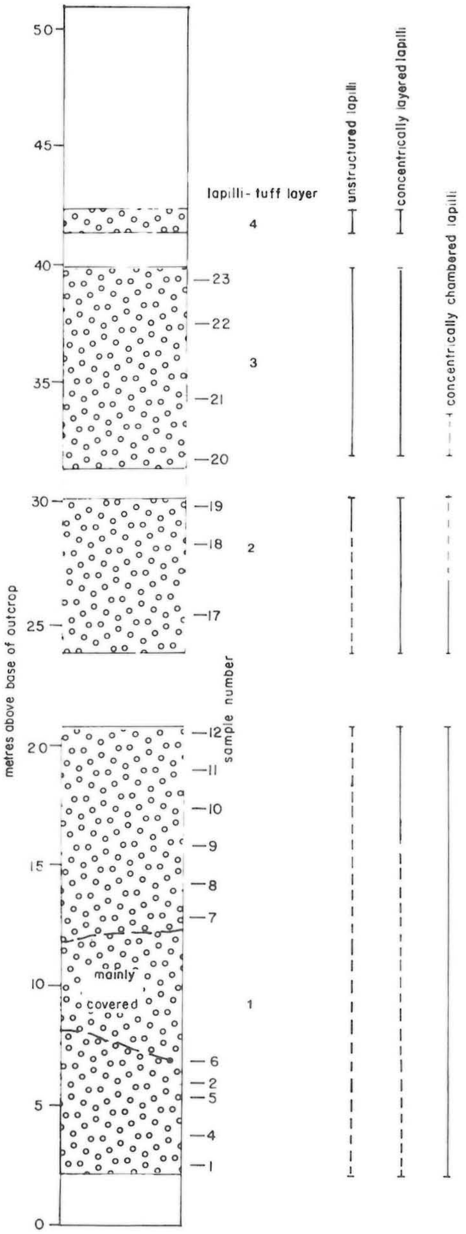

Figure 25: *Measured stratigraphic section of one of the ash-fall and hot air fall deposits in pyroclastic unit C. Lapilli-tuff layers are patterned and tuff layers are unpatterned. The vertical lines to the right of the measured section show distribution and relative abundance of the three lapilli types. Solid lines indicate those lapilli types present in amounts of 35 to 70% and dashed lines those lapilli present in amounts of less than 35% in the four lapilli-tuff layers. The % values refer to % of lapilli, not % of the rock.*

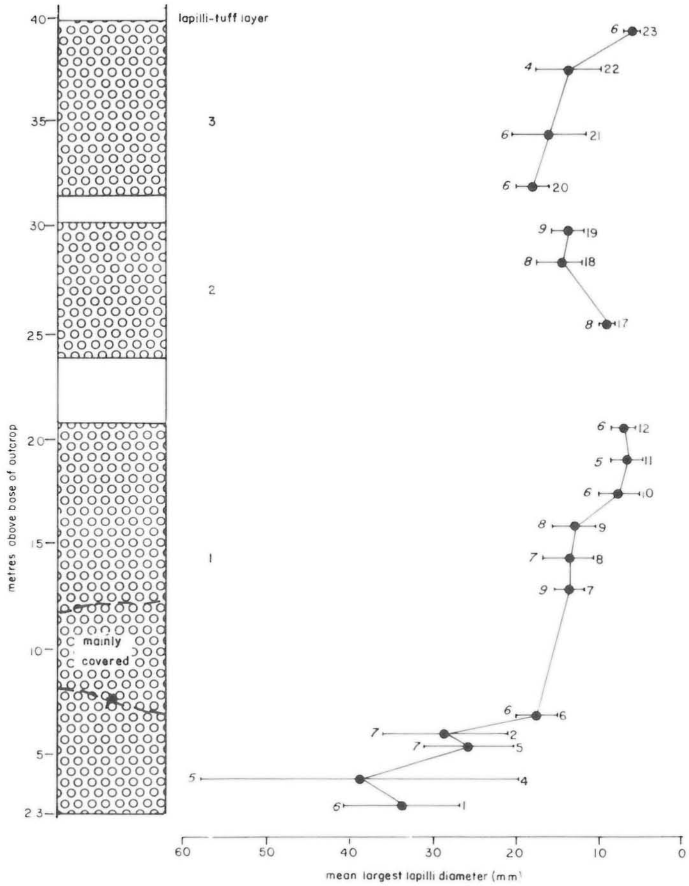

Figure 26: *Mean diameter of largest and most spherical lapilli in lapilli-tuff layers 1, 2 and 3, hot air fall deposits in pyroclastic unit C. Numbers to the right of data points are sample numbers; those to the left are number of lapilli measured in each sample. Error bars represent one standard deviation of the diameters of the measured lapilli.*

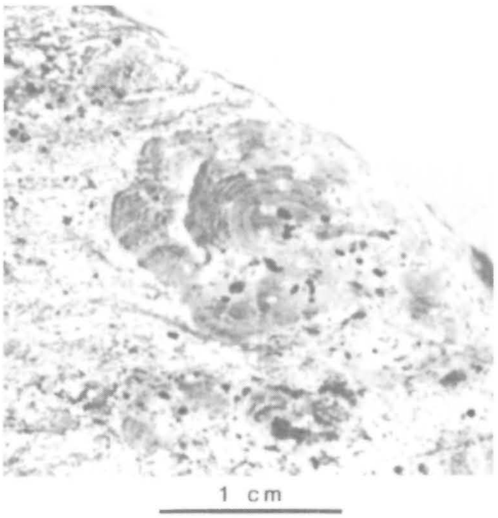

Figure 27: *Etched slab of lapilli-tuff showing spherical concentrically zoned lapillus. The black structures in the lapillus are quartz crystals and the lighter grey structures are plagioclase crystals. Note that the crystals transect layer boundaries.*

Lapilli

Lapilli are generally oblate spheroids with their longest dimension parallel to bedding planes and layer boundaries. Less commonly lapilli are nearly circular in cross section (Fig. 27) or are broken (Fig. 28); coalesced

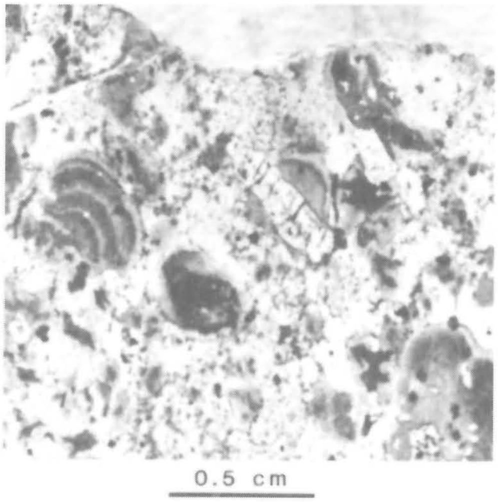

Figure 28: *Etched slab showing broken lapillus in lapilli-tuff.*

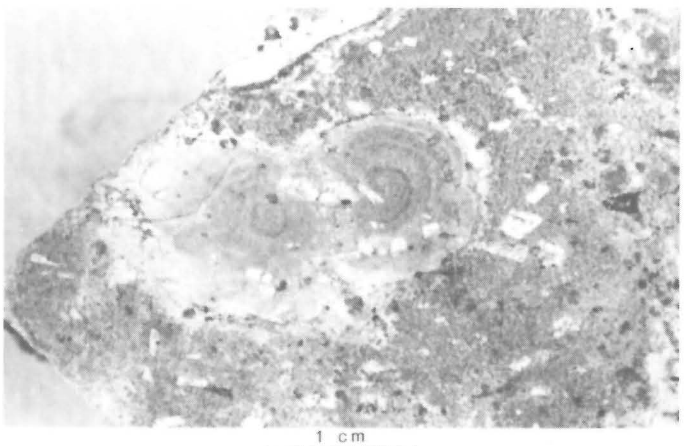

Figure 29: *Etched slab of coalesced concentrically layered lapilli. Changes from light to dark grey within the lapilli result from differing grain size. A quartz crystal transects a dark grey layer surrounding the central part of the lapillus on the left. A plagioclase crystal shows similar relationships to the dark grey layer surrounding the central part of the lapillus on the right. The concentric layering in each lapillus is disrupted at the mutual boundary.*

lapilli (Fig. 29) are rare. Some lapilli that have circular cross sections are nearly spherical in three dimensions and others appear to be ellipsoidal. Many lapilli have concentric zoning and other internal structures.

In the measured section, oblate spheroidal lapilli are less than 10 cm long, have a length:width ratio of between 2:1 and 4:1, and make up 75 to 80% of the lapilli population; they are most abundant in lapilli-tuff layers 1 and 2 and the length:width ratio decreases stratigraphically upward. Lapilli with a circular cross section are somewhat smaller than oblate spheroidal lapilli; largest sizes are 2.5 to 3.8 cm. They compose 15 to 20% of the lapilli population, are most abundant in lapilli-tuff layers 3 and 4, but also occur at the top of lapilli-tuff layer 2. Broken lapilli rarely exceed 5% of the lapilli population; lapilli pieces are less than 1 cm across and occur in all lapilli-tuff layers. In the westernmost outcrops of both sequences where the sequences are thinner, maximum lapilli size is 0.5 cm; most of the lapilli are nearly spherical; and broken lapilli are rare.

Lapilli are composed largely of 0.02 and 0.04 mm, granoblastic quartz and feldspar with 0.7 to 9.4% pyrogenic plagioclase and quartz crystals, and rare, 0.02 to 0.08 mm euhedral oxide grains, 0.02 to 0.04 mm rounded oxide grains, 0.1 to 0.2 mm euhedral pyrite and tabular 0.04 mm flakes of muscovite, or biotite and/or chlorite. Based on X-ray diffraction analysis, the quartz-feldspar mosaic consists of subequal amounts of quartz, albite and microcline.

In lapilli, plagioclase crystal abundance ranges from 0 to 6% and quartz from 0.7 to 3.3%, but the quartz-plagioclase crystal ratio is constant, averaging about 1:2 (Baldwin, 1987). Four to seven % of the crystal population in lapilli are crystal fragments.

Generally crystals are randomly oriented within lapilli although locally, tabular plagioclase crystals are oriented tangentially to lapilli margins and concentric layers in lapilli. Crystals locally transect internal layers of lapilli (Fig. 27, 29) and rarely project beyond the outer margins of lapilli (Fig. 33); projecting crystals are not broken at the outer margins of lapilli.

The euhedral shape of the plagioclase crystals, the euhedral to subrounded shape of quartz crystals, and the embayments in quartz crystals suggest a magmatic origin for these crystals. However, because some crystals are discrete crystal fragments, they are not phenocrysts in their present mode of occurrence in lapilli. Crystal breakage occurred prior to incorporation in the lapilli, and the crystals are thus pyrogenic.

Matrix

The mineral composition and the grain size of the matrix of lapilli-tuff is markedly different from that in the lapilli. Compared to lapilli the granoblastic mosaic of the matrix is coarser grained and it lacks microcline. The matrix contains more pyrogenic crystals and has a different pyrogenic quartz:plagioclase crystal ratio than the lapilli (Baldwin, 1987).

The matrix comprises a 0.04 to 0.1 mm granoblastic mosaic composed of 78 to 91.5% quartz and plagioclase, 3.5 to 21.2% pyrogenic plagioclase and quartz crystals and 5% combined muscovite, biotite, chlorite, iron oxide and pyrite. The plagioclase:quartz ratio in the granoblastic mosaic is 1:2 to 1:5.

Pyrogenic crystals in the matrix have the same size as, and all the features of, pyrogenic crystals in the lapilli. Between 5 and 8% of the pyrogenic crystal population in the matrix are crystal fragments, the same proportion as in the lapilli.

In addition to all the features displayed by pyrogenic crystals in the lapilli, plagioclase crystals in the matrix locally form clusters of 2 to 3 euhedral discrete crystals that in places butt against one another. In a few plagioclase crystals, variable amounts of quartz, carbonate and sericite are concentrated in randomly distributed patches that in places coalesce.

Muscovite in the matrix is uniformly distributed throughout the granular mosaic of plagioclase and quartz. Muscovite grains are elongate, are about 0.01 mm long and have a preferred orientation. Adjacent to pyrogenic plagioclase crystals, muscovite occurs as patchy concentrations that are deflected by the crystals. Poikiloblastic, elongate, 0.02 to 0.04 mm biotite and chlorite grains are uniformly distributed throughout the matrix; they cross-cut muscovite but do not have a preferred orientation. Rounded 0.01 mm iron oxide grains are disseminated in the matrix. Euhedral 0.1 mm iron oxide and pyrite grains are rare.

Internal Structure of Lapilli

In unbroken lapilli, 3 types of internal structure are recognized (Fig. 30): 1) unstructured, 2) concentrically layered, and 3) concentrically chambered. Concentrically chambered lapilli make up about 50% of the lapilli population, concentrically layered lapilli about 25%, and unstructured lapilli about 20%; the remaining 5% are broken lapilli; coalesced lapilli are rare. Unstructured and concentrically layered lapilli occur in all 4 lapilli-tuff layers, but they are most abundant in lapilli-tuff layers 2, 3 and

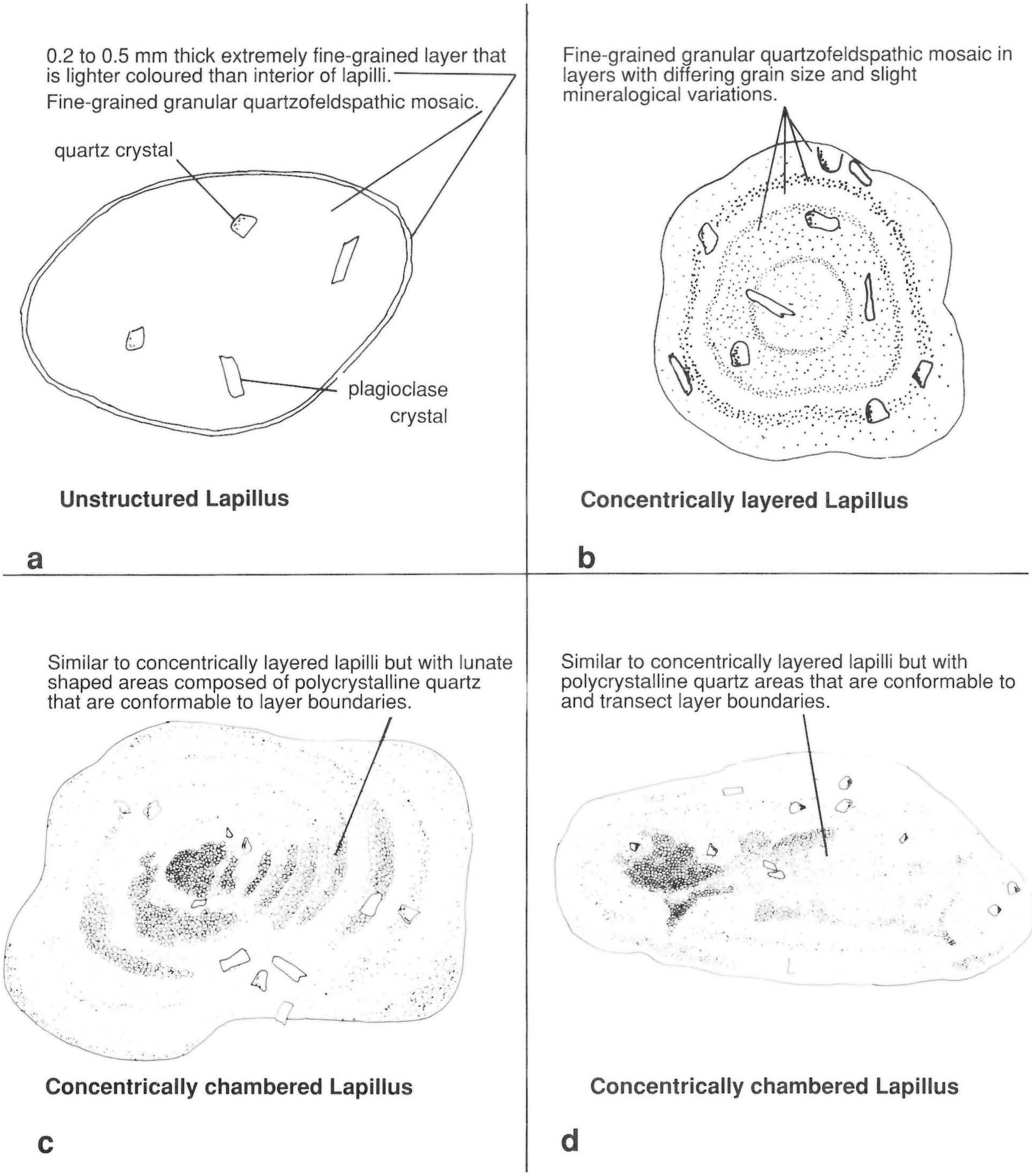

Figure 30: *Schematic sketches of the internal structures and textures used to classify the three different types of lapilli in the hot air fall lapilli-tuff. Sketches drawn by B. Schmidtke.*

4. Concentrically chambered lapilli were observed only in layers 1 and 2 and in the lowermost part of layer 3 (Fig. 25). Concentrically chambered lapilli decrease in abundance stratigraphically upward and also laterally as the lapilli-tuff layers decrease in thickness westward.

Unstructured lapilli typically are a mass of granoblastic quartz and feldspar surrounded by an outer zone 0.2 to 0.5 mm thick, lighter coloured, and extremely fine grained (0.01 mm); most commonly the outer zone is a continuous rim around lapilli, but locally it only partly surrounds a lapillus (Fig. 31). Pyrogenic crystals are unevenly distributed in the cores of lapilli and rarely occur in the outer rim. This outer rim is weakly birefringent, appears to be largely feldspar, and occurs on concentrically layered and concentrically chambered lapilli. In broken lapilli it occurs only on the original outer margin and in coalesced lapilli the rim predates coalescence. Detached pieces of the outer rim have not been observed.

The discontinuous nature of the rim on some lapilli could be due to breakage or it could be a primary depositional feature. If the discontinuous

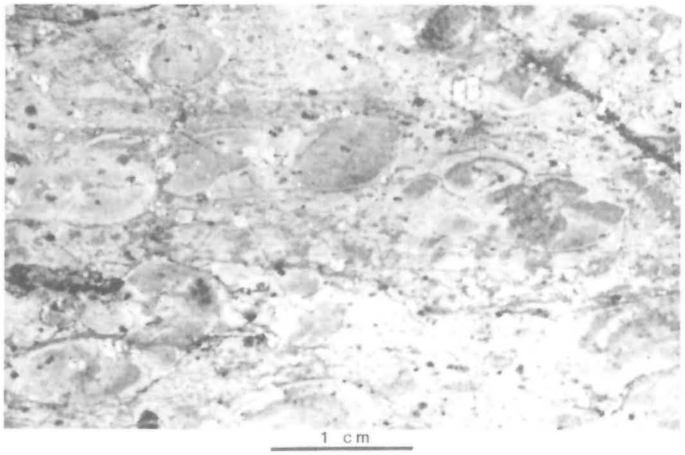

Figure 31: *Etched slab of unstructured lapilli in lapilli-tuff layer 3. Note the single thin light coloured rim surrounding the lapilli. Black specks are quartz crystals and white specks are plagioclase crystals. The high concentration of one structural type of lapilli, as shown in this photograph, is uncommon.*

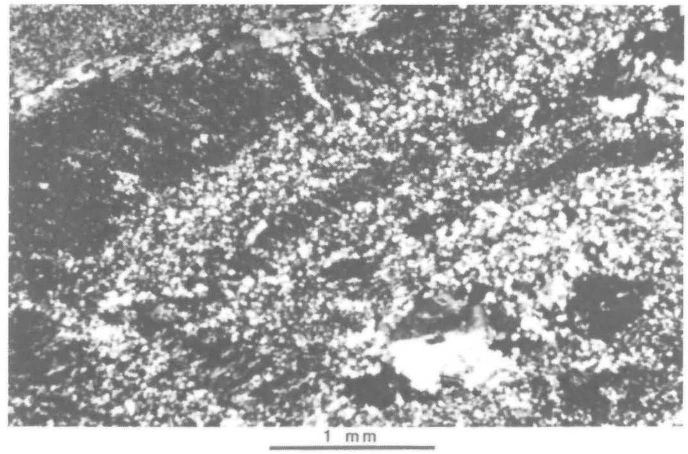

Figure 32: *Photomicrograph of alternating layers of granular quartz-feldspar mosaic and a radial intergrowth of quartz and feldspar in a concentrically layered lapillus, lapilli-tuff, layer 2. The radial texture may be the result of spherulitic crystallization. X-nicols.*

nature of the outer rim on these lapilli is due to breakage, then metamorphic recrystallization has destroyed the evidence. In some unstructured lapilli the outer rim appears to pinch out against the massive core (Fig. 31). Moore and Peck (1962) described incomplete layers within, and at the outer margins of, accretionary lapilli. Thus, the discontinuity of the outer rim appears to be a primary feature of lapilli development.

Concentrically layered lapilli are characterized by 0.5 to 1.5 mm thick layers (Fig. 27, 30) of granular quartz and feldspar that differ slightly in grain size from layer to layer. Typically there is an overall decrease in grain size from the centre to the margin of lapilli, but in some individual layers within lapilli the grain size can coarsen toward either the inner or outer surface of that layer. Most commonly boundaries between layers are sharp and mimic the outer boundary of the lapillus. Some layers pinch out and are discontinuous within the lapilli. Although crystals transect layers, only rarely are layers deflected around crystals. In broken lapilli the layers are truncated at the breakage surface. In coalesced lapilli the layers mimic only the outer margin of each lapillus; nowhere do layers surround more than one lapillus. Thus lapilli growth ceased before coalescence. The outer rim of concentrically layered lapilli is similar to that surrounding unstructured lapilli.

In some concentrically zoned lapilli, layers with granular texture alternate with layers that have fibrous-radial intergrowths of plagioclase and quartz (Fig. 32), or several layers with fibrous-radial intergrowth may occur without intervening granular layers. The fibrous-radial intergrowth is similar to that produced by spherulitic crystallization.

Concentrically chambered lapilli are: 1) concentrically layered lapilli that also contain several, 0.3 to 1.0 mm thick, discontinuous lunate lenses of polycrystalline quartz (Fig. 30c, and d, 33), 2) structureless lapilli that contain 1 to 3, lunate to elongate, concentrically arranged, 0.5 to 2.5 mm thick lenses of polycrystalline quartz (Fig. 34), and 3) concentrically layered and unstructured lapilli that contain irregular-shaped masses of polycrystalline quartz (Fig. 30d, 31, 35). Grain size of the polycrystalline quartz is 0.05 to 0.15 mm. Contacts between polycrystalline quartz and the granoblastic or fibrous quartz and feldspar are sharp. Areas of polycrystalline quartz occupy up to 50% of the area of sectioned lapilli; but the actual volume of polycrystalline quartz was not determined. Rare 0.1 mm anhedral grains of plagioclase, chlorite and/or biotite and euhedral oxide grains occur in polycrystalline quartz at or very close to the contact with granoblastic quartz and feldspar.

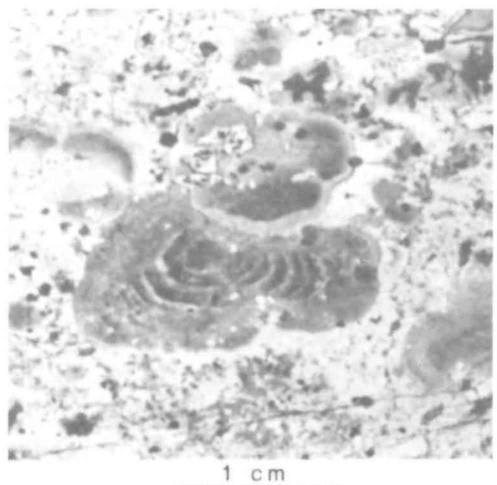

Figure 33: *Etched sample of concentrically chambered laplillus (bottom lapillus) that has several discontinuous, concentrically arranged, lunate structures occupied by polycrystalline quartz (dark grey area). Note that lunate structures do not transect concentric layering or lapillus boundaries. In the upper lapillus there is a single larger lunate structure (dark grey) close to the lapillus boundary. Note the quartz crystal transecting the right hand boundary of this lapillus.*

In concentrically chambered lapilli that are also concentrically layered, the lunate polycrystalline quartz areas occur at various places between the centre and margins of lapilli. The quartz areas are generally conformable with internal layers; they locally transect layer boundaries and lapilli margins, but do not extend into the matrix surrounding lapilli (Fig. 34, 35, 37) or into adjacent lapilli. Generally the lunate structures terminate by gradually pinching out, but less commonly terminations are blunt (Fig. 33). Most commonly layer width is the same in areas of polycrystalline quartz and in areas composed of the granoblastic quartz and feldspar mosaic. Thus it appears there was no expansion of the lapilli to accommodate the polycrystalline quartz (Fig. 30c, 36).

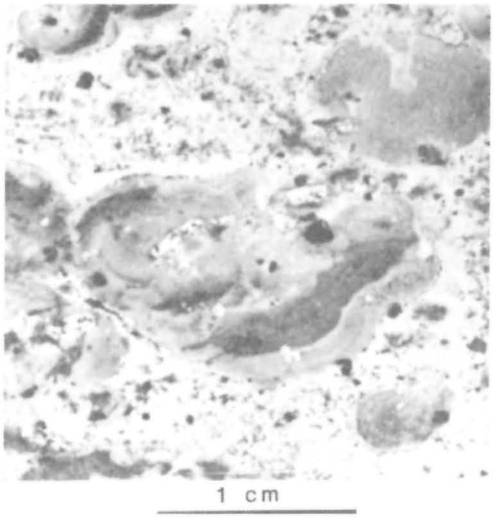

Figure 34: *Etched sample of concentrically chambered lapillus that exhibits 3 discontinuous concentrically arranged lunate structures occupied by polycrystalline quartz (dark grey areas). Polycrystalline quartz locally cross-cuts the finer grained quartz and feldspar aggregate of the lapillus.*

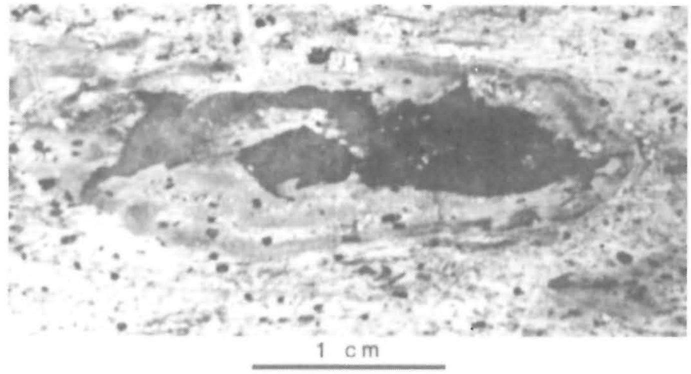

Figure 35: *Etched sample of concentrically chambered lapillus with a large irregular-shaped area occupied by polycrystalline quartz (dark grey) that cross-cuts layering in the lapillus.*

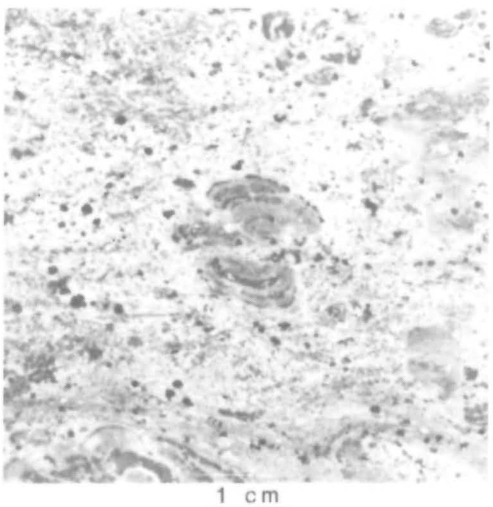

Figure 36: *Etched sample of concentrically chambered lapillus that apparently broke on impact with the depositional surface.*

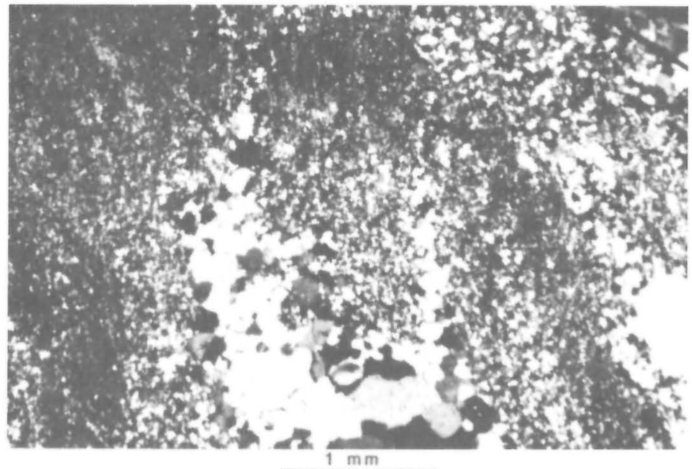

Figure 37: *Photomicrograph of concentrically chambered lapillus with outer layer of fibrous intergrowth of quartz and feldspar enclosing a layer of granoblastic quartz and feldspar. The polycrystalline quartz in a lunate structure also cross-cuts layering in the lapillus. X-nicols.*

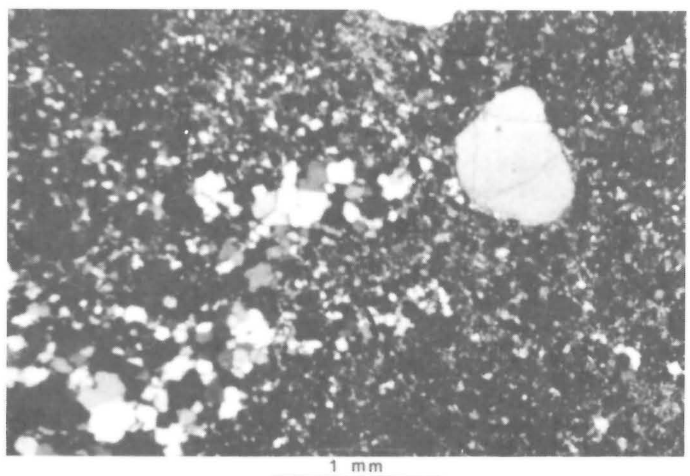

Figure 38: *Photomicrograph of concentrically chambered lapillus showing polycrystalline quartz cross-cutting the quartz and feldspar mosaic of the lapillus but not transecting the lapillus and matrix boundary. Polarized light.*

In concentrically chambered lapilli that are otherwise structureless, the lunate polycrystalline quartz areas occur at various places between the centre and margin of lapilli. Although the distribution of the lunate quartz is not controlled by a pre-existing internal structure, in many places the quartz defines a concentric structure. Generally the terminations of the lunate structures are gradual pinch-outs but some pinch out rapidly (Fig. 34). Polycrystalline quartz protrudes from the lunate structures into cracks or fractures that transect layers in the granoblastic quartz and feldspar (Fig. 37); generally such protrusions do not transect lapilli margins (Fig. 34, 35, 37), but locally where they do transect the margins, they do not extend into the matrix (Fig. 38).

Some pyrogenic crystals transect the boundary between polycrystalline quartz and granoblastic quartz and feldspar (Fig. 34) but are never wholly contained in polycrystalline quartz nor broken at this boundary. Some polycrystalline quartz areas terminate against a pyrogenic crystal.

Some lapilli are broken with straight, concave or serrate boundaries that transect concentric layering (Fig. 36, 28). Most commonly, broken lapilli occur as discrete fragments separated from other fragments by unbroken lapilli, indicating that breakage occurred prior to deposition and that concentric layering is a pre-depositional feature. Locally, numerous small lapilli fragments, 2 to 4 mm in size, are closely clustered together and collectively have the size and shape of unbroken lapilli. Less commonly 2 to 4 lapilli fragments that are separated by less than 1 mm can be reconstructed to form an unbroken lapillus (Fig. 36). These lapilli fragments apparently formed by impact of a lapillus with the depositional surface. Concentrically chambered structure is common in broken lapilli that are associated with unbroken concentrically chambered lapilli. The polycrystalline quartz areas in broken lapilli do not cross-cut the broken margins; there is always granoblastic quartz and feldspar of the lapilli between the polycrystalline quartz and lapilli-tuff matrix.

Coalesced lapilli are rare and consist of two concentrically layered lapilli; no layers are common to both of the mutually adjacent lapilli (Fig. 29). Outer layers in the two adjacent lapilli are disrupted suggesting that layers deformed when the lapilli collided and that coalescence was a late event.

Interpretation

The monolithic lapilli-tuff and/or tuff comprising juvenile or cognate pyroclasts that are spatially associated with other primary volcanic deposits, particularly ignimbrites, have characteristics that suggest deposition from tephra fallout. The rocks form tabular or wedge-shaped units that have sharp and planar upper and lower boundaries and less commonly a gradational lower contact but sharp upper contact. The deposit thicknesses are consistent with those of magmatic and hydrovolcanic tephra fallout deposits (Fisher and Schmincke, 1984). In addition to the above features individual deposits have some of the following characteristics: 1) lateral decrease in deposit thickness, 2) lateral decrease in grain size, 3) lateral change in bed thickness, 4) size and/or abundance grading, 5) well developed bedding, 6) accretionary lapilli, and 7) genetic association with ignimbrites. These characteristics are common to tephra fallout deposits (Fisher, 1964; Fisher and Schmincke, 1984; Moore and Peck, 1962; Self and Sparks, 1978; Waitt and Dzurisin, 1981; Walker, 1971, 1980; Williams and McBirney, 1979).

Although pyroclastic rocks formed by processes other than tephra fallout can have some of these characteristics, the parameters that led to the classification of these deposits as tephra fallout are discussed by Baldwin (1987). In addition, Baldwin (1987) suggests that the genesis of the various tephra fallout deposits is as follows:

— The tephra contained in the block-and-ash deposits of layer 2 in the upper part of pyroclastic unit B was the product of explosive disintegration of a small dome or a plug emplaced following the deposition of layer 1 ignimbrite. The disruption of the dome or plug was probably the initial stage of the eruption that produced the pyroclastic material contained in the layer 3 ignimbrite.

— The interbedded lapilli-tuff and tuff that make up the tephra fallout deposits of pyroclastic unit A and layer 4 of the upper part of pyroclastic unit B resulted from hydrovolcanic eruptions. The bedded nature of the deposits suggests a series of discrete eruptive blasts or variations in the eruptive energy of a continuous but pulsating eruption column.

— The coarse lapilli-tuff beds associated with ash-flow ignimbrites in pyroclastic unit D are interpreted to be pumice fall deposits. The deposition of abundant pumice in discrete beds within the ignimbrite sequence of pyroclastic unit D probably resulted from changes in eruption energy during the ignimbrite eruption.

— Thin tuff beds, at the top of and in sharp to gradational contact with ash-flow ignimbrites in pyroclastic units G and H, are interpreted to be co-ignimbrite ash-fall deposits. The ash contained in the thin tuff beds accumulated from fallout of ash-size material from eruption columns or from an ash cloud that formed above the ignimbrites during their deposition.

— Lapilli-tuff in tephra fallout deposits in pyroclastic unit C are characterized by accretionary lapilli that formed by the accretion of hot volcanic ash particles. The eruption columns associated with the formation of the lapilli-tuff were of low height, contained a high concentration of pyroclasts, and did not greatly expand due to the incorporation of air. Thus, the accumulation rate of lapilli tuff was high and the accretionary lapilli were hot when deposited. The nature of the bedding suggests that the accumulation of lapilli-tuff resulted from a series of discrete eruptions of similar type. Eruption temperatures higher than what is suggested for Cenozoic rhyolitic eruptions may explain why accretionary lapilli, formed by the accretion of hot ash particles, have not been recorded from Cenozoic pyroclastic sequences. The laminated and bedded tuff, that is interlayered with the hot tephra fall lapilli-tuff of pyroclastic unit C, formed from deposition of fine ash that was supported by turbulence in lapilli-tuff-forming eruption columns, rather than by deposition from discrete tuff-forming eruptions. However, temporally equivalent lapilli-tuff and tuff need not be deposited at the same locality. Formation of the accretionary lapilli and deposition of lapilli-tuff would dilute the particle concentration in eruption columns, the columns would then expand, and the fine ash would be deposited distally from lapilli-tuff.

PYROCLASTIC SURGE

General Statement

Only one unit in the northwest segment of the Karsakuwigamak Block has internal features and stratigraphic position consistent with a pyroclastic ground surge associated with ignimbrite deposits. At present, the genesis of such apparently low concentration pyroclastic deposits that were deposited from turbulent flow associated with ignimbrites is controversial. For example, Walker et al. (1980) interpreted the landscape mantling, veneer deposits of the Taupo and Rabaul ignimbrites as tail deposits left in the wake of pyroclastic flows, whereas Fisher et al. (1980a) suggested that they were deposited from ash-cloud surges. The May 18, 1980 lateral blast of Mount St. Helens has been interpreted by Waitt (1981), Hoblitt et al. (1981), and Moore and Sisson (1981) as a pyroclastic surge, whereas Walker and McBroome (1983) suggested that the blast deposit is consistent with a low-aspect ratio ignimbrite deposited from a fast moving flow. Proximal low-angle crossbedded deposits and interbedded plane parallel beds related to the May 18, Mount St. Helens pyroclastic flows have recently been interpreted to represent erosion and deposition by density currents that span the entire spectrum from inflated pyroclastic flows to dense pyroclastic surges (Rowley et al., 1985). Similar controversy exists for some pyroclastic deposits of Mt. Pelée (Fisher and Heiken, 1981; Fisher et al., 1980b; Walker and McBroome, 1983). Until the dispute about the genesis of crossbedded pyroclastic deposits is settled, the deposit described herein will be classified as a pyroclastic surge deposit.

Petrography

The surge deposit consists of 0.5 to 1.3 m of thinly bedded to thinly laminated tuff that occurs below, and in sharp contact with, ignimbrite in pyroclastic unit H (Table 10; Fig. 39, 13). The basal contact of the tuff with underlying siltstone is also sharp. The tuff is exposed discontinuously for 150 m along strike in the northeast corner of the northwest segment of the Karsakuwigamak Block, and also at one locality 1.5 km farther west in the

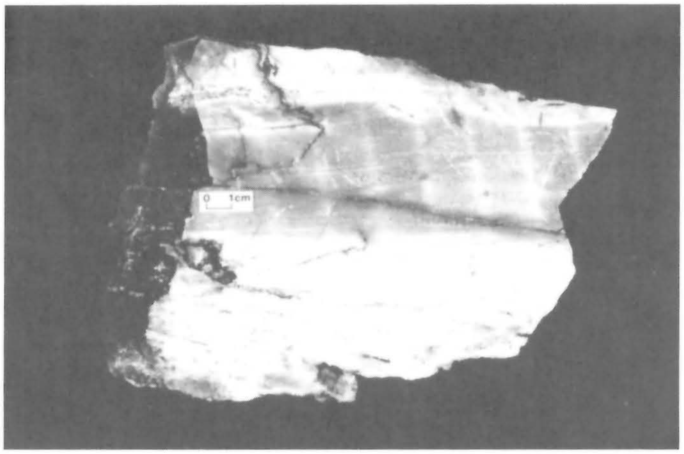

Figure 39: Etched slab of bedded, laminated and cross-stratified rhyolite, layer 1, pyroclastic unit H. Beds are defined by different colour resulting from different grain size: white beds are coarser grained than grey beds. The 2 to 4 mm thick speckled laminations are largely submillimetre sized, broken plagioclase and quartz pyrogenic crystals and angular lithic fragments. Black specks in white tuff are quartz crystals; plagioclase crystals are masked by the etch.

north central part of the block. The unit appears to be thinner in the west than in the east, although, in the west, the position of the basal contact is obscured by moss and soil cover.

Beds are 2 to 5 cm thick and include planar, pinch and swell, and gently undulating morphologies. Bedding is defined by abrupt changes in abundances of pyrogenic crystals and lithic fragments, and in colour that reflects variations in the grain size of the fine grained, quartzofeldspathic aggregate that presumably represents recrystallized vitric material. Some beds are composed entirely of recrystallized vitric material whereas others can contain up to 7%, 0.25 to 0.5 mm, broken and unbroken, pyrogenic quartz and plagioclase crystals and 20%, 0.5 to 1 mm, white, felsic lithic fragments randomly distributed in recrystallized vitric material.

Some beds contain 2 to 4 mm thick laminations in which crystals and lithic fragments are more concentrated. These laminations are composed of 10 to 15%, 0.25 to 0.5 mm broken and unbroken plagioclase and quartz crystals and 10 to 20% similar sized lithic fragments in fine grained recrystallized vitric material. Laminations generally define low-angle oblique stratification (Fig. 39) that is truncated by bedding, but they occur also as parallel laminations and as 1.3 to 5.5 cm long lenses oriented parallel to, or slightly oblique to, bedding. Lenses that are oblique to bedding have an en echelon pattern and terminate within bed boundaries; oblique laminations are always inclined toward the east suggesting that deposition was unidirectional. Locally, lenses that are parallel to bedding occupy apparent depressions in the upper surface of some beds, suggesting that the tops of these beds are erosional surfaces. Lamination is most common in beds that contain pyrogenic crystals and lithic fragments. Only rarely are crystal and lithic-bearing laminations present in beds that otherwise are composed solely of recrystallized vitric material. However, recrystallization may have destroyed fine laminations in vitric ash. The presence of parallel and oblique laminations implies deposition from traction or from turbulent flow (Fisher, 1979; Middleton and Hampton, 1976; Sparks, 1976).

The pyrogenic crystals in the tuff unit are the same species as in the overlying ignimbrite, but are smaller and less abundant than in the ignimbrite. The lithic fragments in the two units appear to be lithologically similar, but they are smaller and locally more abundant in the tuff unit than in the ignimbrite (Tables 9 and 11).

Interpretation

The bed forms and the presence of oblique and parallel lamination in the tuff are typical of fluvial, aeolian and surge deposits. Fluvial deposition of the tuff is not only suggested by the bed structures but is also supported by stratigraphic position; the tuff directly overlies a sequence largely composed of fluvial and lacustrine sediments. If the tuff is a fluvial deposit, the fine grain size implies considerable transport; however, the angularity of pyrogenic crystals and lithic fragments suggests little abrasion and thus little transport in a fluvial system. The angularity of the crystals and lithics is also inconsistent with aeolian deposits in which larger sand grains tend to be well rounded, although the constant orientation of the oblique stratification is consistent with an aeolian origin (Reineck and Singh, 1975). Beds in the tuff are either massive or contain parallel or unidirectional oblique lamination; some massive beds pinch and swell. Unidirectional oblique stratification is characteristic of sand-wave beds, a common bed form in all pyroclastic surge deposits (Crowe and Fisher, 1973; Fisher, 1979; Fisher and Schmincke, 1984; Wohletz and Sheridan, 1979; Wright et al., 1980), where it is commonly associated with massive beds (Wohletz and Sheridan, 1979). Pinch and swell structures and erosional features also occur in pyroclastic surge deposits (Fisher, 1982a; Wright et al., 1980). The association of massive and sandwave beds is indicative of the sandwave facies in pyroclastic surge deposits (Wohletz and Sheridan, 1979). Pyroclastic surges are low concentration, turbulent, density currents (Fisher, 1979) and the concentration of crystals and lithics in laminae is compatible with deposition from a dilute turbulent flow. The stratigraphic position of the tuff beneath the ignimbrites and the presence of pyrogenic crystals of the same species and lithologically similar lithic fragments in both the tuff and the overlying ignimbrite suggest a genetic relationship between the two deposits. Thus the tuff is interpreted to be a ground surge deposit. The deposit is considered to have formed from collapse of a fine grained, lithic and crystal poor outer sheath of a Plinian eruption column (Baldwin, 1987). The fine grain size of the outer sheath probably resulted from high shear gradients in the eruption column or in a volcanic pipe.

HETEROLITHIC VOLCANIC BRECCIA

General Statement

Coarse grained volcanic breccia comprising fragments of different composition and texture (heterolithic volcanic breccia) occurs in the northern domain of the Ruttan Block, the Karsakuwigamak Block and in the Eastern Block (Fig. 40). The breccias form wedge, blanket and lens-shaped units up to 650 m thick that internally may be well or poorly stratified (Table 11). All but one of the breccia units comprise several beds generally less than 5 m thick (Table 11). Heterolithic breccia unit F in the Karsakuwigamak Block consists of a single bed 20 m thick (Table 11, Fig. 40). Most commonly bedding planes are sharp and planar as are unit boundaries. However, in some units bedding planes are commonly gradational over a few centimetres. Breccia beds may be internally stratified. Reverse to normal and normal fragment size grading (Fig. 41) is a common feature in breccia beds. Most beds can be classified as lapilli-tuff but because of fragment size grading a bed can be composed of lapilli-tuff and tuff-breccia zones. In beds that are particularly well reversely or reversely to normally graded a tuff layer is present at the base of the bed (Fig. 42). In a bed, zones with different grain size grade into one another. Bedding is generally defined by a sharp break in fragment size, fragment abundance or changes in the most abundant fragment type. Changes in fragment size, fragment abundance, and most abundant fragment type that take place over a few centimetres are considered to be bedding because gradational changes in fragment size and abundance within a bed occur over several centimetres.

In these breccia units the range in fragment size generally does not

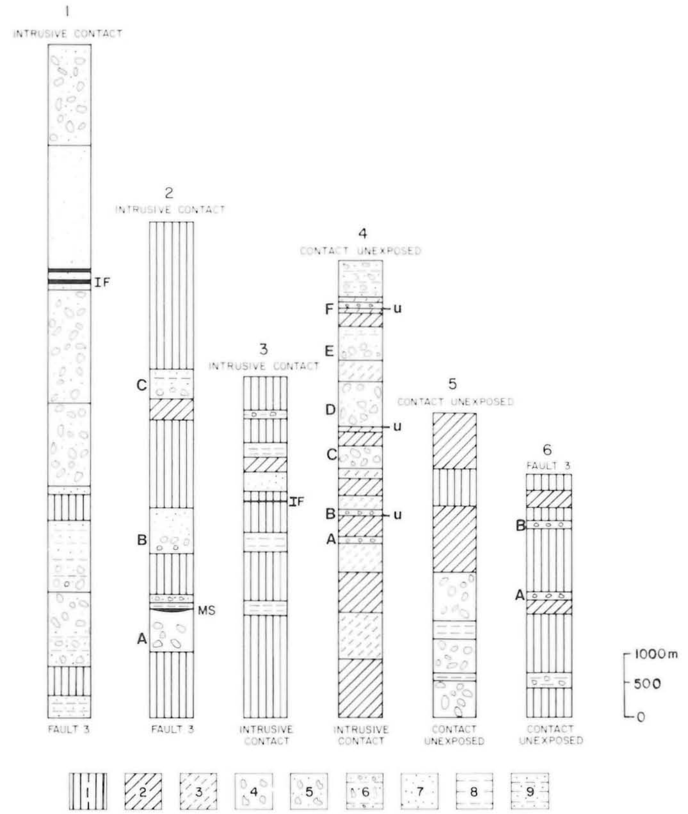

Figure 40: *Stratigraphic distribution of heterolithic breccia (debris flow deposits) in the southern part of the Rusty Lake metavolcanic belt. Stratigraphic sections and symbology are the same as in Figure 4.*

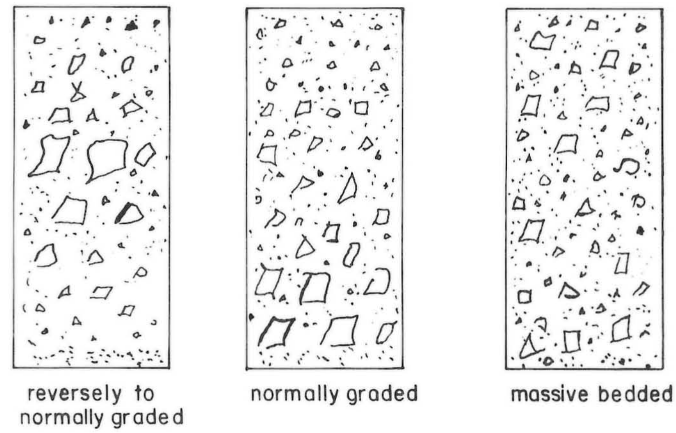

Figure 41: *Schematic diagram of fragment organization in heterolithic volcanic breccia beds. Basal tuff layer is not always present.*

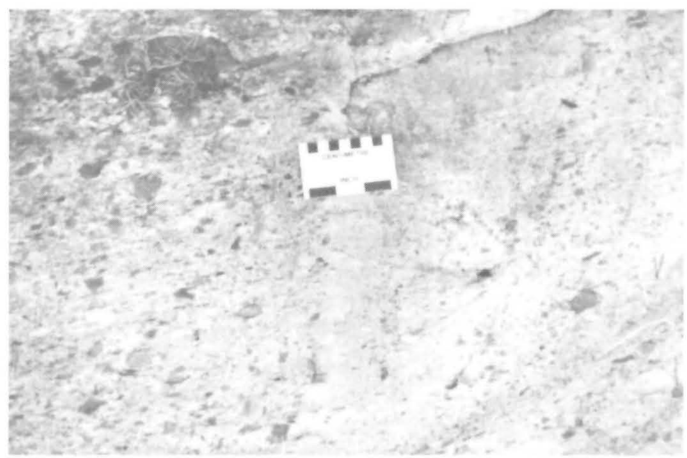

Figure 42: *Fine grained basal layer (centre of photograph) at the base of a heterolithic breccia bed in heterolithic breccia unit B, Karsakuwigamak Block. Stratigraphic top is toward the right side of the photograph.*

vary vertically or laterally. In only one unit is there an upward fining in grain size. In one other there is coarse-tail grading laterally. Breccia beds are poorly sorted, have unimodal grain size distribution, and fragments are matrix-supported. In each breccia unit fragment abundance does not vary vertically or laterally but from bed to bed the variation can be up to 30%.

Breccia units are heterolithic; however, fragments in any one unit are predominantly either angular to subrounded rhyolite and dacite or subrounded basalt and rock of intermediate composition. The heterolithic nature of these breccia units is defined not only by fragment composition but also by textural differences between fragments of similar composition (Table 11).

Matrix in heterolithic breccia units and beds comprises rock fragments that are less than 2 mm across that have compositions similar to the larger fragments in the rock, discrete crystal grains 0.5 to 3 mm across, and a fine grained metamorphic aggregate that has a mineralogical composition consistent with the felsic or mafic to intermediate nature of the breccia unit (Table 11).

In the Ruttan Block heterolithic breccia is felsic in composition, mafic to intermediate heterolithic breccia is subordinate to felsic breccia units in the Karsakuwigamak Block, and in the Eastern Block the identified heterolithic breccia units are intermediate and mafic in composition (Table 11).

In the Ruttan Block heterolithic volcanic breccia units are present only in the northern domain. Here, 3 breccia units that are felsic in composition occur in a stratigraphic sequence dominated by mafic flow rocks (Fig. 40). Two of these breccia units occur in the lower part of the stratigraphic sequence and form a large part of the volcaniclastic and sedimentary sequence that is the host to the Ruttan Cu Zn massive sulphide deposit (Baldwin, 1982). The third unit occurs in the upper one third of the northern domain and appears to form a wedge that overlies a unit of rhyolite flows.

The two heterolithic breccia units in the Eastern Block occur in the middle and near the top of the stratigraphic succession respectively. Fragments are predominantly mafic in composition but 30% of them have dacite composition.

Heterolithic breccia in the Karsakuwigamak Block occurs in the upper two-thirds of a stratigraphic sequence composed almost entirely of felsic flows, ignimbrites and air fall deposits. Four of the six breccia units have felsic composition with minor mafic to intermediate constituents. These breccias form wedges or lenses overlying either felsic flow or felsic pyroclastic units. The mafic breccia units form wedges and contain some felsic fragments but are not associated with any mafic flows or pyroclastic units in the sequence. Mafic flow or pyroclastic units that these breccias could be associated with are absent in the sequence. The maximum fragment size in mafic to intermediate breccias in the Karsakuwigamak Block is always much less than the maximum size in felsic breccia units.

Petrography

Heterolithic volcanic breccia comprises volcanic fragments, of various compositions and textures that are larger than 2 mm diameter, supported in a matrix composed of volcanic fragments that are less than 2 mm, quartz and/or plagioclase or plagioclase and/or amphibole crystals to 3 mm, and a microscopic granoblastic aggregate (Table 11). Breccia units are either felsic or mafic to intermediate in composition. However, minor amounts of mafic and intermediate fragments occur in some felsic breccia units.

In felsic heterolithic breccia, fragments are predominantly angular to subangular, equant to tabular rhyolite or dacite (Table 11). These fragments are rarely larger than 20 cm in diameter, have various proportions of phenocrysts, and are non-vesicular to poorly vesicular. Rare 1 m size fragments occur in unit B in the Ruttan Block. Rhyolite fragments are quartz- and plagioclase-phyric; quartz phenocrysts compose 1 to 3% of rhyolite fragments and the total phenocryst population rarely exceeds 7 to 8% of the rock. Dacite fragments are aphyric or plagioclase-phyric. Plagioclase phenocrysts compose between 1 and 15% of the mineral composition of phyric dacite fragments. Rhyolite and dacite fragments may be vesicular. Quartz, quartz plus feldspar, or quartz plus carbonate-filled vesicles generally compose 2 to 3% of the volume of vesicular felsic fragments. These vesicular felsic fragments generally compose less than 10% of the fragment abundance in felsic heterolithic breccia and rarely compose up to 20%. The groundmass in felsic fragments comprises a microscopic granoblastic aggregate of plagioclase and quartz with accessory muscovite and biotite, and minor amounts of one or more of apatite, epidote, magnetite, carbonate and chlorite.

In felsic heterolithic breccia, basaltic and andesitic fragments generally compose less than 10% of the fragment abundance and rarely are present in amounts up to 20%, but their maximum size is much less than the rhyolite and dacite fragments (Table 11).

The matrix in felsic heterolithic breccia consists mainly of a microscopic granoblastic aggregate of plagioclase, quartz, muscovite and biotite with minor amounts of apatite, epidote, magnetite and carbonate (Table 11). This granoblastic aggregate is mineralogically similar to the groundmass of the felsic fragments, but the grain size of the matrix aggregate is twice that of fragment groundmass. One to two millimetre equant crystals of quartz and 1 to 3 mm equant plagioclase crystals are common (Table 11). Matrix rock fragments have the same compositions as the larger felsic fragments in the breccias. Mafic and intermediate fragments do not occur as a matrix component in felsic heterolithic breccia.

Fragments in mafic to intermediate heterolithic breccia are mainly lapilli size, subangular to subrounded, equant to elliptical basalt and/or andesite. However, some are angular and up to 20 cm across (Table 11). For the most part basalt and andesite fragments are aphyric (Table 11). Phyric basalt fragments contain 10 to 25% hornblende phenocrysts that appear to be pseudomorphs of pyroxene, and 10 to 15% plagioclase phenocrysts. Phyric andesite fragments contain 10 to 20% plagioclase phenocrysts and less than 10% hornblende phenocrysts that, for the most part, appear to be pseudomorphs of pyroxene. These fragments are generally non-vesicular but some contain 20 to 30% vesicles filled with carbonate, quartz plus carbonate, or carbonate plus plagioclase. The groundmass in basalt fragments is a microscopic granoblastic mosaic of amphibole with minor plagioclase and accessory epidote, carbonate chlorite and magnetite. Groundmass in andesite fragments is also a microscopic granoblastic mosaic and comprises subequal amounts of amphibole and plagioclase with minor quartz and accessory epidote, carbonate, chlorite, magnetite and apatite.

The matrix of mafic to intermediate heterolithic breccia is largely a microscopic granoblastic mosaic composed of amphibole and plagioclase (Table 11). Amphibole is generally more abundant than plagioclase but in some thin sections the two minerals are present in equal or subequal amounts. Accessory minerals in decreasing order of abundance are epidote, carbonate, magnetite and chlorite. Two to three millimetre euhedral crystals of amphibole and plagioclase compose 3 to 5% and 5 to 10% of the matrix in some units (Table 11). Chlorite pseudomorphs of pyroxene crystals are rare. Matrix rock fragments are petrographically similar to the larger fragments in the breccia units. They are typically equant but elliptical shaped fragments are locally common. The grain size of the matrix granoblastic mosaic is always equal to or coarser grained than the groundmass in mafic fragments. Felsic fragments are rare in mafic to intermediate heterolithic breccia (Table 11). Where present they compose a minor component of the fragment population and have a maximum size of about one-half that of the largest mafic fragments. The maximum fragment size in mafic breccia is generally much smaller than the maximum size in the felsic breccia units.

Interpretation

Volcanic debris flows are coarse grained, poorly sorted and most commonly heterolithic (Fisher, 1971). Deposits are thick and bedding may or may not be well developed depending upon rate of debris supplied to the depositional site. Grading is commonly reverse to normal but normal grading and massive texture are equally common (Fisher, 1982b). Large fragments are angular to subrounded, but rounded fragments may become incorporated during flow and erosional lower surfaces are rare (Fisher and Schmincke, 1984). A common feature of volcanic debris flow deposits is a basal layer that can be several centimetres thick, and that is extremely fine grained compared to the coarser grained parts of the flow deposit. Because the heterolithic volcanic breccias in the Rusty Lake greenstone belt have many features common to debris flow deposits and lack the more diagnostic features of till, fluvial and pyroclastic flow deposits, they are interpreted to be volcanic debris flow deposits. Baldwin (1987) discusses in detail, and compares the features of, these coarse grained heterolithic breccias and breccias of differing genesis. The genesis of the heterolithic volcanic breccia units (Baldwin, 1987) is summarized below.

For the most part fragment shape resulted from explosive volcanism that caused breakage of non-vesicular to poorly vesicular viscous magma and/or explosive fragmentation of consolidated non-vesicular to poorly vesicular volcanic strata during volcanic eruptions. Subrounded fragments that have compositions and/or textures similar to more abundant angular to subangular fragments, and the rounded fragments that form a small proportion of the fragment population and have compositions that are different from the more abundant fragment types, probably resulted from erosion and downslope transport prior to incorporation in the debris flows. In deposits that contain 50% or more of one fragment type, fragment mixing may have been due to volcanic eruptions. However, fragment mixing in all of the deposits could have resulted from either simultaneous mass transport or stepwise downslope transport of fragmental material. The small proportion of fragments that are markedly different in composition and/or texture and/or degree of angularity were probably picked up and incorporated into the debris flows during flow on steep slopes (Baldwin, 1987). The tops of some debris flows were apparently reworked during interruptions in the initiation of debris flows, and sand flows and pebbly sandstone were deposited.

The debris flows were initiated by catastrophic events directly and/or indirectly related to an eruption (Baldwin, 1987). Emplacement of the volcanic debris in bedded deposits may have been either as a series of individual flows where each flow contains the products of a discrete eruption event, or emplacement of the entire volume of ejecta from an eruption as debris flows that followed different channelways from the source of the flows to the site of deposition.

The size, shape, vesicularity and composition of the fragment types in the volcanic debris indicate that the fragments originated as pyroclasts form Vulcanian eruptions (Baldwin, 1987).

POLYMICTIC VOLCANIC CONGLOMERATE (5a)

General Statement

Coarse grained, polymictic, volcanic derived conglomerate comprising rounded and subrounded cobbles and pebbles, interbedded with lesser volcanic derived sandstone and siltstone, occurs in the Ruttan, Karsakuwigamak and Eastern blocks.

Conglomerate beds make up 60 to 70% of the beds in these units. However, the abundance of, bed thickness of, and maximum clast size in conglomerate beds vary vertically, but not laterally. The abundance of sandstone and siltstone beds varies sympathetically with conglomerate beds, but bed thickness remains relatively constant both vertically and laterally.

Most commonly units are mafic or felsic in composition and the clasts have a wide range of textures, but some contain subequal amounts of clasts with various compositions and textures. Associated sandstone and siltstone beds reflect the composition of conglomerate beds.

Conglomerate beds may be massive, normally graded, or reversely to normally graded. The associated sandstone and siltstone are most commonly normally graded, and siltstone forms a fine grained top on sandstone beds. Bed boundaries between conglomerate beds are sharp and planar. Most commonly bed boundaries between sandstone and conglomerate are also sharp and planar, but cut and fill structures are present in some units.

Conglomerate and sandstone sequences form wedge and blanket shaped units that range in thickness from 150 to 600 m. Conglomerate beds are 0.4 to 5 m thick; the average is about 3 m. Sandstone beds range from 12 to 65 cm thick and siltstone beds from 5 to 15 cm. With the exception of fragment shape and abundance of interbedded sandstone and siltstone, the conglomerate units are similar to the heterolithic volcanic breccia units.

Petrography, bed thickness and bed texture

Karsakuwigamak Block

In the Karsakuwigamak Block there are 2 units of polymictic volcanic conglomerate (Fig. 43). Both units occur in the upper 20% of the stratigraphic succession in the block and one of these occurs at the top of the succession.

Conglomerate unit A is an eastward thickening wedge of poorly sorted, well stratified conglomerate that ranges in thickness from 65 to 200 m. The unit was deposited on an erosional unconformity. Except where the overlying unit has been removed by a younger gabbro intrusion, the conglomerate is overlain by dacite flows. Outcrop is sparse and lateral changes are unknown. All of the data presented here were collected from a 50 x 100 m area, containing about 30% outcrop, in the eastern part of the unit.

The conglomerate consists of 10 to 18% mafic and 10 to 18% intermediate volcanic fragments that range in size from 2 mm to 10 cm. Most of the fragments are rounded and equant, and are less than 4 cm in size but subrounded fragments are also present. Fragments in the conglomerate unit are more rounded than those in heterolithic breccia units in the stratigraphic succession.

The fragments are supported in a matrix that consists of 7% combined mafic and intermediate sand-sized rock fragments, 3% euhedral plagioclase crystal grains, and 90% light green, fine grained, metamorphically recrystallized aggregate composed of 40% plagioclase, 40% amphibole, 10 to 13% chlorite and 5 to 7% quartz; epidote and carbonate are present in minor amounts.

Conglomerate beds are 0.7 to 2 m thick and average about 1 m. Beds are massive and identified by changes in total fragment abundance or in the ratio of fragment types. Bedding planes are generally sharp and planar, but some beds are amalgamated with changes in fragment abundance and ratio, and are gradational over 5 to 15 cm.

Conglomerate unit B is the stratigraphically highest unit in the northwest segment of the Karsakuwigamak Block. The unit is divided into 3 segments by gabbro intrusions (Map GR86-1), which precludes determination of thickness, lateral extent, and the top of the unit. As exposed, the unit has a minimum thickness of 500 m and can be traced laterally for 2.3 km. The base of the unit is not exposed. Conglomerate forms 50 to 60% of the unit, lithic greywacke 30 to 40%, and siltstone 10%. The abundance and bed thickness of conglomerate and lithic greywacke varies vertically, but lateral changes were not observed. The abundance and bed thickness of conglomerate decrease upward, whereas the abundance of lithic greywacke increases but its bed thickness decreases.

Conglomerate is polymictic and contains 20 to 35%, rounded, non-vesicular, volcanic cobbles and pebbles; cobbles compose about 25% of the fragment population and have a maximum size of 8 cm. The fragment population includes: 1) 35 to 45% aphyric felsic fragments; 2) 10% quartz- and plagioclase-phyric rhyolite; 3) 10% plagioclase-phyric dacite; 4) 17 to 20% aphyric intermediate fragments; 5) 17 to 20% plagioclase- and hornblende-phyric intermediate fragments; and 6) 2 to 3% mafic fragments.

Cobbles and pebbles are supported in a lithic greywacke matrix that contains 20 to 30%, rounded to rarely subrounded, sand-sized and a few % 3 to 5 mm, angular, felsic and intermediate rock fragments; 5 to 10% rounded, 0.25 to 1.5 mm quartz grains, and 50 to 70%, 0.03 to 0.07 mm, metamorphically recrystallized aggregate composed of biotite, musco-

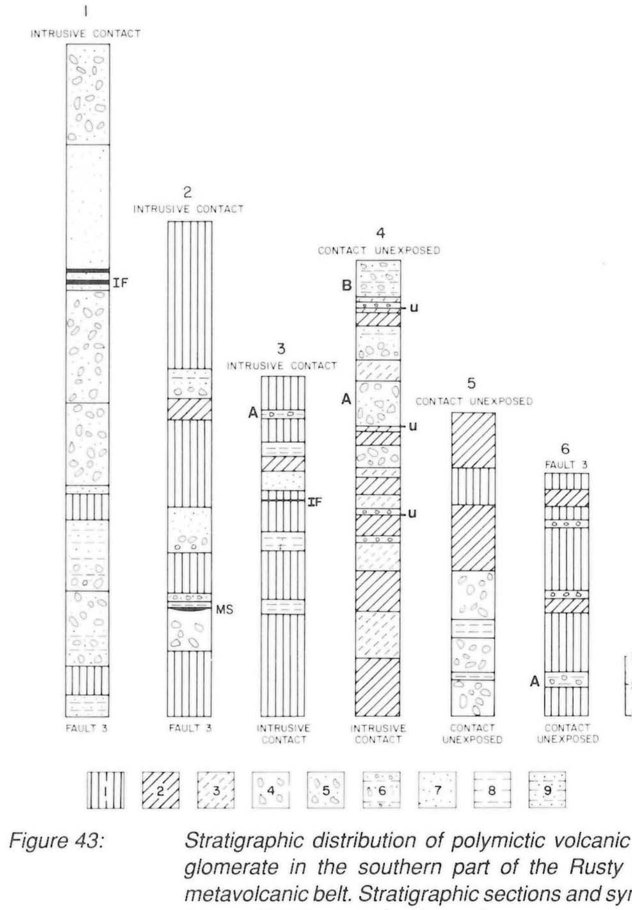

Figure 43: *Stratigraphic distribution of polymictic volcanic conglomerate in the southern part of the Rusty Lake metavolcanic belt. Stratigraphic sections and symbology are the same as in Figure 4.*

vite, plagioclase and quartz. The recrystallized aggregate contains 35% biotite, 20 to 25% muscovite, 20 to 25% plagioclase and 20 to 25% quartz; thus it contains nearly 60% mica.

Conglomerate beds range in thickness from 0.3 to 2 m and form bed sets 5 to 40 m thick. Beds are generally massive but some have vertical coarse-tail grading. Maximum bed thickness and bed set thickness decrease upward from 2 m to 50 cm and from 40 m to 7 m respectively, and in some bed sets bed thickness decreases upwards. The abundance of conglomerate decreases upward from 95% in the lower 120 m of the formation, to about 45% in the upper 50 to 60 m of the exposed part of the unit.

Lithic greywacke is composed of 30 to 50%, rounded to subrounded, sand-sized, felsic and intermediate rock fragments; 5 to 10% rounded to rarely euhedral, 0.25 to 2 mm plagioclase grains; 5 to 10% rounded, 0.25 to 1.5 mm quartz grains; and 30 to 60% metamorphically recrystallized aggregate that has the same components in the same proportions as in the recrystallized aggregate of conglomerate matrix. Thus, lithic greywacke contains less recrystallized aggregate and more recognizable rock fragments than conglomerate matrix. Beds are 15 to 50 cm thick and massive to normally graded; some beds have a well sorted, 5 to 8 mm thick basal zone composed of 70 to 80% rock fragments and plagioclase and quartz grains that are 1 to 2 mm across; bed sets are 2 to 30 m thick. The range in thickness of lithic greywacke beds is constant throughout the unit, but upward in the unit the abundance of beds 15 to 30 cm thick increases. In addition the thickness of bed sets of lithic greywacke increases upwards, and the total abundance of lithic greywacke increases from 5 to 55% in this same direction.

Siltstone has been completely recrystallized and is petrographically similar to the fine grained recrystallized aggregate in lithic greywacke of both the discrete beds and the conglomerate matrix. Siltstone forms 5 to 10 cm thick, fine grained portions to many normally graded lithic greywacke beds and here the boundary between the two lithologies is always gradational; the boundary between these siltstone layers and the base of the overlying lithic greywacke bed is always sharp. Siltstone also forms 5 to 10 cm thick beds, with sharp upper and lower boundaries, interbedded with lithic greywacke.

Eastern Block

Polymictic volcanic conglomerate in the Eastern Block (Fig. 43) occurs between 2 mafic volcanic flow units near the base of the Eastern Block stratigraphic succession. It comprises 70% conglomerate and 30% siltstone. The conglomerate is composed of 50 to 60%, 0.2 to 15 cm, rounded to subrounded clasts of felsic and intermediate compositions that are present in subequal amounts and are supported in a sandstone matrix that has a greywacke composition. The majority of the clasts (60 to 70%) in the conglomerate are 3 to 8 cm across. The felsic clast population comprises 60% non-vesicular, white, aphyric clasts, 30% non-vesicular, white to light grey, plagioclase- and quartz-phyric clasts, and 10% white, aphyric, highly vesicular clasts. The intermediate clast population is 80% light green, non-vesicular, plagioclase-phyric clasts, and equal amounts of greenish grey, non-vesicular, aphyric and light green, non-vesicular, aphyric clasts. The sandstone matrix in the conglomerate comprises 45% felsic and intermediate clasts less than 2 mm across, 10% felsic and intermediate clasts 2 to 10 mm across, 15% plagioclase crystal grains 0.5 to 2.5 mm across, rare 1 mm rounded, quartz crystal grains and 30% microscopic granular aggregate of plagioclase, quartz, biotite, minor amphibole and sericite, and accessory epidote, apatite and magnetite.

Outcrops of polymictic volcanic conglomerate in the Eastern Block are few and small. Therefore, the thickness and the nature of bedding is poorly known. However, it appears that most sandstone beds are AE beds of the Bouma Cycle and conglomerate beds appear to be normally graded or ungraded. Conglomerate beds are 0.6 to 1.5 m thick and sandstone beds are 15 to 40 cm.

Ruttan Block

Polymictic volcanic conglomerate in the south domain of the Ruttan Block (Fig. 43) comprises 60% conglomerate and 40% interbedded sandstone. Outcrop of this unit occurs at only two localities (Map GR-86-1-1), thus details of petrography and bedding characteristics are rare. It appears from an exposure in the west of the unit that fragments in this conglomerate have the same size, shape, composition, texture, and distribution as conglomerate unit A in the Eastern Block. Where bedding is observed, conglomerate beds are 40 to 80 cm thick and sandstone beds are 15 to 40 cm thick. Conglomerate beds are normally graded and some have a 2 to 6 cm thick sandstone cap that has a gradational contact with the conglomerate in the same bed. Sandstone beds generally have the AE division of the Bouma cycle, but some are massive.

Sandstone and conglomerate matrix comprises 45% felsic and intermediate rock fragments less than 2 mm across, 5 to 10% felsic rock fragments 2 to 10 mm, 10 to 15% plagioclase crystal grains 0.5 to 2 mm across and 30 to 40% microscopic granoblastic mosaic consisting of plagioclase, quartz, biotite, minor amphibole and sericite, and accessory epidote and apatite.

Interpretation

The rounded to subrounded nature of the clasts in the polymictic volcanic conglomerate units and the heterolithic nature of the rocks suggest that they probably underwent considerable transport in rivers and streams. The volcanic character of the units implies either resedimentation of material that was probably previously contained in heterolithic volcanic debris flow deposits or redeposition of volcanic materials through erosional agents without the formation of debris flow deposits.

The conglomerate and sandstone units form upward thinning and fining sequences, or sequences in which there is no variation in the lithology abundance. The sequences lack structures indicative of fluvial transport and deposition, such as crossbedding and scours associated with well developed normal graded beds and interbedded pebble conglomerate, pebble sandstone, sandstone and siltstone. The conglomerates are poorly sorted, and cobbles and pebbles are supported in a finer grained matrix. Conglomerate beds are mostly massive, but in some beds the coarsest fraction is normally graded. These features suggest transport as, and deposition from, mass sediment flows in which larger fragments were supported by a matrix that had the property of strength. Poor sorting, matrix strength, lack of grading and paucity of coarse-tail grading are common to debris flow deposits (Fisher, 1971; Fisher and Schmincke, 1984; Schultz, 1984; Smith, 1986). On the other hand, massive beds may result from very rapid deposition from turbulent flows (Walker, 1975), and coarse-tail grading of only the coarsest sizes occurs in high concentration turbulent flows (Middleton, 1967). However, conglomerates associated with turbidites are generally clast-supported (Walker, 1979), whereas conglomerates deposited from debris flows are commonly matrix-supported (Nardin et al., 1979; Walker, 1979). Thus it appears that the conglomerates in the southern part of the Rusty Lake metavolcanic belt were probably transported and deposited from mass sediment flows of the debris flow type. Sandstone beds are both massive and normally graded, and some graded beds have Bouma AE divisions. In the absence of fluvial structures the massive to graded character of the sandstones suggests transport by, and deposition from, sediment gravity flows (Walker and Mutti, 1973). Massive sandstone beds were probably transported as, and deposited from, fluidized flows or from turbulent flows in which the load was held in suspension above the bed plane; the normally graded sandstones, on the other hand, including those with Bouma AE divisions, were probably deposited from turbidity currents in which there was a bed load and different flow regimes from bottom to top of the flow (Blatt et al., 1972).

Thick sequences of conglomerate and sandstone, deposited from debris flows, fluidized flows and turbidity currents, commonly represent alluvial and submarine fans. Subaerial alluvial fans typically contain fluvial deposits interbedded with mass flow deposits, or are composed largely of downstream fining fluvial deposits, with mass flow deposits restricted mainly to proximal regions (Bull, 1977; Collinson, 1978; Rust, 1979). Submarine fans, on the other hand, are typified by mass flow conglomerate deposits, and thin bedded turbidites in the upper fan region with well bedded and well graded turbidites in the mid-fan and lower fan regions; well bedded and well graded pebbly sandstone and massive sandstone occupy channels in the mid-fan region (Walker, 1975, 1977; Walker and Mutti, 1973). With the exception of the conglomerate and sandstone sequence in unit B of the Karsakuwigamak Block the conglomerate units discussed here appear to have characteristics of subaqueous deposits of the upper fan region.

The overall distribution of conglomerate and sandstone in unit B of the Karsakuwigamak Block does not appear to fit either the alluvial or submarine fan models. However, the thick accumulation of conglomerate with minimal interbedded greywacke in the lower part of the unit could represent deposition in the upper fan region of either model. The unit consists of several thinning and fining upward conglomerate and sandstone sequences that have an overall upward thinning and fining trend. This trend is particularly pronounced in the upper part of the formation. Mutti (1977) and Walker (1977) have suggested that upward thinning and fining sequences result from progressive channel abandonment. Although channels have not been mapped in unit B of the Karsakuwigamak Block, channel dimensions in fans are commonly larger than the largest outcrops in the formation, and, although the abundance of conglomerate and sandstone is similar in both the east and west of the unit, sequences cannot be mapped continuously along the lateral extent of the unit. Thus, it is suggested that the upward thinning and fining, conglomerate and sandstone sequences in unit B probably represent transport and deposition in channels that were progressively abandoned.

This conglomerate and sandstone unit was deposited on a felsic volcaniclastic sequence that includes fluvial and lacustrine sedimentary rocks. Thus it appears unlikely that unit B represents a submarine fan unless there was considerable tectonic sinking prior to deposition of the conglomerate and sandstone. Sinking resulting in the tectonic transport of sedimentary deposits from the fluvial and lacustrine to the submarine environment would subject the sedimentary deposits to erosional processes such as wave action and possibly slope instability unless subsidence was very rapid. This does not appear to be the case as evidenced from distribution of beds and bed attitudes in sedimentary and volcanic rocks underlying unit B conglomerate (Baldwin, 1987). Therefore it appears most likely that unit B conglomerate and sandstone are alluvial deposits and the present erosional plane exposed a sedimentary sequence representing the upper fan region.

POLYMICTIC CONGLOMERATE (VOLCANIC AND PLUTONIC DERIVED) (5b)

General Statement

Coarse grained polymictic conglomerate, containing rounded to subrounded pebbles or pebbles and cobbles of volcanic and plutonic rock, interbedded with sandstone, occurs only in the Northern Block. The conglomerate and sandstone sequences form 2 units that compose the majority of the upper 30% of the Northern Block stratigraphic succession (Fig. 44). In the northwestern part of the map area only the stratigraphically lower of the 2 units is exposed. In the northeastern part of the area both units are exposed south of Muskyak Lake.

Beds of conglomerate compose 60 to 65% of the rock in these units and sandstone 35 to 40%. Conglomerate is unsorted, generally ungraded and matrix-supported. Maximum clast size is 12 to 30 cm across and bed thickness ranges from 3 to 20 m. Clast abundance ranges from 30 to 50%. Matrix in conglomerate is the same as sandstone. Sandstone beds are 0.3 to 7 m thick, ungraded, and contain 50% lithic clasts that have similar lithologies to the pebbles, cobbles and boulders in conglomerate.

In both conglomerate units the clasts are flattened in a foliation plane parallel to bedding and elongated down the dip of the foliation. The length:width ratio on outcrop surface ranges from 3:1 to 5:1. All clast sizes given below are the length of the clasts in the outcrop surface.

Petrography, Bed Thickness and Bed Texture

Conglomerate unit A (Fig. 44) comprises 65% conglomerate beds and 35% sandstone beds. Conglomerate beds consist of 30 to 50% rounded and subrounded, poorly sorted, matrix-supported pebbles, cobbles and boulders of differing lithology. Clasts range in size from 0.2 to 30 cm but in the majority of the conglomerate beds cobble size clasts make up 40 to 60% of the clast population; pebble beds are common but boulder beds are absent. Volcanic and plutonic derived clasts make up 60% and 25% of the clast population respectively; the remainder is composed of subequal amounts of vein quartz, chert, cherty iron formation and sedimentary rock.

The conglomerate and sandstone sequence in polymictic conglomerate unit A (Fig. 44) is 1650 m thick in the east and 750 m thick in the northwest part of the area (Map GR 86-1-1). Conglomerate beds are poorly sorted and are generally ungraded and matrix-supported. However, in some beds there is a basal layer that is clast supported; a few of the thinner beds are normally graded. The basal layer is less than 25% of bed thickness. Conglomerate beds are 2 to 15 m thick. In the east conglomerate beds are 15 m thick at the base of the unit and decrease in

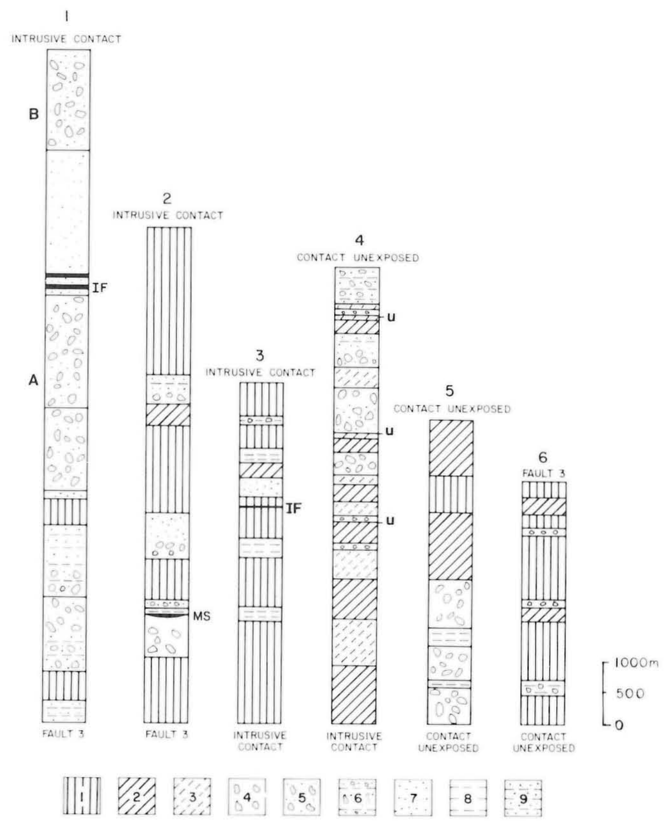

Figure 44: Stratigraphic distribution of polymictic volcanic and plutonic derived conglomerate in the southern part of the Rusty Lake metavolcanic belt. Stratigraphic sections and symbology are the same as in Figure 4.

thickness upward to 3 or 4 m at the top. In the west conglomerate beds are 3 to 5 m thick. Maximum clast size decreases upward and is larger in the west than in the east. Bedding planes are sharp and planar.

The volcanic derived clasts are 0.2 to 15 cm across. Intermediate and mafic clasts are rounded as are most felsic clasts; however, some of the felsic ones have one or two fairly angular corners despite the flattening in the foliation plane. Plutonic clasts are all rounded and 0.2 to 30 cm across. Clasts derived from vein quartz, chert and cherty iron formation are subround and less than 4 cm across. Rarely they are up to 7 cm across. Sedimentary rock clasts are less than 2 cm across and all appear to be siltstone.

Volcanic derived clasts with intermediate composition are dark grey to greyish green and aphyric. Microscopically they comprise a granular aggregate composed of 50 to 60% plagioclase, 30 to 40% light green hornblende, 10% quartz and accessory epidote, carbonate, magnetite and apatite. In some of these clasts there is 2 to 5% acicular green amphibole up to 0.25 mm in length.

Mafic volcanic clasts are dark green, aphyric, plagioclase-phyric or plagioclase- and hornblende-phyric. Plagioclase phenocrysts are present in amounts of 5 to 10% and hornblende phenocrysts from 3 to 20%. The groundmass of phyric clasts comprises a microscopic granular aggregate composed of 75 to 80% amphibole (hornblende), and 20 to 25% plagioclase, with accessory epidote, carbonate, chlorite and magnetite. The groundmass in a few of the phyric clasts is composed of 60 to 70% epidote, 10 to 15% plagioclase, and accessory minerals. Aphyric clasts have the same mineral composition and texture as the groundmass of phyric clasts.

Felsic volcanic clasts are white to light grey, aphyric, plagioclase-phyric or plagioclase- and quartz-phyric. White, phyric clasts comprise 2 to 4%, equant, quartz phenocrysts to 1 mm across, and 3 to 6%, tabular, plagioclase phenocrysts to 2.5 mm across or, 3 to 10%, tabular, plagioclase phenocrysts to 2.5 mm across, in a microscopic granular aggregate groundmass composed of 50 to 55% plagioclase, 30 to 35% quartz, 20% sericite with accessory biotite, apatite, magnetite, zircon and rare chlorite or carbonate. White aphyric clasts have the same mineral composition and texture as the groundmass in white phyric clasts. Light grey felsic clasts are largely aphyric and consist of a microscopic granular aggregate comprising 60 to 65% plagioclase, 25 to 30% quartz, 10 to 15% biotite with accessory sericite, apatite, magnetite, zircon and rare chlorite or carbonate. Light grey phyric clasts differ from white phyric clasts only in that they contain 3 to 10%, tabular, plagioclase phenocrysts to 3 mm in length.

Plutonic clasts are pale pink to cream, medium grained tonalite gneiss. These particles are mineralogically and texturally similar to the Opachuanau gneiss (Zwanzig, pers.comm., 1980) that outcrops on the northwest shore of Churchill River west of Rusty Lake (Hinds, 1982).

The conglomerate matrix is arkosic. It contains 35 to 45% combined volcanic and plutonic clasts to 2 mm across, 15 to 20% combined quartz and plagioclase crystal grains to 2 mm across, and the remainder is a microscopic granular aggregate composed of plagioclase, quartz, sericite and biotite, and hornblende, with accessory carbonate, apatite, magnetite, zircon, and rare chlorite and sphene. Sandstone is mineralogically similar to the conglomerate matrix but it can contain 10 to 15% combined volcanic and plutonic clasts to 1.5 cm across.

Sandstone beds are generally ungraded, but some are normally graded. Some normally graded beds contain a clast-supported basal layer less than 15 cm thick composed of clasts up to 1.5 cm across. In the west sandstone beds have a maximum thickness of 3 m and in the east they are up to 7 m. Minimum thickness in both the west and east is 30 cm; however, beds less than 1 m thick are rare.

Polymictic volcanic and plutonic derived conglomerate unit B (Fig. 44) outcrops on the southwest and north shores of Muskayk Lake. The unit is folded around the east end of a granite pluton that underlies the area to the west and north of Muskayk Lake. The conglomerate comprises 60% polymictic volcanic and plutonic derived conglomerate and 40% arkosic sandstone. Conglomerate is poorly sorted and comprises 30 to 50% rounded and subrounded, matrix-supported, pebbles, cobbles and boulders of differing lithology. Clasts range in size from 0.2 to 30 cm across but all beds are cobble conglomerate beds. The clast population, based on visual estimates of outcrop surfaces, is 25% felsic volcanic, 25% intermediate volcanic, 10% plutonic, 10% mafic volcanic, 15% vein quartz, and 15% combined greywacke and siltstone. The mineralogy, texture and size of the volcanic and plutonic clasts is the same as in unit A polymictic volcanic and plutonic derived conglomerate. The matrix of unit B conglomerate and the sandstone beds are similar to matrix of the conglomerate and the sandstone beds in unit A except that they contain 5 to 10% tabular hornblende up to 3 mm long, and only half the biotite content in unit A conglomerate matrix and sandstone.

Unit B conglomerate beds are ungraded, matrix-supported, and range in thickness from 1 to 20 m. Sandstone beds are also ungraded and range in thickness from 0.25 to 7 m. Bedding planes between sandstone and conglomerate are sharp and planar. Vertical and lateral variations in conglomerate and sandstone abundance, maximum clast size, and bed thickness have not been observed. The contact relationship between unit A and unit B with the intervening greywacke unit are unknown.

Interpretation

The typical thick beds, the matrix-supported and ungraded nature of both the conglomerate and sandstone beds, and the sharp and planar bedding planes in the polymictic volcanic and plutonic derived conglomerate units imply rapid emplacement and deposition from high concentration mass sediment flow. The absence of organization of both clast sizes and primary sedimentary structures in the beds suggests that the sediment flows were of the debris flow type. However, graded bedding and clast supported basal layers of some beds suggest that these beds were emplaced by turbulent flow. The roundness of the clasts suggests considerable reworking during or prior to transport or the clasts were exposed to weathering processes prior to transport. However, evidence of weathering has not been observed on any of the clasts in the conglomerates. The mixing of gneissic plutonic and volcanic clasts implies two separate source areas for the clasts. The source of the plutonic clasts appears to be to the west of the Rusty Lake volcanic belt, and the volcanic clasts from the volcanic belt itself. Therefore, it seems most likely that eroded material from two source areas collected in a valley or basin between these source areas. Subsequently this material was mobilized and redeposited as conglomerate and sandstone sequences.

SANDSTONE (6)

General Statement

Sandstone with minor interbedded polymictic pebble conglomerate and siltstone forms units 0.15 to 2.0 km thick and also occurs as beds in polymictic conglomerate units. Sandstone units occur in the Northern Block, in both the north and south domains in the Ruttan Block, and in the northwest segment of the Karsakuwigamak Block (Fig. 45). In the Northern Block there is one sandstone unit; it is a lithic greywacke and in the west contains two layers of sulphide facies iron formation. In the Ruttan Block sandstone units are either lithic greywacke or arkose. The stratigraphically lowest sandstone unit in the north domain in the Ruttan Block contains several thin beds of chemical sediments as well as conglomerate and siltstone. All sandstone beds except those in the sandstone unit in the south domain in the Ruttan Block have features common to turbidites. The conglomerate beds are typically normally graded and siltstones are thinly laminated. Sandstone in the south domain in the Ruttan Block is massive bedded.

Sandstone beds range from 15 to 90 cm thick and, except for the unit in the south domain in the Ruttan Block, are organized into ABE or AE turbidite beds. Conglomerate beds are 15 to 25 cm thick, and locally sandstone beds contain a 2 to 3 cm thick basal conglomerate layer.

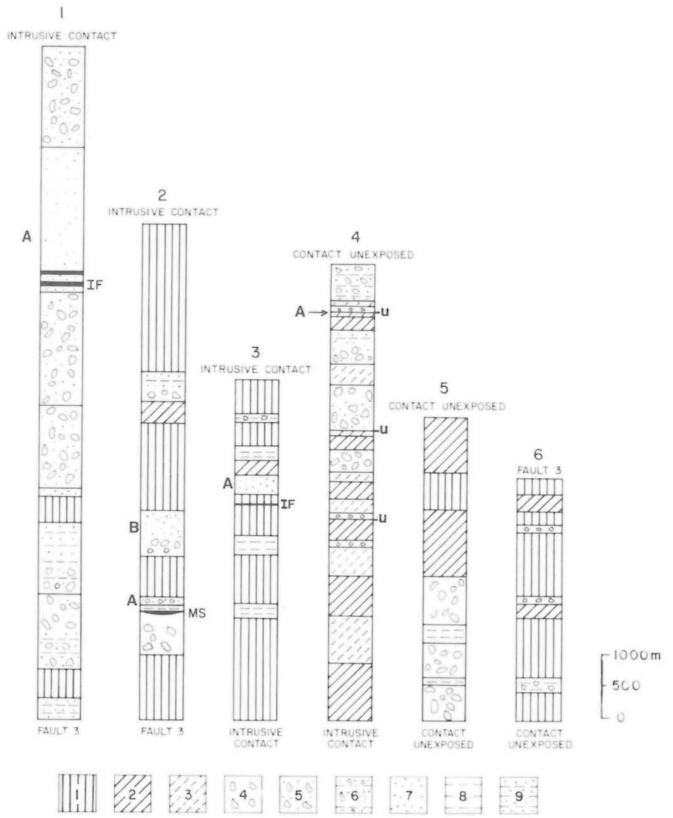

Figure 45: *Stratigraphic distribution of sandstone units in the southern part of the Rusty Lake metavolcanic belt. Stratigraphic sections and symbology are the same as in Figure 4.*

Siltstone that does not form the E division of turbidite beds forms 10 to 15 cm thick finely laminated beds that are interbedded and have sharp contacts with sandstone beds.

Petrography

The sandstone unit in the Northern Block is lithic greywacke and contains 2 sulphide facies iron formation layers. In the west, within the map area boundaries, the unit is 0.75 km thick, and in the east, where exposures are few, it has an estimated thickness of 2 km. The sulphide iron formation layers are only exposed in the west and each one is about 10 m thick. In the east the presence and stratigraphic position of these iron formations is interpreted from geophysical data (Baldwin, 1982).

Lithic greywacke comprises 65%, 0.5 to 2 mm, grains of quartz, volcanic rock fragments, feldspar, muscovite and biotite, in decreasing order of abundance, and 35%, microscopic quartzofeldspathic granular aggregate that contains minor amounts of muscovite, biotite, apatite, amphibole and rare sulphide. The rock weathers grey to brownish-grey and is dark grey on a fresh surface. Bedding is well developed and the rock possess a foliation that is defined by the alignment of micas parallel to bedding. The beds are 15 to 30 cm thick and most commonly are AE beds. Less commonly beds have ABE divisions of the Bouma cycle and least commonly beds are ungraded. Bedding planes are sharp and generally planar and locally load casts, scours, rip-ups and flames are present. Approximately 10% of the sandstone beds contain a 1 to 5 cm thick basal layer composed of grit or pebble conglomerate.

In the north domain of the Ruttan Block there are 2 sandstone units. The stratigraphically lowest of these units (Fig. 45) forms the stratigraphic top of the Ruttan Cu-Zn massive sulphide deposit. In the vicinity of the Ruttan Mine the base of the unit comprises several metres of iron-rich cherty beds interlayered with chlorite-staurolite-garnet-cordierite rock. These rocks are overlain by lithic greywacke with minor interbedded polymictic volcanic conglomerate. Eastward the unit comprises only sandstone and conglomerate and the amount of conglomerate decreases.

Lithic greywacke is greyish brown to greenish grey on weathered surface and dark to light grey on fresh surface. Generally, the sandstone comprises 20 to 25% quartz grains, 25 to 30% volcanic rock fragments, 15% plagioclase grains and 5% biotite grains from 0.5 to 3 mm across, and 30% microscopic quartzofeldspathic granular aggregate. The granular aggregate consists of 65 to 70% combined quartz and plagioclase, 15 to 20% biotite, and the remainder is muscovite, amphibole, apatite, epidote ± carbonate and rare magnetite. Some beds contain up to 50% volcanic fragments and some of these fragments can be 0.5 cm across.

Lithic greywacke is well bedded. The majority of the beds are 15 to 20 cm thick, but some are up to 75 cm thick. Beds display either AE divisions (Fig. 46) or ABE divisions (Fig. 47) of the Bouma Cycle. Common primary sedimentary structures include normal graded bedding, horizontal and convolute laminations (Fig. 48), rip-ups (Fig. 49), interclasts, flames, load structures and scours.

Polymictic volcanic conglomerate beds are 0.5 to 1 m thick and typically coarse tail graded both vertically and laterally. Clasts in conglomerate are volcanic, mafic to felsic in composition, and have either aphyric or phyric textures. They range in size from 0.2 to 30 cm and are rounded to subangular. Clasts make up 40 to 50% of the rock, are poorly sorted, and matrix-supported (Fig. 33). The matrix comprises a microscopic granular aggregate of amphibole and plagioclase with 5 to 10% combined tabular plagioclase and stubby amphibole crystals 0.5 to 3 mm long. Accessory minerals are epidote, minor sulphide and carbonate.

Sandstone unit B (Fig. 45) comprises largely arkosic sandstone, with lesser polymictic volcanic conglomerate that has an arkosic matrix, and a few siliceous siltstone beds. Arkosic sandstone comprises 50%, 0.5 to 3 mm grains of quartz and plagioclase, 10%, 0.5 to 4 mm lithic

Figure 46: *AE bed in turbidite sandstone unit A, north domain of the Ruttan Block.*

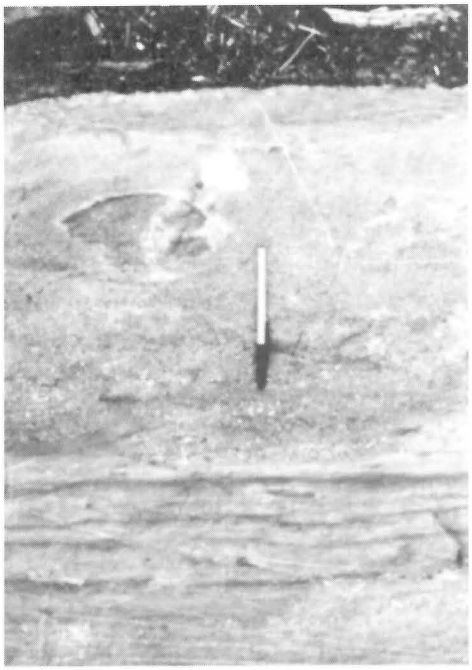

Figure 47: *ABE bed in turbidite sandstone unit A, north domain of the Ruttan Block.*

Figure 48: *Parallel and convolute laminations in turbidite sandstone unit A, north domain of the Ruttan Block.*

fragments, and 40% microscopic granular quartzofeldspathic aggregate. The lithic fragment population is predominantly felsic volcanic but it also includes some intermediate volcanic fragments, rare mafic volcanic fragments and siltstone fragments. The microscopic granular quartzofeldspathic aggregate contains 85 to 90% combined quartz and plagioclase, 10% muscovite, 2 to 5% biotite, minor magnetite, and accessory apatite. Bed thickness and primary sedimentary structures are the same as in unit A sandstone in the north domain in the Ruttan Block.

Conglomerate in unit B sandstone comprises 30 to 35% rounded felsic, intermediate, and rare mafic volcanic pebbles supported in a matrix that is the same as that of unit B sandstone. Beds range in thickness from 15 to 40 cm and clasts range in size from 0.2 to 7 cm. The abundance and thickness of conglomerate beds and the maximum clast size decrease upwards.

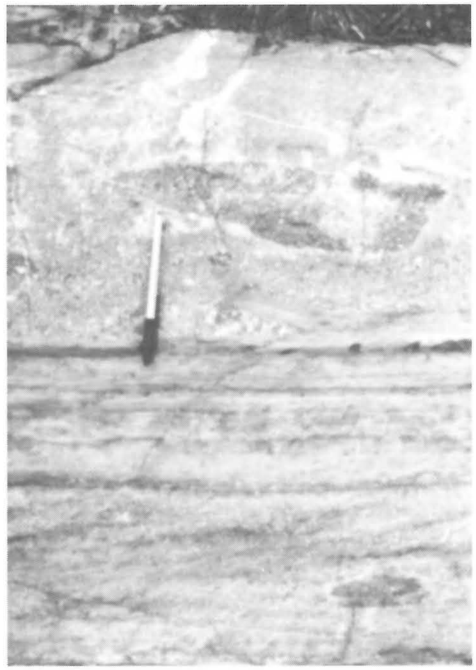

Figure 49: *Rip-up in turbidite sandstone unit A, north domain of the Ruttan Block.*

The sandstone unit in the south domain of the Ruttan Block is very poorly exposed; outcrops are small and widely spaced. From the outcrops that were examined this sandstone unit appears to be similar in composition, bed thickness and bed organization to the sandstone unit in the Northern Block .

The sandstone unit in the northwest segment of the Karsakuwigamak Block (Fig. 45) is 0 to 80 m thick, and consists of 85 to 90% massive lithic greywacke and minor interbedded siltstone, pebble conglomerate and pebbly lithic greywacke, most of which are confined to the upper 3 to 7 m of the unit. Pebble conglomerate also forms discrete dish-shaped lenses in lithic greywacke in the lower 15 m of the unit. Because of rapid lateral changes in the thickness and a maximum thickness of only 80 m, the unit is not shown on Map GR 86-1-1.

The lithic greywacke has a uniform composition and consists of 35 to 40%, largely subrounded, equant to elliptical, sand-sized and rare 3 to 4 mm felsic volcanic rock fragments; 5% plagioclase and 5% quartz crystal grains, both of which are angular to subrounded, euhedral and broken; and 50 to 55%, 0.04 to 0.08 mm equigranular, metamorphically recrystallized aggregate composed of 65% combined plagioclase and quartz, 25% biotite and 10% muscovite. Boundaries between the sand grains and recrystallized aggregate are sharp.

Lithic greywacke in the lower 73 to 77 m of the unit appears to be unbedded and generally structureless. However, in the upper 30 m, local 0.5 mm thick, biotite-rich layers, spaced 10 to 50 cm apart and parallel to bedding in the upper 3 to 7 m of the unit, indicate that the lithic greywacke is bedded. Although fragment abundance and type remain constant, there is an upward decrease in grain size. In the lower half of the unit sand-size rock fragments are mostly 1 to 2.5 mm across, whereas in the upper half, sand grains greater than 1 mm across are rare. In the lower half of the unit the coarse size of the sand grains may mask bedding. In the lower 15 m in the eastern part of the unit, pebble conglomerate, composed of 60 to 70% equant pebbles of felsic volcanic rock, 3 to 4 mm across, and 30 to 40% recrystallized aggregate similar to that in lithic greywacke, forms isolated, flat-topped, dish-shaped lenses 0.8 m thick and 3 m long, in lithic greywacke. These conglomerate bodies are interpreted to fill channels in the lithic greywacke. Similar structures and grain size variation have not been observed in the west, where only the lithic greywacke of the lower part of the unit is exposed.

The upper 3 to 7 m thick, heterogeneous zone is in sharp contact with the underlying lithic greywacke, and is composed of 30% pebble conglomerate, 30% pebbly lithic greywacke, 20% lithic greywacke and 20% siltstone; maximum pebble size is 1 cm. The pebble conglomerate and pebbly lithic greywacke contain 25 to 30% and 5 to 15% pebbles, respectively, in a matrix that is similar to that of the underlying lithic greywacke. Lithic greywacke is the same as the lithic greywacke in the upper half of the 73 to 77 m thick basal part of the unit. Siltstone is compositionally and texturally similar to the fine grained plagioclase-quartz-biotite-muscovite aggregate in the lithic greywacke. The pebble conglomerate, pebbly lithic greywacke and lithic greywacke form 7 to 13 cm thick normally graded beds. Siltstone is massive to thinly laminated and occurs in beds that are generally 5 to 40 cm thick, but are locally 1 m thick. Local scours in the siltstone are filled with pebbly lithic greywacke, or lithic greywacke, and scours in pebbly lithic greywacke are filled with siltstone.

Interpretation

The interbedded nature of sandstone and conglomerate, the organization of sandstone into AE or ABE beds, and the abundance of primary sedimentary structures associated with sediment deposition from turbidity currents suggest that the sandstone units in the Northern and Ruttan blocks are turbidites.

Several aspects of the sandstone unit in the northwest segment of the Karsakuwigamak Block imply fluvial deposition. These include 1) the dish-shaped structures in the lower 15 m of the unit that appear to be the result of scour and fill; 2) the interbedded nature of the pebble conglomerate, pebbly lithic greywacke, lithic greywacke and siltstone in the upper 3 to 7 m of the unit; and 3) the presence of normally graded beds and local scouring in the upper heterogeneous zone. However, the apparent lack of stratification and fluvial structures in most of the lithic greywacke, together with the upward decrease of grain size and thin partings shown by biotite concentrations, may indicate a different mode of deposition for the lithic greywacke, possibly by sediment-laden floods (Collinson, 1978; Wells, 1984).

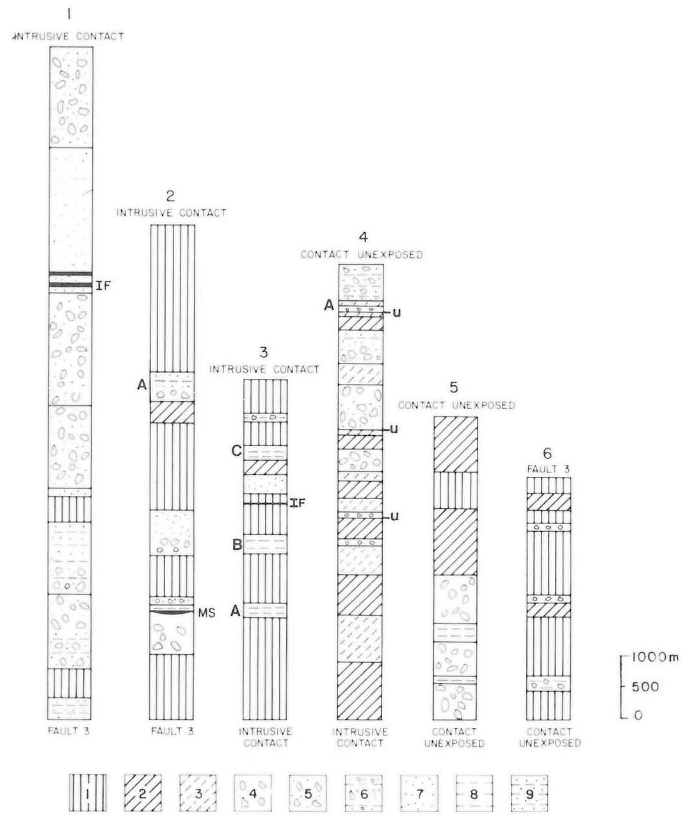

Figure 50: Stratigraphic distribution of siltstone units in the southern part of the Rusty Lake metavolcanic belt. Stratigraphic sections and symbology are the same as in Figure 4.

SILTSTONE (7)

General Statement

Units composed entirely of siltstone, or mainly of siltstone and lesser sandstone, occur in the Ruttan Block and in the northwest segment of the Karsakuwigamak Block. In the Ruttan Block one of these units occurs in the north domain (Fig. 50) and three in the south domain (Fig. 50). Composition of siltstone units is mafic to felsic; however, in any one unit one composition is most abundant. Siltstone units are interbedded with mafic flow units or associated with felsic volcanic units and heterolithic volcanic breccia (Map GR 86-1-1, in pocket). Units composed entirely of siltstone are the one in the north domain of the Ruttan Block, the stratigraphically youngest (unit C) in the south domain of the Ruttan Block, and the one in the Karsakuwigamak Block. They are 60, 80 and 2 m thick respectively; however, on the accompanying geological map their thickness has been exaggerated. Units composed of siltstone and sandstone have maximum thicknesses of 200 and 400 m. Laterally the siltstone units can be traced discontinuously for up to 7 km.

Petrography

The siltstone unit in the north domain of the Ruttan Block has intermediate composition. It comprises a fine grained granular aggregate of 60% combined quartz and plagioclase, 25 to 30% biotite, and 10 to 15% amphibole, with accessory apatite, epidote and carbonate. These rocks are bedded and laminated. Beds are 2 to 6 cm thick and laminations are 0.5 to 1 cm thick. Locally beds contain a few millimetres of sand size material at their base.

The stratigraphically youngest siltstone unit in the south domain of the Ruttan Block, unit C (Fig. 50), has a felsic composition. It comprises 75% combined quartz and plagioclase, 20% sericite, and 5% biotite, with accessory apatite and rare magnetite octahedra to 0.25 mm across. Bed and lamination thicknesses are the same as in the siltstone unit in the north domain.

Siltstone units A and B in the south domain of the Ruttan Block (Fig. 50) are similar to one another and have a mafic composition. These rocks consist of interbedded siltstone and sandstone. Sandstone makes up about 10 to 15% of the rock in these units. Siltstone is composed of 60% amphibole, 35% combined plagioclase and quartz, and 5% biotite, with accessory epidote and carbonate. Sandstone is composed of 30% amphibole, 25% plagioclase, and 15% mafic, lithic fragments 0.5 to 3 mm across, and 30% fine grained granular aggregate that is similar to siltstone. Siltstone is laminated; the laminations are 0.1 to 1 cm thick. Sandstone beds are 5 to 12 cm thick and are generally normally graded. Stratification in these siltstone units is sharp and planar.

The siltstone unit in the Karsakuwigamak Block is very thin bedded and internally laminated. The rock is black and consists of a 0.01 to 0.03 mm, metamorphic biotite-plagioclase-quartz aggregate composed of 50% biotite, 25% plagioclase, and 25% quartz.

Interpretation

The two stratigraphically lower siltstone units in the south domain of the Ruttan Block have mafic composition and occur in a volcanic succession dominated by basalt flows. The basalt flow units that directly underlie each siltstone unit are petrographically and morphologically the same. These two siltstone units are also petrographically and morphologically similar to one another. The stratigraphic position of the siltstone units and their mafic composition suggests a genetic relationship with the basalt flow units. These siltstone units with minor interbedded sandstone are considered to be fine ash and ash deposits, derived either from fragmentation at the surfaces of subaqueous basalt flows or from submarine basaltic pyroclastic eruptions related to the extrusion of the basalt flows.

The felsic siltstone unit near the top of the south domain of the Ruttan Block directly overlies a felsic flow unit with associated pyroclastic deposits. The siltstone unit probably represents the subaqueous redeposition of fine ash deposits associated with the underlying felsic pyroclastic rocks.

The siltstone unit in the north domain of the Ruttan Block straddles underlying heterolithic volcanic breccia. This siltstone unit is probably redeposited fine ash genetically related to the material contained in the underlying redeposited volcanic breccia unit.

Because of the thinness of the siltstone unit in the Karsakuwigamak Block and the proximity to fluvially deposited sandstone, pebbly sandstone and pebble conglomerate, the siltstone probably represents a lacustrine deposit (Baldwin, 1987).

CONGLOMERATE, SANDSTONE, SILTSTONE (8)

General Statement

Volcanic derived conglomerate, sandstone and siltstone sequences that have lithologic proportions and bed thicknesses similar to those in the volcanic conglomerate units (unit 5a) occur both in the Northern Block and in the southeast segment of the Karsakuwigamak Block (Fig. 51). However, these rocks have not been included in unit 5a because they form units 1000 to 1300 m thick, primary bedding structures are very well developed, conglomerate bed sets are rare, sandstone bed sets are common, and lateral variations in bed thickness and lithology abundance are common. In addition, the conglomerate, sandstone, siltstone sequences in the Northern Block form a major part of a thick epiclastic sequence, whereas unit 5a sedimentary sequences are typically interlayered with volcanic flows and sequences dominated by pyroclastic rock. Sandstone in unit 8 sedimentary sequences are typified by partial Bouma cycles, grit layers at the base of some beds, and the presence of flames, rip-ups, scours, load structures and, locally, soft sediment deformation; sandstone in unit 5a is characterized by massive bedding, normal grading, and rare turbidite features.

Northern Block

There are three volcanic derived conglomerate, sandstone, siltstone units in the Northern Block (Fig. 51). In stratigraphic succession they are mafic in composition (unit A), arkosic (unit B) and intermediate (unit C). All units are poorly sorted.

The stratigraphically oldest unit (unit A) comprises 60% conglomerate, 30% sandstone and 10% siltstone. Clasts in the conglomerate beds are almost entirely mafic in composition. In some beds there are 5 to 10% felsic volcanic clasts. Associated sandstone and siltstone are also mafic in composition.

Clasts are matrix-supported, compose 30 to 50% of the rock, and are predominantly rounded, but subrounded clasts make up 10 to 15% of the clast population. Mafic clasts are 2 to 100 mm in diameter and felsic clasts are generally 2 to 60 mm; locally, 150 to 200 mm diameter felsic

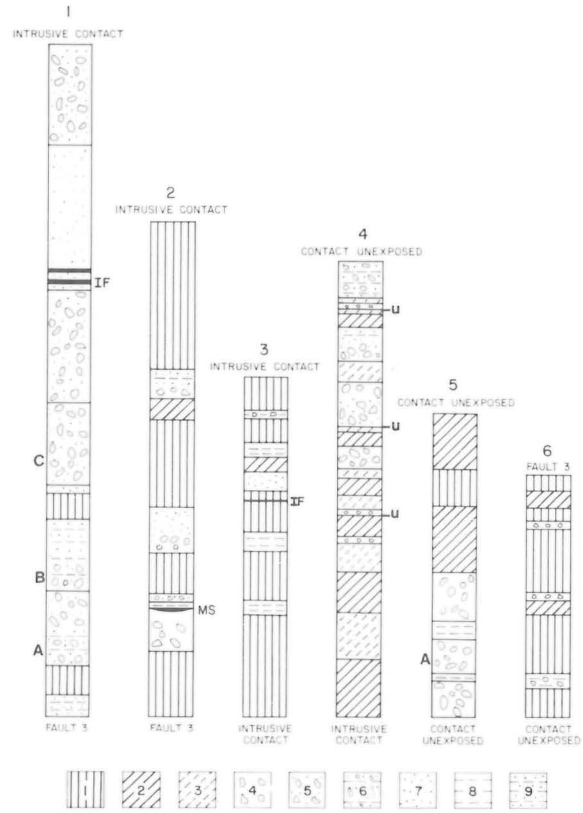

Figure 51: *Stratigraphic distribution of volcanic derived conglomerate, sandstone, siltstone sequences in the southern part of the Rusty Lake metavolcanic belt. Stratigraphic sections and symbology are the same as in Figure 4.*

clasts are present. The mafic clast population comprises 20 to 30%, greenish black, aphyric basalt, 20 to 30%, dark green, plagioclase- and hornblende-phyric basalt, 20%, dark green, hornblende-phyric basalt, and 10 to 15%, light green, aphyric to sparsely plagioclase-phyric basalt or andesite. In phyric clasts plagioclase phenocrysts are up to 4 mm, and hornblende phenocrysts are 2 to 5 mm; the phenocryst content is less than 20%. All mafic clasts types can be vesicular; however, the greenish black aphyric clasts and phyric clasts with less than 10% phenocrysts are generally more vesicular than the other clast types. Amygdules are up to 3 mm across, compose up to 25% of the vesicular clasts, and comprise quartz and plagioclase, or quartz, plagioclase and carbonate. Felsic clasts are typically light grey and aphyric, or contain either 2 to 5%, 1 to 3 mm plagioclase phenocrysts, or 1 to 2%, 1 mm quartz phenocrysts and 2 to 3%, 1 to 3 mm plagioclase phenocrysts. They are rarely vesicular and, where present, quartz amygdules are less than 2 mm across and compose less than 5% of the clasts in which they occur.

Conglomerate beds in the mafic volcanic conglomerate unit range in thickness from 0.4 to 5 m, but most commonly they are 1 to 3 m thick. All beds are poorly sorted and 50 to 60% of them are ungraded. Normally and reversely to normally graded beds are present in subequal amounts. Only in the lower 200 m of the unit are 2 to 3 conglomerate beds superposed to form conglomerate bed sets. Upwards in the unit each conglomerate bed is separated by one or several sandstone beds; also, the conglomerate beds become thinner and the maximum fragment size decreases to 3 cm. Eastward, conglomerate beds become thinner. Ungraded, normally graded, and reversely to normally graded beds are uniformly distributed throughout the vertical and lateral extent of the unit.

Sandstone beds comprise: 10 to 15%, mafic volcanic clasts, 2 to

30 mm across; 50 to 60%, mafic volcanic clasts, plagioclase crystals and hornblende crystals to 2 mm across; and the remainder is a microscopic granular aggregate of mainly amphibole, with less plagioclase and, locally, minor quartz and biotite. Epidote, carbonate and magnetite are accessory minerals. Commonly the larger clasts form a 0.5 to 4 cm thick grit layer at the base of sandstone beds. Sandstone beds most commonly are organized into ABE or AE divisions of the Bouma cycle. These beds compose 75 to 80% of the sandstone beds; the remainder are ungraded and commonly occur in the lower 100 to 150 m of the unit. Sandstone beds range from 12 to 45 cm thick but average 20 to 30 cm. Eastward the beds become thinner and attain a maximum thickness of 15 to 20 cm.

Siltstone is dark green and comprises a microscopic granular aggregate of 70 to 80% amphibole and 30 to 20% plagioclase, with trace quartz, an opaque mineral (magnetite), and rare clasts 1 to 3 mm across. Epidote and carbonate are accessory minerals. Siltstone most commonly occurs as the E division in Bouma beds. Beds composed entirely of siltstone are 5 to 15 cm thick, but most are between 5 and 10 cm. These beds generally occur between massive sandstone beds and, in places, between conglomerate beds, or conglomerate and sandstone beds. Siltstone beds increase in abundance eastward but thicknesses remain constant.

Conglomerate, sandstone and siltstone with arkosic composition (unit B) overlie the mafic volcanic conglomerate unit. Clasts in arkosic conglomerate and sandstone are 80 to 85% felsic volcanic rock and 15 to 20% mafic and intermediate volcanic material. Conglomerate beds in unit B have the same thicknesses as those in unit A. However, in unit B reversely to normally and normally graded beds are more abundant than ungraded beds and conglomerate makes up 50% of the unit. Conglomerate beds thin eastward but upward and eastward their abundance does not change. Matrix in conglomerate beds is arkosic volcanic sandstone. Clasts are matrix-supported, compose 20 to 50% of the rock, and are mainly well rounded. Felsic volcanic clasts in conglomerate are a maximum of 10 cm across but the majority are 4 to 6 cm. Mafic and intermediate clasts have a maximum diameter of 4 cm, but most commonly they are less than 1.5 cm. The felsic volcanic clast population comprises: 40%, white, plagioclase-phyric clasts; 20 to 30%, white, plagioclase- and quartz-phyric clasts; 10 to 20%, light grey, plagioclase-phyric clasts; and 15 to 20%, white and light grey, aphyric clasts. Phenocrysts in phyric clasts compose 3 to 7% of a clast. Plagioclase phenocrysts are tabular and 1 to 2 mm long; quartz phenocrysts are equant, 1 mm across, and rarely attain 2 mm diameter. Quartz phenocrysts never exceed 2% of the volume of a clast. Vesicular clasts are rare and make up less than 5% of the fragment population. Most commonly, vesicular clasts are plagioclase- and quartz-phyric. In vesicular clasts, amygdules make up 10 to 20% of the clast, and contain quartz and a minor amount of plagioclase. Mafic clasts in conglomerate are similar to those in the underlying mafic conglomerate unit (unit A).

Arkosic sandstone beds compose 40 to 45% of unit B. They are similar to conglomerate, but 50 to 60% of the rock consists of felsic and mafic clasts, less than 2 mm in diameter, and 0.5 to 3 mm plagioclase and quartz crystal grains. Clasts larger than 2 mm and up to 5 mm across are rare and make up a maximum of 5% of the rock. The remainder of the rock is a microscopic granular aggregate of plagioclase and quartz, with 5 to 10% biotite and sericite, minor magnetite, and accessory epidote, carbonate and apatite. Sandstone beds are 15 to 50 cm thick, but commonly 20 to 25 cm thick. Beds are generally massive, but normally and reversely to normally graded beds collectively account for 20% of the sandstone beds. Light grey to white siltstone commonly forms a 3 to 5 cm thick layer at the top of sandstone beds. Sandstone beds do not appear to vary in thickness laterally.

White to light grey siltstone beds 3 to 10 cm thick, comprising a microscopic granular aggregate of plagioclase, quartz, sericite and biotite, make up 5 to 10% of the rock in unit B. They occur as discrete beds between ungraded sandstone beds and, in places, between conglomerate beds. Eastward, siltstone increases slightly in abundance and locally in thickness.

Conglomerate unit C is poorly exposed and the proportion of, and the relationship between, conglomerate, sandstone and siltstone are poorly known. Conglomerate makes up 65 to 70% of the outcrop in the unit, sandstone 30%, and siltstone beds 0 to 5%. Conglomerate, sandstone and siltstone in unit C have greywacke composition. Subequal amounts of mafic and felsic clasts are present in both conglomerate and sandstone.

Conglomerate comprises 40 to 50%, rounded clasts, 0.2 to 10 cm across, supported in a sandstone matrix; most commonly the clasts 3 to 5 cm. Felsic clasts are largely non-vesicular and plagioclase- and quartz-phyric; mafic clasts are most commonly non-vesicular and hornblende-phyric. However, mafic and felsic clasts that are aphyric and mafic clasts that contain plagioclase phenocrysts are present. Because of the small size of outcrops of conglomerate, bed thickness and texture are unknown.

Sandstone is the same as conglomerate except for grain size. The rock has the same features as sandstone in unit B except for composition. The microscopic granular aggregate in unit C sandstone is largely plagioclase and biotite, with subordinate quartz and sericite. Amphibole is present in minor amounts and epidote, carbonate and an opaque mineral (magnetite?) are accessory minerals. Sandstone beds are 15 to 65 cm thick but the majority are 20 to 30 cm. Ungraded, normally graded, and reversely to normally graded beds are present in subequal amounts. Normally graded beds commonly have a 14.2 cm grit layer at the base and a 2 to 3 cm siltstone layer at the top.

Dark grey siltstone comprises a microscopic granular aggregate of mainly biotite and plagioclase, with subordinate quartz and sericite, and accessory carbonate and an opaque mineral (magnetite?). Beds are 2 to 10 cm thick and commonly contain a 0.5 to 1 cm thick sandstone layer at the base of the bed. Load structures are common in these beds.

In unit C, conglomerate thins and decreases in abundance eastward. Sandstone thins eastward but abundance appears to remain constant. Siltstone beds are absent in the west; in the east, superposed siltstone beds form sequences 2 to 5 m thick.

Karsakuwigamak Block

A conglomerate, sandstone, siltstone sequence, derived from felsic volcanic rocks, composes the lower 2000 m of the southeast segment of the Karsakuwigamak Block (Fig. 51: unit A, Column 5). Outcrops of these rocks are few and those that were located measure less than 3 m perpendicular to bedding. Thus, the proportions of the different lithologies, nature of bedding, and internal variations in the unit are poorly known. However, from the examined outcrops, it appears that bed thickness, grading and clast abundance are similar to that in unit B conglomerate, sandstone, siltstone in the Northern Block; in addition, the texture of the clasts is similar to the felsic clasts in the same unit.

Interpretation

The bed thickness and the massive, normal graded, and reverse to normal graded character of the conglomerates, in addition to a matrix-supported texture, suggests that the conglomerates were transported as, and deposited from, debris flows. Partial Bouma cycles and primary sedimentary structures imply that the sandstones were emplaced as turbidites. It is therefore suggested that the sedimentary sequences included in unit 8 represent subaqueous fan deposits. In the Northern Block the eastward lateral variations, such as thinning of conglomerate beds, decrease in the abundance of conglomerate, and increase in thickness and abundance of siltstone, suggest that fan development resulted from prograding.

IRON FORMATION (9)

Iron formation occurs in the Northern Block, where it is interlayered with greywacke, and in the south domain of the Ruttan Block, where it is associated with a thin greywacke unit that is interlayered with basalt flows.

In the Northern Block, iron formation is sulphide facies. The rock has a rusty weathered surface and is composed of massive fine grained quartz that contains 15 to 25% disseminated pyrite and pyrrhotite, 5% plagioclase, and 1 to 3% biotite. Banded chert has been observed in two outcrops. Tension gashes occur at a high angle to bedding (78° to 80°) and are filled with coarse grained milky white quartz. Tension gash filling is devoid of sulphide. However, coarse grained patches of pyrrhotite occur adjacent to the tension gashes.

Iron formation in the Ruttan Block is oxide facies, locally contains sulphide and is associated with altered rocks. The iron formation most commonly consists of interlayered solid magnetite, tremolite schist and tremolite-garnet schist. Less commonly, it consists of interlayered solid pyrite, solid magnetite and tremolite schist. Locally, quartzite (possibly recrystallized chert) is interlayered with the other components of the iron formation. The iron formation is bounded by, and has sharp contacts with, variably altered metasedimentary rocks (Baldwin, 1982). Magnetite and pyrite layers range in thickness from 0.1 to 1.5 cm; layers of tremolite schist, tremolite-garnet schist and quartzite are 0.1-20 cm thick. The thickness of the iron formation ranges from 3 to 16 m.

In some drill intersections of the iron formation the mineralized layers consist of solid magnetite. In others the mineralized layers are solid pyrite and solid magnetite. Where solid pyrite and solid magnetite layers are present in the iron formation, the pyrite layers occur in a zone about 1 m thick; magnetite layers occur throughout the remainder of the iron formation. The change from pyrite to magnetite is gradational, and generally pyrite veinlets occur in the tremolite schist adjacent to the massive sulphide layers.

In addition to the iron formation there are meta-argillite units that most commonly contain 2-3% finely disseminated magnetite. Locally in these meta-argillite units, finely disseminated sulphide zones (1-2 m thick) alternate with magnetite-bearing meta-argillite.

It is suggested that the habit and spatial relationships of oxide and sulphide in the iron formation and meta-argillite are due to sulphidization of iron oxide.

GENERAL STATEMENT

Three unconformities have been recognized in the northwest segment of the Karsakuwigamak Block. They occur at the top of lava flow unit C, and at the base of both heterolithic breccia unit D and sandstone conglomerate unit A. The unconformities can be defined by a number of criteria, such as 1) presence of regoliths, 2) truncation of underlying units, and 3) irregular deposition surfaces.

LAVA FLOW UNIT C

At the top of lava flow unit C there is a 0 to 4 m thick, laterally discontinuous, black, fine grained, magnetite-rich unit that grades downward into the underlying sparsely plagioclase-phyric dacite flow. The magnetite-rich unit contains concentrically zoned fragments of dacite that appear to be joint blocks derived from the underlying flow. These fragments are 2 to 40 cm in diameter and have equant to elliptical shapes. Fragment abundance decreases upward from 50 to 20%, and the maximum size decreases from 40 to 20 cm. There is a corresponding increase in the abundance of magnetite-rich matrix from 50 to 80%. Three fragment types can be recognized from differences in size, shape, degree of zonation and stratigraphic position in the unit.

Type I fragments are 25 to 40 cm diameter, subangular to subrounded composite blocks consisting of several 8 to 10 cm, polygonal, subangular to rounded, dacite fragments, separated by a 1 to 7 mm wide, vein-like network of black magnetite-rich matrix material, and/or 30 to 70% magnetite-rich material enclosing 30 to 70%, subrounded to rounded, sand- and granule-size, dacite fragments. Rounded dacite fragments occur at the margins of composite blocks, and polygonal subangular fragments occur in the interiors and at the margins of composite blocks (Fig. 52). Composite blocks, and each fragment in composite blocks, show a zonation from margin to interior. Each composite block has a 2 to 7 cm thick dark grey rim that is gradational with a light grey interior; the rim is continuous except where it is intersected by the vein-like network that separates the fragments in blocks (Fig. 52). Each fragment in a composite block is surrounded by a single 2 to 5 mm thick dark grey rim that mimics the fragment shape and is gradational with a light grey interior (Fig. 52).

The vein-like network between the fragments in blocks is generally 1 to 3 mm wide, but at block margins it is up to 7 mm wide and forms reentrants between polygonal fragments. At the reentrants the corners of the polygonal fragments are well rounded, rather than angular as in the interior of composite blocks. The vein-like network generally comprises diffuse granules of dark grey material similar to fragment rims but, near and at block margins, the veins contain 70 to 30% dark grey rounded granules in 30 to 70% black magnetite-rich matrix; the abundance of black matrix generally increases toward block margins and is most abundant in reentrants. Granular dark grey material that occurs in the vein-like network between polygonal, subangular and rounded fragments, in composite Type I fragments, is a fine grained, metamorphically recrytallized, granoblastic aggregate composed of 30% plagioclase, 40% quartz, 15 to 20% magnetite, and 10% biotite. The outer dark grey rim of the composite blocks, and the rim on each fragment in the composite block, are mineralogically similar to the granular grey material. The light grey cores of each fragment in the composite blocks consist of 2 to 3% plagioclase phenocrysts and 5% plagioclase microlites in a recrystallized groundmass consisting of 50% plagioclase, 40% quartz, 7-8% biotite, 2-3% magnetite, and about 1% muscovite, chlorite, epidote and carbonate.

Type II fragments are 20 to 40 cm in diameter and rounded; they consist of a diffuse mass of 75 to 90%, 1 to 5 mm, rounded, dark grey, granules and 10 to 25% black magnetite-rich material that encloses 5 to 10 cm, rounded, dacite fragments spaced 6 to 10 cm apart (Fig. 53). The boundaries between the masses of granular dacite and enclosed dacite fragments are sharp. Most commonly the 5 to 10 cm fragments are concentrically zoned. These fragments consist of three to four, 2 mm to 1 cm thick zones of different shades of grey that are generally darker than,

Figure 52: *Photograph of Type I fragment, in regolith at top of lava flow unit C, showing internal polygonal jointed character of the fragment, and alteration in and adjacent to the joints.*

Figure 53: *Photograph of part of a Type II fragment, in regolith at top of lava flow unit C, showing concentrically zoned dacite rafts enclosed and partially enclosed in grey granular dacite material. The Type II fragment is in turn enclosed by black magnetite-rich material (upper part of photograph). The dark area in the lower right and central part of the photograph is due to a shadow caused by relief on the outcrop.*

and surround, a light grey core; the outer zone is always dark grey and 2 to 5 mm thick. Less commonly these fragments consist of a single 2 to 5 mm thick, dark grey rim surrounding a light grey core. In concentrically zoned fragments the boundary between the outermost dark grey zone and the adjacent zone is generally sharp but some are gradational; the boundary between the other zones is always gradational. In fragments with a single outer rim, the boundary between the rim and the interior is sharp to gradational. The dark grey granules in the material surrounding the 5 to 10 cm fragments, and the outer grey zone or rim of the fragments, are similar to the dark grey granules in the vein-like network in, and the dark grey rims of, Type I fragments. The light grey cores of Type II fragments are similar to the interiors of the fragments that compose composite block Type I fragments. The concentric zones, which are characterized by various shades of grey, have mineralogies that range between that of the plagioclase-phyric core and the darker grey outer zones of fragments. Because of sampling difficulties on flat outcrops, all of the mineralogical variations are not quantified, but it appears that the abundance of magnetite increases, and plagioclase phenocrysts and microlites decrease, from core to margin of the fragments. Boundaries between the masses of granular dacite and black matrix are sharp to gradational.

Type III fragments are 0.6 to 10 cm diameter, rounded and concentrically zoned dacite; most are 2 to 10 cm across. They consist of 1) an outer dark grey, 0.4 to 1 cm thick rim surrounding a light grey core, 2) a few 0.4 to 1 cm thick concentric zones of various shades of grey surrounding a light grey core, or 3) a 5 cm wide zone that grades from dark grey at the margin to light grey in the centre. Boundaries between different coloured zones are generally gradational, although some are sharp. In general Type III fragments are similar to the rounded concentrically zoned fragments that are surrounded by the granular grey material in Type II fragments. Locally there is 2 to 3 cm of granular dark grey material adjacent to, but not always surrounding, Type III fragments. The mineralogy of the different zones is similar to the zones in Type I and Type II fragments.

The matrix is a 0.01 to 0.05 mm, metamorphically recrystallized, granoblastic aggregate of magnetite, quartz, plagioclase and chlorite. The magnetite content in the matrix increases upward from about 20 to 35%, plagioclase abundance decreases from 30 to 15%, quartz content remains constant at about 45%, and chlorite remains at 5%.

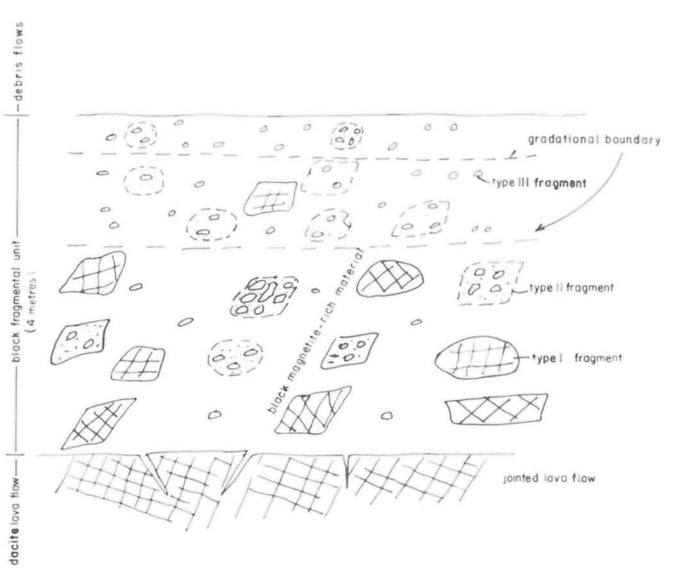

Figure 54: *Schematic sketch of the distribution of fragment types in the regolith at the top of unit C dacite lava flow sequence.*

The boundary between Type I fragments and black matrix is generally sharp, but locally adjacent to the composite blocks there is a 4 to 5 cm thick zone in which rounded dark grey granules occur in black matrix. Boundaries between the masses of granular dacite of Type II fragments and black matrix are sharp to gradational. Rarely, a rounded, concentrically zoned or rimmed fragment in a Type II fragment occurs at the boundary of the Type II fragment and has a sharp contact with black matrix. Type III fragments have sharp contacts with black matrix.

In areas where the magnetite-rich unit attains maximum thickness, the abundance of various fragment types varies stratigraphically (Fig. 54). Type I fragments are most abundant in the lower 2 to 2.5 m of the unit where they compose 60% of the fragment population; Type II and Type III fragments compose 25% and 15% of the fragment population respectively in this lower part of the unit. Type II fragments compose 70% of the fragment population in the middle 1 to 1.5 m of the unit, and, although there are more of the small Type III than of the large Type I fragments here, these two fragment types compose subequal volumetric amounts of the fragment population. In the upper 1 m of the unit, Type I fragments were not observed, and Type II and Type III compose subequal volumetric amounts of the fragment population. The upward change in fragment type and abundance is continuous, and thus boundaries between the upper, middle and lower parts of the unit (Fig. 54) are gradational to arbitrary. However, the relative stratigraphic position of isolated outcrops of the unit can be approximated by examining the fragment population.

The contact between the black magnetite-rich unit and the underlying dacite flow is generally sharp. At the top of the underlying dacite flow a 1 to 2 m thick zone is polygonally jointed; the joints are spaced 5 to 10 cm apart and the joint blocks are similar in size and shape to the polygonal fragments in Type I composite blocks. These joint blocks also have a dark grey rim, similar to that in polygonal fragments of Type I composite blocks, but the vein-like network between fragments is absent. In this jointed zone, fractures up to 2 cm wide penetrate 15 to 35 cm downward into the jointed flow material and are filled with black magnetite-rich matrix, similar to that in the lower part of the overlying fragmental unit (Fig. 55). Petrologically,

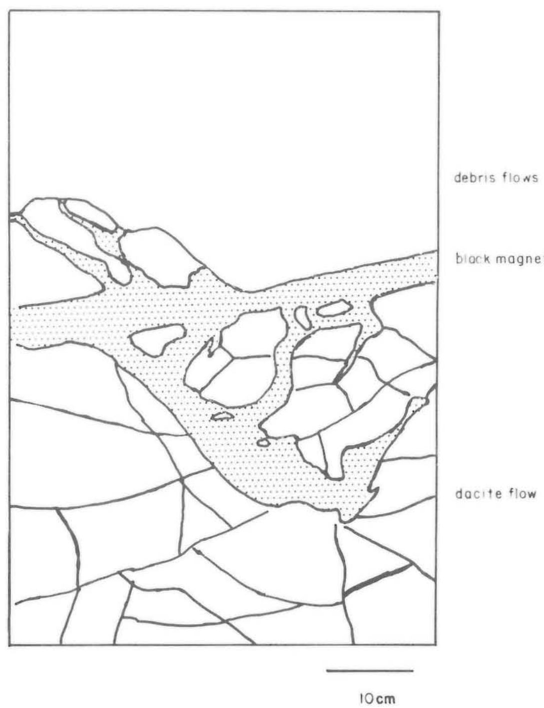

Figure 55: *Sketch of a photograph of a jointed dacite flow-top, lava flow unit C, showing fractures filled with black magnetite-rich material (patterned) in contact with overlying debris flow.*

the massive part of the flow, the rimmed joint blocks at the flow top, the cores of polygonal fragments in Type I composite blocks, and the cores of Type II and Type III fragments are very similar.

Chemical data and more petrographic data on the black magnetite-rich matrix, concentric zones in all fragment types, vein-like material in Type I blocks, and rimmed joint blocks are required in order to quantify the genesis of the black magnetite-rich fragmental unit. However, the megascopic features and available petrographic data suggest that the fragmental unit is a regolith that developed from progressive weathering and alteration of a felsic flow.

The distribution of fragment types and concentric zonation in the fragments (Fig. 54, 53, 52) suggest that spheroidal weathering progressed downward from the top of the flow and inward from the joints. The three fragment types apparently represent different degrees of pervasive weathering of the flow.

The mineralogical changes from the cores of fragments to the black magnetite-rich matrix are, 1) increase in modal magnetite, 2) decrease in modal plagioclase, 3) increase in modal quartz, 4) disappearance of biotite, and 5) appearance of chlorite. Because the alteration of the dacite is apparently due to weathering and there is no evidence of hydrothermal alteration in the dacite flows, it is doubtful that the high magnetite content of the regolith was due to addition of extraneous iron.

The decrease in modal plagioclase, absence of plagioclase phenocrysts or relicts of these phenocrysts in fragments derived from the underlying plagioclase-phyric dacite flow, and the change from biotite to chlorite from the cores of fragments to the black magnetite-rich matrix, suggests that during weathering plagioclase was unstable and considerable alkalies and calcium were removed from the developing regolith. The breakdown of plagioclase and loss of alkalies and calcium are common occurrences in weathering processes (Berner, 1971; Goldich, 1938). However, the simple removal of alkalies and calcium does not explain the observed high increase in the abundance of iron, the comparatively low increase in quartz, which in the precursor dacite is present in a much larger amount than magnetite, and absence of an aluminous phase other than plagioclase and chlorite in the matrix. Thus, it appears that considerable aluminum and silica were removed from the developing regolith, and that iron remained in the weathered residue. This suggests that, under the prevalent weathering conditions, iron was least mobile, and silica and aluminum were more mobile than iron, but less mobile than alkalies and calcium. In a study of weathering of the Morton gneiss, Goldich (1938) found a similar order in the stability of the rock components.

The top of lava flow unit C has an irregular upper surface. The unit is thinnest in the central part and thickens eastward and westward. In the east there is a maximum of 80 m relief on the upper surface of the unit (Baldwin, 1987). Although primary irregularities such as spines and flow folds occur on the upper surfaces of felsic lava flows (Macdonald, 1972; Fink, 1980), these structures do not attain heights of 80 m. Therefore, it is most likely that the irregular upper surface is the result of considerable erosion. As a result, the topography developed on the unit apparently controlled the distribution of overlying debris flows and ignimbrites (Baldwin, 1987). Since the maximum thickness of the fragmental unit is 4 m and the relief on the unit is 80 m, and because the zone of rimmed jointed blocks and fractures filled by black magnetite-rich material occurs on the points of highest and lowest relief, the fragmental unit developed after the erosion that produced the relief. In addition this suggests that the joints at the present surface of the unit presumably developed as the flow was eroded and/or during the weathering process.

The change in thickness of the fragmental unit may be due to uneven development of the unit or local erosional removal of the unit during or after regolithic formation. However, of these possible processes, local erosional removal of part or all of the regolith seems most likely. Evidence in support of this includes 1) the lower part of the unit containing the highest abundance of Type I fragments is persistent, 2) the zone of rimmed joint blocks containing fractures filled by black magnetite-rich matrix material is directly or nearly directly overlain by debris flows, 3) the unit is laterally discontinuous, and 4) the regolith is thin or absent on the topographically highest parts of the formation and thickest in the depression in the east (Baldwin, 1987).

BASE OF HETEROLITHIC BRECCIA UNIT D

Unconformable relationships at the base of heterolithic breccia unit D include, 1) a regolith at the top of lava flow unit E, 2) truncation of the underlying units (Baldwin, 1987), and 3) the westward and eastward increase in the thickness of heterolithic breccia unit D. However, contact relationships between all the pertinent units are not exposed. The gap in outcrop between the different units is about 15 to 50 m.

A black magnetite-rich fragmental rock overlies a dacite flow at the top of lava flow unit E. This magnetite-rich unit has the same megascopic features as the regolith at the top of lava flow unit C and thus is also considered to be a regolith. The regolith is exposed at only one locality where it can be traced laterally for about 85 m and maintains a constant thickness.

The original lateral extent of heterolithic breccia unit C must have been greater than that shown on Map GR86-1-1. The unit is composed of debris flows and must have extended farther to the east, because the boundary between the debris flow and gabbro to the east is unrealistic for the natural termination of a debris flow unit considering that the overlying and underlying volcanic units are continuous east and west of the gabbro.

The shapes and present spatial relationships of units underlying and overlying the proposed unconformity can be interpreted in 2 ways (Fig. 56). In the first case (Fig. 56a) dacite flows were conformably deposited on the debris flow sequence and extended farther west than present unit boundaries. Subsequently these two units were truncated by erosion that removed 590 m of stratigraphic section; a regolith developed on this erosional surface. The westward thickening geometry of the debris flow unit overlying the proposed unconformity supports deposition on a

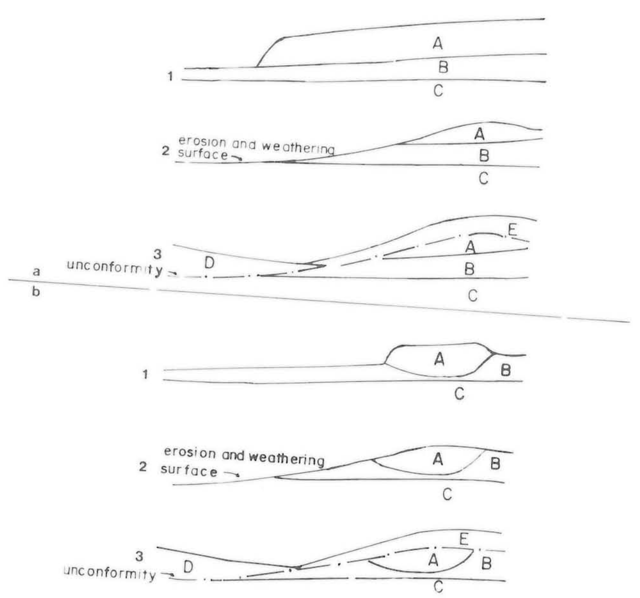

Figure 56: *Sketch showing two possible mechanisms for development of the unconformity at the base of heterolithic breccia unit D, northwest segment of the Karsakuwigamak Block; a) layer cake model where, 1) A was deposited on B, 2) subsequent erosion and weathering, 3) deposition of D and E; and b) where, 1) A was deposited in an existing channel in B, 2) subsequent erosion and weathering, 3) deposition of D and E.*

westward dipping surface. In addition, overlying conglomerate, which probably had a different source and transport direction than the overlying debris flows, drapes the dacite flow unit, is in contact with underlying debris flows and overlying debris flows to the west of the dacite flows, and thins to the west of, and thickens to the east of the dacite flows. These relationships suggest that the conglomerate was in part deposited on a topographic high.

In the second scenario (Fig. 56b) the dacite flows were deposited in an erosional channel in the underlying debris flow sequence and formed a topographic prominence above the upper surface of the debris flows. Subsequent geological processes were the same as those presented for the layered geological model (Fig. 56a). However, in this latter model the thickness of stratigraphic section removed during erosion could have been considerably less than in the former model.

Regardless of which model is chosen to explain the shape and spatial relationships of all these depostional units, an erosional unconformity at the base of heterolithic breccia unit D is supported by, 1) a regolith at the top of dacite flow unit C, 2) the truncation of the dacite flow unit and underlying heterolithic breccia, and 3) the geometry of overlying heterolithic breccia and conglomerate. It is not known whether erosion occurred prior to or after the development of the regolith at the top of the dacite flow unit.

BASE OF SANDSTONE UNIT A

The distribution of lithologies in the eastern part of flow unit I, pyroclastic unit G, and sandstone unit A suggests that sandstone unit A was deposited on an erosional unconformity. Here, an eastward thinning wedge of sedimentary rocks overlies flows and ignimbrites (Fig. 57). The thinning is most apparent in the fluvial sandstone unit A sequence that decreases in thickness from 80 to 0 m in a lateral distance of 200 m. The thinning is also present in the overlying heterolithic breccia unit F, but siltstone unit A and the pyroclastic unit H ignimbrite, tephra fall and surge deposit sequence have a relatively constant thickness.

The contact between the lower ignimbrite sequence (pyroclastic unit G) and flows (felsic lava flow unit I), and layering in this ignimbrite, are truncated by the lithic greywacke in sandstone unit A. The lower part of the lithic greywacke sequence that contains the dish-shaped structures occupied by pebble conglomerate is observed only in the lowermost outcrops suggesting that this part of the lithic greywacke wedges out against this same boundary. Bedding in lithic greywacke sequence is parallel to that in the flow and ignimbrite sequence, although bedding in the lower part of the greywacke sequence is difficult to recognize. However, bedding in the lithic greywacke sequence, and in the overlying sedimentary and volcanic rocks, appears to be oblique to the basal contact of the lithic greywacke sequence. The contact between the lithic greywacke sequence and the underlying volcanic rocks is nowhere exposed, and the gap between outcrops of each of the units ranges from 1 to 15 m, being most commonly about 3 m. Based on distribution, the trace of the contact is undulating (Fig. 57).

These relationships could have resulted from either fault juxtaposition of these units or deposition of the lithic greywacke sequence in an erosional topographic depression. An erosional unconformity is supported by the irregular surface of the flow and ignimbrite sequence in conjunction with, 1) the rapid thinning of the lithic greywacke sequence, 2) the thinning of the heterolithic breccia unit, 3) the relatively constant

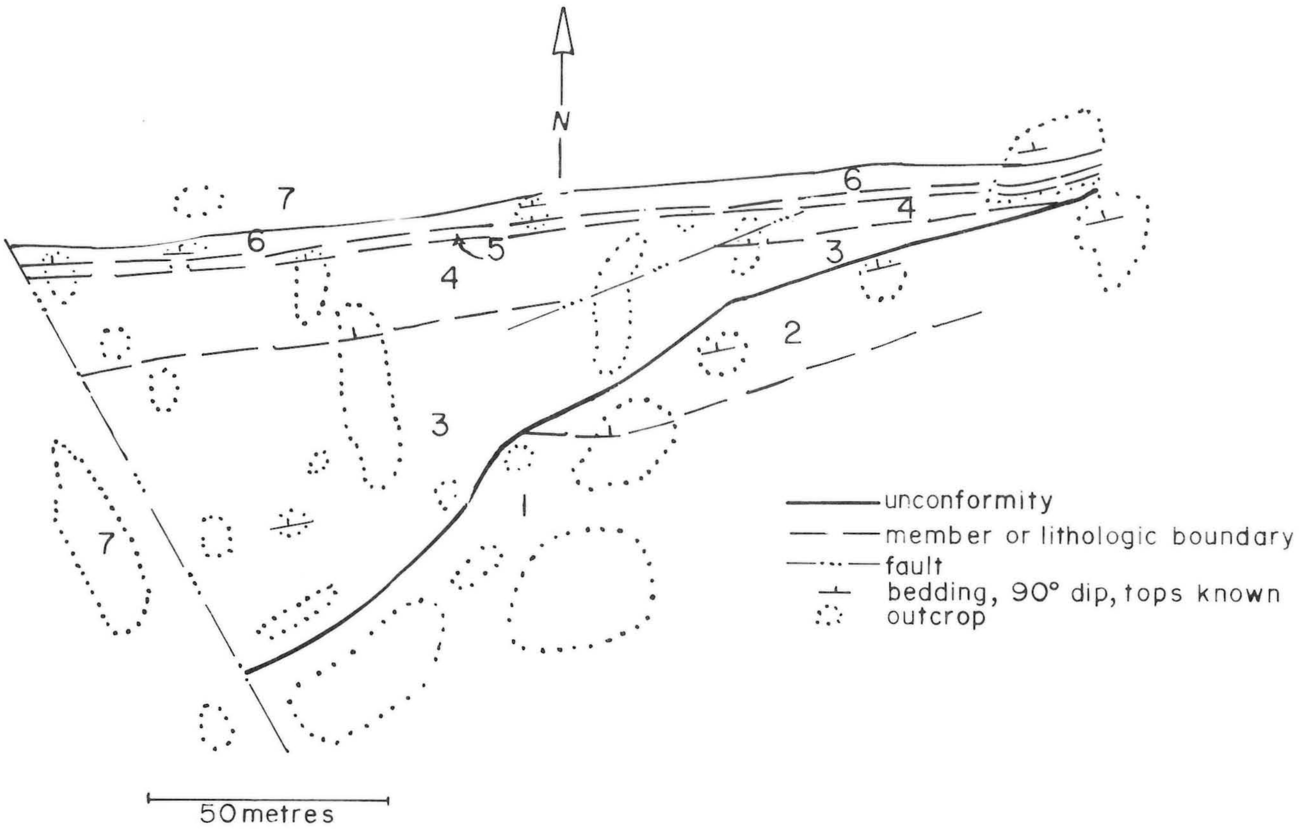

Figure 57: *Sketch map showing the geological relationships among felsic flow unit I, pyroclastic unit G, and sandstone unit A in the northeastern part of the northwest segment of the Karsakuwigamak Block; 1 - felsic flow unit I; 2 - pyroclastic unit G; 3 - sandstone unit A; 4 - heterolithic breccia unit F; 5 - siltstone unit A; 6 - pyroclastic unit H; 7 - volcanic conglomerate unit B.*

thickness of the siltstone and overlying ignimbrite unit, 4) wedging out of lithologies in the lithic greywacke, 5) parallelism of bedding in units above the proposed unconformity to that in underlying units, 6) truncation of lithologic boundaries and layering in the flow and ignimbrite sequence, and 7) the absence of shearing or brecciation in outcrops close to the unexposed contact between the flow and ignimbrite sequence and the lithic greywacke sequence.

Except for points 2 and 7 listed above, all of the features described could fit a fault model. However, the minor fault that transects the lithic greywacke and overlying heterolithic breccia and parallels the proposed unconformity was apparently the cause of most of the thinning of the heterolithic breccia unit. Sheared and brecciated rock may be covered by overburden that separates outcrops of the two formations.

Nevertheless, the outcrop distribution of the lithologies close to the contact of the flow and ignimbrite and lithic greywacke sequences suggests that this contact is an undulating irregular surface and is more likely to be an erosional surface than a fault.

STRATIGRAPHY

GENERAL STATEMENT

The stratigraphy within each of the fault blocks is summarized in Tables 1, 2, 3, 4 and 5, and in Figure 4. Stratigraphy can be correlated within each fault block. Attempts to correlate stratigraphic units from one fault block to another have been unsuccessful.

Many of the lithologic units have wedge or lens shapes and the areas of maximum unit thickness are displaced geographically relative to one another. Thus the maximum aggregate thickness of stratigraphic successions is greater than true thickness. In the Ruttan Block, the Karsakuwigamak Block, and the lower half of the Northern Block, preserved unit thickness probably approximates original thickness because there is only minor tectonic flattening of fragments in flow breccia, heterolithic breccia and conglomerate. Locally, intrusion of younger plutonic rocks has expanded and in some places, removed stratigraphic section.

NORTHERN BLOCK

The Northern Block comprises six apparently conformable but, compositionally and lithologically diverse stratigraphic units that collectively have a maximum aggregate thickness of 9300 m (Table 1). The stratigraphic succession is homoclinal, trends 110° to 120°, dips steeply to the south and faces north; i.e., it is overturned. The base of the succession is truncated by Fault 3 and the top is a younger intrusion. As a result of faulting and intrusion the maximum exposed thickness at any one locality is 5500 m. The stratigraphic succession comprises 54% volcanic derived metasedimentary rocks, 37% volcanic and plutonic derived metasedimentary rocks, 8% mafic flow rocks and 1% siliceous sulphide iron formation. The metasedimentary rocks, are largely polymictic conglomerate and lithic sandstone with minor interbedded siltstone.

The six stratigraphic units range in maximum thickness from 1150 to 2000 m (Fig. 4) and, because of faulting and intrusion, the known lateral extent of the units ranges from 7 to nearly 30 km (Map GR-86-1-1). The six stratigraphic units can be grouped into two major subdivisions. The lower division has a maximum thickness of 4400 m and consists of three compositionally distinct units composed entirely of volcanic material. The upper division has a maximum thickness of 4900 m and consists of three metasedimentary rock units, composed mainly of volcanic and plutonic detritus, but each of these units has a different lithology. The west part of the Northern Block is underlain mostly by lower division units, whereas in the east most outcrops are upper division rocks.

The lower division comprises three eastward thinning units that have maximum thicknesses of 1150 to 1800 m. The three units consist mainly or entirely of volcanic derived conglomerate, sandstone and minor siltstone. Basalt flow rocks occur near the base of the lower unit and near the top of the upper unit in the division. Detritus in the lower unit is largely mafic volcanic; in the middle unit detritus is nearly all felsic volcanic; and the upper unit contains subequal amounts of mafic and felsic volcanic detritus. Conglomerate is the dominant rock type in the west in the lower division, but in the east the abundance of conglomerate and the bed thickness decrease in each of the three units. Eastward conglomerate abundance and bed thickness decrease and sandstone abundance increases, but sandstone bed thicknesses are similar laterally. Conglomerate beds are massive or are reversely to normally graded; normally graded conglomerate beds are rare and occur only in the uppermost parts of the units. Bouma divisions and primary depositional sedimentary structures are ubiquitous in the sandstones in the lower unit. In the middle and upper units, Bouma divisions are abundant in sandstone but other primary sedimentary structures are only locally abundant.

The upper division consists of three apparently eastward thinning units that range in maximum thickness from 1350 to 2000 m. The lower and upper units comprise interbedded, massive, polymictic, volcanic and plutonic derived conglomerate and sandstone. The middle unit consists of bedded greywacke and, near the base, two thin siliceous sulphide iron formations. Vertically and laterally there are no changes in abundance of rock type or bed thickness in any of the three units. A superimposed foliation parallel to bedding increases in intensity northward from the contact between the lower and upper divisions. Primary sedimentary structures other than bedding were not observed.

Isolated bodies of massive, equigranular, fine- to medium-grained gabbro occur in both the lower and upper subdivisions, but are most abundant in the lower division. Fine grained mafic to intermediate sills and dykes in the lower division are commonly amygdaloidal at their boundaries and locally display anastomosing contacts. Sills are commonly compound intrusive bodies. Many of these dykes and sills were intruded prior to lithification of the metasedimentary rocks and may have been feeders to the mafic flow units.

RUTTAN BLOCK

The Ruttan Block comprises two metavolcanic and volcanogenic metasedimentary domains that are separated by a granitic pluton (Fig. 2). The north domain consists of ten conformable stratigraphic units (Fig. 4) separated on the basis of composition and lithology; the supracrustal succession has an aggregate thickness of 5.5 to 7 km. Part of the stratigraphic section has been removed by the emplacement of a 2.5 km thick compound granitic pluton (Fig. 2).

The north domain has a broadly curved outline; one limb trends 90 to 120°, is steeply dipping and south-facing; the other limb trends 225 to 235°, is steeply dipping and faces southeast. The base of the succession is truncated by Fault 3, the top and westward extensions are truncated by younger intrusions, and the eastward extension by Fault 1 (Fig. 2). The supracrustal succession comprises 70% basalt flows, 7% felsic flows, and 23% volcanic derived metasedimentary rocks. Thick basalt flow sequences occur at the base, in the middle, and at the top of the stratigraphic succession. Intervening units are largely volcanic derived polymictic conglomerate and sandstone with lesser siltstone, rhyolite flows and pyroclastic rocks. (Table 2, Fig. 4).

Maximum thickness of basalt flow sequences ranges from 850 to 2000 m. Generally flow sequence thicknesses increase upward in the succession. Pillowed flows are most abundant in the lowest basalt flow sequence. Massive and brecciated flows dominate in the other three basalt flow sequences. Volcanic derived conglomerate and sandstone sequences have maximum thicknesses of 120 to 700 m. In some sequences conglomerate and sandstone are present in subequal amounts, and in others conglomerate or sandstone is the dominant rock type. Generally conglomerate beds become less abundant and thinner upwards in a sequence; monolithic and heterolithic lithologies are present (Table 2). Felsic flows and associated flow breccia and pyroclastic flows form one unit in the upper third of the north domain succession. It has a maximum thickness of 325 m. A 20 to 30 m thick siliceous siltstone and sandstone unit, with minor massive and banded chert, overlies the massive sulphide at the Ruttan Mine. This unit is laterally continuous for 9 km and eastward it gradually becomes less siliceous.

Most units in the north domain are truncated by faults or by intrusive rocks. Thus, the lateral extent and thickness variation of many units is unknown. However, some units thin westward but others appear to be lens shaped. Some can be traced laterally for 9 km. Most conglomerate and sandstone sequences fine upward and some also fine eastward. Conglomerate and sandstone sequences commonly interdigitate with basaltic flow sequences, suggesting that sedimentation and mafic volcanism were in part contemporaneous.

The south domain comprises thirteen conformable stratigraphic units that have an aggregate thickness of 3.5 to 4.8 km. The supracrustal succession comprises 73% basalt flows, 4% felsic flows, and 23% volcanic derived sedimentary rocks including oxide facies iron formation. Basalt flow sequences form the upper and lower units in the supracrustal succession as well as occurring at various levels in the succession. These flow sequences are separated by volcanic derived sedimentary sequences that are generally sandstone and siltstone; polymictic volcanic derived conglomerate occurs near the top of the supracrustal succession (Table 3, Fig. 4). A single unit comprising felsic flows occurs in the upper part of the succession.

The south domain trends between 250 and 270°, dips between 50° and 70° to the north, and rare younging criteria suggest that it faces north to northwest. It is truncated in the west, north and south by plutonic rocks (Fig. 3; Steeves and Lamb, 1972) and to the east by Fault 1.

Basalt flow sequences range in maximum thickness from 100 to 1000 m. Those sequences that are not thinned due to emplacement of plutonic rocks, thin eastward. Metasedimentary sequences consist mainly of sandstone and siltstone and have a maximum thickness of 100 to 250 m. In the lower parts of the south domain sandstone and siltstone sequences do not appreciably change thickness laterally, but siltstone abundance increases eastward. In the upper part of the south domain sandstone and siltstone sequences form lens shaped units. One, 100 m thick unit of conglomerate and siltstone occurs near the top of the succession; the conglomerate thins eastward but the unit thickness remains constant laterally. The felsic flow sequence is 200 m thick and does not change thickness laterally. In the lower part of the south domain stratigraphic units can be traced laterally for 5 to 6 km. In the upper part the lateral extent of units is 2.5 to 4 km, because some are lens shaped and also because of termination at intrusion boundaries.

The south domain is lithologically similar to the north domain and the proportions of lithologies in both is nearly identical; however, units are thinner and the volcanogenic metasedimentary deposits are finer grained in the south domain. The south domain is interpreted to be equivalent to the north domain but more distal from the volcano.

EASTERN BLOCK

The Eastern Block comprises 10 conformable lithologic units that have an aggregate thickness of 3.3 km, trend 80° to 90°, and dip vertically or steeply south; facing direction is unknown. The stratigraphic succession comprises 73% mafic metavolcanic rocks, some that are basalt flows and some of uncertain origin, 15% felsic flows, and 12% volcanic derived metasedimentary rocks. Basalt flow sequences and mafic volcanic rocks of uncertain origin are interbedded with less abundant felsic flows and polymictic volcanic derived conglomerate sequences (Table 4, Fig. 3).

The top of the succession is truncated by Fault 3; to the south, east and west, there is no outcrop, but the westward boundary is interpreted to be Fault 2 (Fig. 2). Outcrop is sparse and lichen and moss covered, and the area is accessible only by helicopter. As a result details of the geology in this fault block are poorly known. Vertical and lateral variations within units are unknown. The origin of some mafic metavolcanic rocks has not been determined with confidence, but the occurrence of breccia and amygdules in plagioclase- and hornblende-phyric rocks suggests that they are flows. Flow and metasedimentary sequences have minimum lateral extents of 3 to 5 km and generally thin westward. Lithologic unit thicknesses are similar in the Eastern Block and the south domain of the Ruttan Block. The proportion of mafic metavolcanic rocks is the same in both blocks but there is a higher proportion of felsic flows and a lesser amount of volcanic derived metasedimentary rocks in the Eastern Block. Nevertheless, the two blocks may be stratigraphically equivalent.

KARSAKUWIGAMAK BLOCK

The Karsakuwigamak Block comprises two volcanic and volcanogenic sedimentary domains separated by Fault 4 and a younger gabbro intrusion (Fig. 3, Map GR 86-1-1). Stratigraphic correlation across Fault 4 does not appear to be possible. For the most part, the rock types that occur in the succession on either side of the fault are similar, but the stratigraphic position of the succession that outcrops southeast of the fault relative to the succession outcropping northwest of the fault is unknown. Younger gabbro intrusions expand and locally remove stratigraphy on both sides of Fault 4.

The stratigraphic succession southeast of Fault 4 comprises eight stratigraphic units that have an aggregate thickness of 4.1 km. Conformity of the units is assumed, although a younger gabbro intrusion has obliterated relationships between most units. The supracrustal succession comprises 48% volcanic derived sedimentary rocks, 39% felsic flows and 13% basalt flows. The sedimentary rocks are mostly polymictic volcanic conglomerate interbedded with lesser sandstone and siltstone; they form the basal sequence in the succession. In the upper half of the supracrustal succession two felsic flow sequences are separated by a basalt sequence that consists of pillowed flows (Fig. 4). The felsic flow sequence that occurs above the basalt flow sequence has the same colour, phenocryst types, and range in phenocryst abundance as the basal felsic flow sequence on the northwest side of Fault 4 suggesting a possible stratigraphic correlation. However, flow thicknesses in the sequence southeast of Fault 4 are unknown and thus correlation between the two sequences cannot be positively made.

The preserved stratigraphic succession of volcanic and volcanogenic sedimentary rocks northwest of Fault 4 has a maximum aggregate thickness of 6.7 km, exclusive of intrusive rocks, and a maximum lateral extent of 4 km. The succession at any place is less than 3.5 km thick. The top of the succession is intruded by gabbroic to dioritic rocks and truncated by Fault 1; the bottom is intruded by gabbro and granodiorite. In the west the stratigraphy is truncated by a granitic pluton, and Fault 1 and Fault 4 form the eastern boundary.

The stratigraphic succession comprises 37% rhyolite and dacite flows, 35% rhyolite and dacite pyroclastic rocks, and 27% volcanic derived sedimentary rocks, divided into 3 groups — Lower Group, Middle Group and Upper Group — with a total of 21 stratigraphic units (Fig. 4). The division of the stratigraphic succession into groups is based upon the distribution of lithologies. The Lower Group comprises primary volcanic material, whereas the Middle Group comprises both primary and reworked volcanic material; the Upper Group is dominated by reworked volcanic material. The contact between the Lower and Middle Groups is placed at the first appearance of reworked volcanic material. The contact between the Middle and Upper groups is a major erosional unconformity that transects several stratigraphic unit boundaries.

Most stratigraphic units are compositionally homogeneous although generally more than one rock type occurs in a unit (Table 5). Some units are both compositionally and lithologically homogeneous (Table 5). Contacts between stratigraphic units are generally conformable and planar; however, some are unconformable and had considerable topographic relief. Unit thicknesses range from 0 to 540 m, but average thickness varies from group to group. Units are thicker and more laterally continuous in the Lower and Upper groups compared to the Middle Group (Fig. 4).

Sequences of rhyolite and dacite flows have maximum thicknesses of 70 to 440 m; individual flow thickness ranges from 0 to 240 m. Ignimbrite consists of compound sheets that have maximum thicknesses of 170 to 400 m, or they consist of a single flow unit with a maximum thickness of between 2 and 60 m. Ignimbrite units are the deposits of ash-flows or block-and-ash flows. Air fall deposits form well bedded rapidly laterally thinning wedges that have maximum thickness of 60 to 300 m, well bedded laterally continuous units 0.35 to 3 m thick, and co-ignimbrite ash-fall units a few tens of centimetres thick. Only one surge deposit has been identified; it is 0.5 to 1.3 m thick, has parallel and oblique stratification, and immediately underlies the stratigraphically youngest ignimbrite in the fault block. Volcanic derived sedimentary rocks comprise mainly bedded, coarse grained, heterolith, volcanic breccia that forms sheet, wedge and lens shaped units with maximum thickness of 20 to 450 m. Bed thickness ranges from a few centimetres to 20 m. Polymictic volcanic pebble conglomerate and interbedded sandstone form two units, one at the base and one at the top of the Upper Group. Maximum thicknesses are 435 and 580 m and bed thickness seldom exceeds a few metres. Fluvial and lacustrine deposits are rare and occur only near the top of the Upper Group. Some units maintain a fairly consistent thickness along strike; others pinch and swell, form wedge- or pod-shaped lenses, or comprise several pod-shaped lenses.

Lower Group

The Lower Group comprises 4 major stratigraphic units (Fig. 4) that collectively are subdivided into eight depositionally and/or genetically distinct stratigraphic units (Table 5). It has a maximum aggregate thickness of 2.45 km but at any one place is about 2 km thick. The group comprises 60% rhyolite to dacite flows and associated breccia, and 40% primary rhyolite to dacite pyroclastic rocks (Fig. 4). The pyroclastic rocks comprise ignimbrite and air fall deposits (Table 5). Two units are composed of flows and flow breccia; two are composed of ignimbrite and associated air fall deposits; two are composed entirely of ignimbrite; another is composed entirely of air fall deposits; and one comprises flow and associated flow breccia as well as block-and-ash flows (Table 5).

The units in the Lower Group are some of the thickest in the Karsakuwigamak Block. Collectively the units in the group make up one third of the thickness of the entire stratigraphic succession. Unit thickness ranges from 150 to 540 m; however, with the exception of one ignimbrite unit, all are at least 300 m thick (Table 5). Units in the Lower Group have the least variation in thickness along strike as compared to those in the Middle and Upper groups.

Middle Group

The Middle Group comprises 9 major stratigraphic units (Fig. 4) that collectively are subdivided into 12 depositionally and/or genetically distinct stratigraphic units (Table 5); they have a maximum aggregate thickness of 1.5 km (Table 5). Maximum unit thicknesses are displaced relative to one another, some have limited lateral extent, and several are truncated by the unconformity that defines the top of the group. As a result, the group is 1.2 km thick in the east and thins westward.

The stratigraphic sequence in the Middle Group comprises 40% rhyolite to dacite flows and associated flow breccia, 30% rhyolite and dacite primary pyroclastic rocks and 30% volcanic derived sedimentary rocks (Table 5, Fig. 3). The pyroclastic rocks include ignimbrite and air fall deposits; volcanic derived sedimentary rocks are debris flow deposits (Table 5).

Two units comprise rhyolite or dacite flows with or without associated flow breccia; two units consist of rhyolite ignimbrite; one consists of rhyolite ignimbrite and associated air fall deposits; two consist of air fall deposits. Three units are composed of debris flows that consist of felsic volcanic materials; one debris flow unit is composed of mafic volcanic material; and one comprises dacite flows and associated ignimbrite.

Units composed of rhyolite or dacite flows have a maximum thickness of 70 to 300 m. Ignimbrite deposits range in maximum thickness from 15 to 155 m, consist of a single flow unit or multiple flow units, and generally thin westward. Debris flow deposits have a maximum thickness of 3 to 310 m; all but one debris flow deposit consists of multiple flow emplaced beds. They form westward thinning units, or lenses that thin eastward and westward. Air fall deposits form westward thinning wedges, and are composed either of numerous beds that have maximum aggregate thickness of 50 to 60 m, or of single beds, between ignimbrite flow units, that are 0.3 to 0.5 m thick.

Stratigraphic units in the Middle Group display more variation in thickness and shape than do their counterparts in the Lower and Upper groups, and only two units can be traced continuously along the exposed lateral extent of the group. This is probably because an erosional unconformity occurs in, and another occurs at the top of, the group. The majority of the stratigraphic units in this group are much thinner than those in the Lower and Upper groups. Grain size variations in air fall deposits and in some debris flow deposits are upward and westward fining.

Upper Group

The Upper Group comprises 8 major stratigraphic units that collectively are subdivided into 13 depositionally and/or genetically distinct stratigraphic units (Table 5, Fig. 4). The group has a maximum aggregate thickness of 2.25 km and thickens from about 800 m in the east to 2.0 km in the west. Volcanic derived sedimentary rocks make up 72% of the group thickness, and the remaining 28% is made up of equal amounts of rhyolite and dacite flows and associated breccias, and rhyolite to dacite primary pyroclastic rocks (Fig. 4, Table 5). The pyroclastic rocks comprise ignimbrite, ground surge and air fall deposits (Table 5). Metasedimentary rocks are heterolithic volcanic breccia and volcanic derived conglomerate, sandstone and siltstone. Two sedimentary units consist of interbedded polymictic volcanic conglomerate, and sandstone with or without siltstone; these units are the thickest in the Upper Group and have maximum thicknesses of 435 to 500 m. Four other sedimentary units comprise heterolithic volcanic breccia, and minor sandstone, and one contains lacustrine siltstone; maximum thicknesses of these units are 100 and 450 m. One unit comprises a sequence of rhyolite and dacite flows and another contains both dacite flows and ignimbrites. Two units comprise rhyolite ignimbrite and associated surge and/or ash-fall deposits; (Table 5). Sequences composed of flows and ignimbrites are about 250 m thick, whereas units composed of only pyroclastic rocks are 5.5 to 10 m thick.

Generally the stratigraphic units in the Upper Group have considerable variation in thickness along strike and they can be traced laterally for 3 to 4 km. The top of the ignimbrite and pyroclastic surge sequence that overlies the rhyolite and dacite flow sequence (Fig. 4) is truncated by an erosional unconformity; thus it is exposed only in the eastern part of the fault block.

PLUTONIC ROCKS

Plutonic rocks in the map area include granite, quartz monzonite, diorite, gabbro, quartz-feldspar porphyry and diabase. The petrography, nature and age relationships of these rocks are not described in this report. The reader is referred to Steeves and Lamb (1972) for details regarding the plutonic rocks.

SYNTHESIS

NORTHERN BLOCK

The three volcanic derived metasedimentary rock units that compose the lower division of the Northern Block form a sequence of turbidites that have a maximum thickness of 4.4 km. Volcanic conglomerate that is massive, normally graded and reversely to normally graded is interbedded with sandstones that commonly have AE or ABE Bouma divisions. In addition primary depositional structures are abundant and include flames, rip-ups, load casts, and scours in sandstone that are filled with conglomerate. Conglomerate is the most abundant lithology in the west of the lower division of the Northern Block, and laterally sandstone becomes the dominant lithology. Sandstone in the west most commonly has AE divisions or is massive; in the east ABE beds predominate. The conglomerates and sandstones in the lower division have the features of sediment gravity flows. The sandstones are characteristic of low concentration turbulent sediment flows. The conglomerate, on the other hand, has features associated with high concentration debris flows and hyperconcentrated sediment gravity flows. The lateral transition from predominantly conglomerate to predominantly sandstone, both transported as sediment gravity flows, is suggestive of deposition in a sediment fan, and the occurrence of siltstone overbank deposits implies that sediment flows that deposited the conglomerates were channelized. The association of massive conglomerate, massive sandstone and AE sandstones suggests that the rocks in the west part of the lower division were deposited in the upper fan to midfan environment. The increase in abundance of ABE beds and the decrease in conglomerate abundance eastward suggest deposition in the lower part of the midfan and probably the upper part of the lower fan. Thin bedded classical turbidites indicative of deposition in the outer parts of the lower fan are not present in the Northern Block. Thus, the conglomerate and sandstone sequences in the lower division apparently represent deposition of volcanic material, transported as high concentration debris flows, hyperconcentrated sediment flows, and turbidity flows, that formed a submarine fan.

The high abundance of rounded clasts in the conglomerate and sandstone sequence suggests considerable abrasion, transport and reworking of the detritus. Clast rounding must have occurred prior to transport to, and deposition in, the submarine fan because the clasts in the conglomerates deposited from debris flows are as rounded as the clasts deposited from turbulent flows. Although the conglomerate and sandstone sequence represents deposition in a submarine fan, the heterolithic nature of the deposits suggests the source area for the detritus in the lower division was apparently a subaerial compositionally bimodal volcano.

The upper and lower units in the upper division of the Northern Belt consist of interbedded, massive, polymictic conglomerate and sandstone largely composed of plutonic and volcanic detritus. The plutonic detritus was apparently derived from an orthogneiss terrane west of the Rusty Lake volcanic belt; thus the detritus in these units was derived from two physically separated sources. The complete mixing of the material from these different sources and the rounded to subrounded shape of the clasts in conglomerate imply considerable reworking and transport of the detritus. However, the massive, bedded, and laterally extensive nature of texturally and compositionally uniform conglomerate and sandstone suggests that the preserved sedimentary sequence in these two units was emplaced as high concentration sediment gravity flows. Therefore, it is suggested that the conglomerate formed from polygenetic processes; a possible model is that the conglomerate and sandstone sequences are resedimented deposits. The plutonic and volcanic detritus was fluvially transported in a tributary river system; mixing of the detritus then took place in a fluvial system fed by the tributaries. Fluvial deposits thus formed were later mobilized, transported and redeposited as debris flow deposits.

Between and apparently conformable with the two polymictic conglomerate and sandstone sequences in the upper division in the Northern Block is a unit of volcanic derived lithic greywacke deposited from turbidity currents. However, the presence of massive fine grained quartz layers containing disseminated and massive sulphide (Baldwin, 1982) suggests considerable hiatuses in the deposition of the greywacke turbidites.

With the exception of two thin basalt flow units in the lower division, the rocks in the Northern Block are sedimentary. The lower division contains only volcanic material, whereas the upper division contains plutonic and volcanic detritus. The nature of the boundary between the upper and lower divisions is unknown but, because of the apparent abrupt change in depositional processes and lithologies between the two divisions it is suggested that the rocks in the upper division not be included in the Ruttan Group.

Deposition of the stratigraphic sequence in the Northern Block appears to have been in a submarine environment, but the source of the detritus was apparently subaerial. During deposition of the rocks in the upper division there was considerable erosion of a granitic gneiss terrane to the west of the Rusty Lake volcanic belt.

EASTERN BLOCK

In the Eastern Block there is a paucity of rock exposures and the distribution of lithologies portrayed on the accompanying geological map is highly interpretive; units have been extrapolated with little outcrop control. The presence of mafic and felsic flow rocks indicates that volcanism was compositionally bimodal. The felsic flow rocks are characterized by massive and flow layered pods surrounded by breccia and microbreccia, and sandstones with turbidite bed forms. These features are indicative of submarine deposition. However, the occurrence of both felsic flow rocks and turbidites is an unusual facies association. Therefore it is suggested that the detritus in the conglomerate and sandstone sequences was transported into the present depositional site from some distance, and was not derived from the mafic flow units in the Eastern Block stratigraphic sequence, and that the rocks were deposited in a submarine environment.

RUTTAN BLOCK

The north domain of the Ruttan Block comprises several mafic volcanic flow sequences separated mainly by sedimentary sequences and felsic flow sequences. Sedimentary rocks were deposited from debris flows and turbidity currents; felsic flow rocks include massive flows and rare pyroclastic flow deposits. Debris flow deposits contain mostly felsic volcanic detritus with minor mafic constituents whereas turbidites contain only felsic material or substantial amounts of both felsic and mafic detritus. Rare siltstone is spatially associated with felsic volcanic rocks.

The interlayered character of mafic and felsic volcanic rocks, the absence of intermediate volcanic material, and the abundance of sedimentary rock composed of felsic detritus compared to felsic flow material suggest that volcanism was largely pyroclastic. Felsic flow rocks occur near the top of the north domain stratigraphic succession and form thin units between mafic flow sequences or, as in the stratigraphically highest felsic sequence, form a thin unit of massive flow and pyroclastic flow deposits overlain by an equal thickness of felsic volcanic sedimentary rocks. Thus, for the most part, the felsic volcanic rocks in the north domain are redeposited. This, and the low abundance of primary volcanic rocks, suggest that primary felsic pyroclastic material was rapidly eroded following primary deposition. Pillowed mafic flows occur throughout the stratigraphic succession and imply submarine deposition. Mafic flows that have a massive base and an overlying breccia in which the breccia fragments are supported in tuff are also considered to be deposited in the submarine environment; the tuff component in the breccia is considered to be hyaloclastic.

Pillowed, massive and brecciated mafic flow sequences are interbedded with thick sedimentary sequences typified by debris flow and proximal turbidite deposits in the lower half of the north domain succession. The distribution of lithologies and the depositional environment suggest that the lower half of the north domain succession was deposited on the flank of a submarine shield volcano. During active felsic volcanism, pyroclastic deposits were rapidly eroded, transported and redeposited as debris flow deposits and proximal turbidites on the submarine flank of the volcano. This implies that the felsic vent was shallow marine or subaerial.

The upper half of the north domain succession comprises submarine mafic flows with minor, thin intercalated felsic flows and a thin felsic sedimentary sequence that directly overlies one of the felsic flow sequences that also contains felsic pyroclastic flow deposits. The presence of massive felsic flows suggests that the rocks in the upper half of the succession were deposited closer to the vent than the rocks in the lower half of the succession. However, the sedimentary sequence overlying the felsic massive and pyroclastic flow sequence in the southeast part of the upper half of the succession is inconsistent with deposition closer to the vent compared to the rocks in the lower half. This sedimentary sequence consists of massive debris flow deposits and overlying sandstone and siltstone that are commonly normally graded. The felsic flow sequences probably were extruded from a vent on the submarine flank of a mafic volcano.

The rocks in the south domain of the Ruttan Block are similar to those in the north domain except that the sedimentary units are much thinner and sandstone siltstone sequences are more abundant than debris flow sequences. The sandstone sequences are greywacke and consist of mixed mafic and felsic volcanic detritus; felsic flow rocks are rare. The rocks are interpreted to have been deposited in a submarine environment but farther from source than those in the north domain.

KARSAKUWIGAMAK BLOCK

As opposed to the other fault blocks in the area, which are composed mainly of either mafic volcanic flow rocks and/or volcanic derived metasedimentary rocks, the Karsakuwigamak Block contains predominantly felsic volcanic rocks consisting of flows, ignimbrites, air falls and redeposited breccias. Thus the stratigraphic succession and the nature of volcanism in the Karsakuwigamak Block are different from the other fault blocks.

The following discussion deals with only that part of the Karsakuwigamak Block occurring northwest of Fault 4. The limited outcrop and lateral extent of the rocks to the southeast of Fault 4 does not permit a stratigraphic synthesis. However, the abundance of felsic flow rock in the southeastern part of the fault block suggests a genetic association with the stratigraphic succession to the northwest of Fault 4.

From stratigraphic bottom to top of the sequence the proportion of primary volcanic rocks decreases, and secondary volcanic rocks (debris flow) and epiclastic volcanic derived metasedimentary rocks increases. This upward change in facies and the presence of regoliths and erosional unconformity in the upper two thirds of the sequence suggest temporal changes in eruption style and periodicity.

The volcanic rocks composing the Lower Group are the deposits of lava flow, pyroclastic flow and tephra fall without intervening redeposited volcanic rocks or epiclastic rocks. Thus, the stratigraphic sequence in the lower group developed from essentially continual active volcanism and any periods of volcanic quiesence must have been temporally insignificant. In the lower part of the Lower Group, flow and ignimbrite sequences thin eastward and tephra fall units fine upward and eastward suggesting a westward vent location. In the upper part of the Lower Group tephra fall units fine and decrease in thickness westward implying that the vent was located to the east. Thus, the volcanic rocks in the Lower Group are apparently the products of more than a single vent, but each vent appears to have been active at a different time. The eruptive sequence in the Lower Group comprises thick accumulations of pyroclastic deposits alternating with extrusion of viscous flows. In pyroclastic successions tephra falls overlie ignimbrites or are intercalated with only the upper parts of ignimbrite accumulation.

Volcanic rocks associated with the westerly located vent comprise all of the lava flow units in the Lower Group, block-and-ash flow deposits genetically related to the lava flow units and a thick accumulation of tephra fall formed from hydrovolcanic processes. The rocks associated with the easterly located vent are ash-flow deposits and thin accumulations of tephra fall from explosive dome disintegration and ash-fall. Thus, with change in location of the active vent, the style of eruption and the nature of the magma also change. The lava flow, block-and-ash flow association resulted from extrusion and explosive eruption of poorly vesiculated felsic magma. Similarly the blocky, angular, non-vesicular nature and fine grain size of the particles in the tephra-fall units are consistent with hydrovolcanic fragmentation of poorly vesiculated magma. The lava flow, block-and-ash flow association derived from poorly vesiculated magma is similar to Peléan eruptions. During an eruptive phase of the volcano, water had access to the vent and eruptions were hydrovolcanic in nature. On the other hand, the accumulation of pumice-bearing ash-flow deposits in the upper part of the Lower Group apparently resulted from explosive eruption of vesiculated magma and generation of pyroclastic flows from gravitational collapse of vertical eruption columns, associated with Plinian type explosive eruptions.

The Middle Group comprises an interlayered sequence of primary and secondary volcanic rocks. Primary volcanic rocks include the deposits from lava flow, pyroclastic flow and tephra fall; secondary volcanic rocks are the deposits from debris flows consisting of transported and redeposited pyroclastic material. Units composed of flows and ignimbrites are much thinner than units of similar rocks in the Lower Group; some ignimbrite units consist of the deposited material from a single pyroclastic flow. Ignimbrites in the Middle Group are the products of ash flows. With the exception of the stratigraphically highest unit, the debris flow deposits are redeposited Vulcanian breccias; for the most part these debris flow units overlie units composed of lava flows and underlie ash-flow units, but they do not contain volcanic debris from the underlying lava flows. The debris flow deposit that occurs at the base of the Middle Group underlies a unit composed of lava flows and overlies the upper ignimbrite of the Lower Group. Thus, the stratigraphic position of the redeposited Vulcanian breccias is not always the same with regards to bounding volcanic deposits. However, they do directly underlie primary volcanic rocks, and instability of crater walls caused by pre-eruptive events such as faulting or fracturing due to magma rise and/or earthquake activity can cause failure and generation of debris avalanches and debris flow. Since there is no evidence of channeling or fluvial activity with the debris flows, and because they do not appear to be dry avalanches, the water that mixed with the debris to form a flowing slurry probably came from a lake in a crater or from rapidly melting snow or ice on the volcano.

The air fall deposits in the Middle Group were the subject of a detailed study (Baldwin, 1987). In summary the well bedded deposits thin rapidly westward and contain hot formed accretionary lapilli that are normally and laterally graded; bed thickness also decreases westward. The deposit apparently formed from the rapid accumulation of accretionary lapilli, pyrogenic crystals and ash. Eruption columns were of low height, dense, and consisted of a high concentration of particles in eruption columns, allowing for many collisions of the particles and formation of the lapilli by particle fusion. The fine grain size and high temperature of the ejecta is attributed to the rapid rise of magma from depths of about 15 to 20 km. The rapid ascension of the magma resulted in tremendous decompression and thus extreme fragmentation of the magma.

The primary volcanic rocks and the constituents in the debris flows are the products of magmatic explosions and extrusion. However, the Vulcanian eruptions that produced the debris contained in the debris flows may have been in part hydrovolcanic, particularly because of the low vesicularity, large size range and shape of the fragments. The thin accumulations of ignimbrite composed of single ash-flow units could be the result of small-volume ignimbrite-forming eruptions, or these units represent ash flows that followed a flow path different from but associated with other flows from a much larger volume eruption.

The top of the Middle Group is marked by a major erosional uncomformity that in places also has a preserved regolith. The amount of volcanic material removed by erosion is unknown. As a result there are not enough preserved primary and secondary deposits to determine cyclicity in eruption styles during deposition of the Middle Group.

The Upper Group contains predominantly redeposited volcanic rocks as debris flow deposits and conglomerate and sandstone sequences, and lesser primary volcanic rocks including units composed of lava flows, ash-flow deposits and block-and ash-flow deposits.

The occurrence of conglomerate and sandstone sequences and debris flow deposits in the same stratigraphic succession suggests that there was more than one source for the reworked material in the Upper Group. The rounded shapes of the components in the conglomerate beds imply considerable transport relative to the angular to subrounded shapes of the fragments in debris flow deposits. The debris flow deposits are either felsic or mafic composition, but the thickness of the mafic deposits is much greater than that of the felsic debris flow deposits. The mafic deposits contain minor interbedded sandstone and siltstone that could indicate that deposition was in channels or that some flows had a low concentration of particles and that transport of these flows was as hyperconcentrated or turbulent flows. The felsic debris flow deposits on the other hand have the features of normal high concentration debris flows. Volcanic material in the mafic debris flow deposits could be either redeposited Strombolian or Vulcanian breccia, but in the felsic debris flow deposits the material is apparently reworked Vulcanian breccia.

Near the top of the Upper Group felsic volcanic sandstone and pebble conglomerate are interbedded. Pebble conglomerate forms lenses in sandstone and locally conglomerate fills scours in sandstone. These features suggest fluvial deposition.

Compared to redeposited volcanic material the abundance of primary volcanic rocks in the Upper Group is small. However, near the top of the Middle Group an erosional unconformity transects ash-flow deposits; thus the original accumulated thickness of these deposits is unknown. Nevertheless, deposition of reworked material in that part of the Upper Group below this unconformity greatly exceeds deposition of primary volcanic rocks.

Therefore, during deposition of the rocks in the Upper Group felsic volcânism was not as prolific as it was during deposition of the Middle and Lower Groups. For a period of time volcanic activity was dominated by mafic volcanism. During periods of volcanic quiesence clastic material from a source other than the immediate source contributed to the depositional sequence of the Upper Group.

Most of the volcanism in the northwest segment of the Karsakuwigamak Block was pyroclastic and subaerial (Baldwin, 1987). From textures and structures it can be shown that some of the rocks in that area were subaerially deposited, whereas the depositional environment of other rocks is conjectural (Baldwin, 1987). However, some of the rocks for which the depositional environment cannot be positively identified occur in sequences of rocks that were subaerially deposited. Thus, it is likely that these rocks also were deposited subaerially although they could have been deposited subaqueously if depositional environments were changing rapidly. In addition, regolithic development and erosional unconformities suggest subaerial weathering and erosion. Thus, there is abundant evidence to support subaerial deposition.

Other evidence in support of subaerial deposition is the lack of interbeds of normal sedimentary rocks composed of modified volcanic products. Such interbeds are common on the subaqueous flanks of volcanoes (Ayres, 1982; Carey and Sigurdsson, 1984; Kuenzi et al., 1979; Roobol, 1976; Sigurdsson et al., 1980) and can compose a high proportion of the rock succession in subaqueous volcanic depressions (Busby-Spera, 1985). Therefore, it seems unlikely that the volcanic deposits of the northwest segment of the Karaskuwigamak Block were deposited on the subaqueous flank(s) of a pyroclastic cone(s) or in a subaqueous volcanic depression. Although most deposits can be inferred to be subaerial, some may have been subaqueous.

The northwest segment of the Karsakuwigamak Block is a 3.4 km thick preserved volcanic sequence largely composed of pyroclastic material; the top and bottom of the sequences are not exposed. Thick successions of the felsic volcanic rocks comparable to those preserved in the northwest segment of the Karsakuwigamak Block represent either: 1) a tectonically emplaced fault block that preserved a segment of what was once an areally extensive felsic succession whose lateral equivalents in other fault blocks were removed by subsequent erosion or younger intrusion in, and on the margins of, the Rusty Lake metavolcanic belt, or 2) an aerally restricted felsic volcanic succession deposited in, and confined to, a volcanic or tectonic depression.

Fault Block Model

The stratigraphic succession in the northwest segment of the Karsakuwigamak Block contains numerous deposits at various levels of the succession that were apparently deposited proximal to volcanic vents. This is indicated by the presence of lava flows, block-and-ash flow ignimbrites, and in some tephra fallout deposits by rapid lateral decreases in bed thickness, deposit thickness and grain size. In addition, the great thickness of the succession suggests proximal deposition. Felsic lava flows are a common constituent of all three groups. Walker (1973) suggested that subaerial felsic flows rarely exceed 10 km in length. Block-and-ash flow ignimbrites, which occur in several formations also rarely exceed 10 km in travel distance (Fisher and Schmincke, 1984). Subaerial, hot tephra fall deposits formed from dense, low height eruptions, lapilli were deposited while still hot, and deposit thickness and grain size decrease rapidly over a lateral distance of 2.0 km. These features suggest deposition proximal to eruption site. Similarly the rapid decrease in particle size, bed thickness, and lithologic unit thickness over a lateral distance of 1.8 km in pyroclastic unit A tephra fallout deposit in conjunction with the 200 to 400 m accumulated thickness of this unit, suggest proximal deposition.

Ash-flow ignimbrites formed from Plinian eruptions and debris flow heterolithic breccia deposits are common in the Middle and Upper Group (Fig. 5). Ash flows and debris flows can have travel distances of up to 100 km (Crandell, 1971; Fisher and Schmincke, 1984; Smith, 1960; Wright et al., 1980), although ash flows generally travel farther than debris flows (Fisher and Schmincke, 1984). Thus, a large felsic volcanic centre can be circumscribed by deposits with a diameter of 200 km. Although many of the deposits in the Karsakuwigamak block are proximal, many other deposits should have extended a long distance beyond the present exposure.

In the Rusty Lake metavolcanic belt the maximum distance between Faults 1 and 2, which form the boundaries of the Karsakuwigamak Block, is 10 km (Fig. 2). Therefore, considering the thickness of the felsic volcanic sequence and the possible lateral extent of the products of a large felsic volcanic centre, more distal facies deposits should be exposed in the adjacent fault blocks if the Karsakuwigamak Block is a tectonically emplaced fault block of a once much more areally extensive felsic volcanic succession. The absence of such deposits in adjacent fault blocks suggests that the distribution of the felsic volcanic rocks was restricted. However, the possibility of a once much more areally extensive felsic succession cannot be ruled out because none of the adjacent fault blocks appear to fit together either stratigraphically or in facing directions (Fig. 2). This indicates considerable movement on faults. As well, the subvertical dip of the strata in all fault blocks indicates isoclinal folding. Thus a much more extensive felsic volcanic succession could have been removed from adjacent fault blocks by erosion and/or intrusion of later plutonic rocks in, and on the margins of, the Rusty Lake metavolcanic belt rocks with accidental preservation of the felsic volcanic succession in the Karsakuwigamak Block.

The felsic lava flows, ignimbrites, debris flows and sedimentary rocks in the Ruttan and Eastern blocks could be lateral equivalents of deposits in the northwest segment of the Karsakuwigamak Block. However, this seems unlikely because the abundance of these rocks in the adjacent fault blocks is low, and the upward change in volcanic processes observed in the northwest segment of the Karsakuwigamak Block is not reflected in the deposits of the adjacent fault blocks.

Although the existence of a once much more areally extensive felsic volcanic sequence is a possibility, deposition in a volcanic depression is more compatible with the preservation of the great thickness of largely subaerial deposits, limited erosion of these deposits, and upward changes in volcanic processes. The preservation of the thick largely subaerial succession and limited erosion not only points to deposition in a depression but also suggests concomitant subsidence and deposition.

Caldera Model

Calderas are volcanic collapse depressions with diameters many times greater than the diameter of any included vents from which associated pyroclastic rocks were extruded (Williams, 1941, 1942; Williams and McBirney, 1979). Most calderas apparently formed in areas in which there had been earlier volcanism (Lipman, 1984; Williams and McBirney, 1979). In subaerial calderas associated with felsic volcanism, collapse and thus caldera formation may occur simultaneously with ash-flow ignimbrite-forming eruptions; the ignimbrite-forming stage is commonly preceded and followed by extrusion of lava flows and/or domes (Henry and Price, 1984; Lipman, 1967; Ratté et al., 1984; Sparks et al., 1973; Varga and Smith, 1984). Post-collapse volcanism may continue from vents within calderas and the volcanic processes and magma composition may change upwards (Aramaki, 1984; Henry and Price, 1984; Hildreth, 1979; Lipman, 1984; Yoshida, 1984). Breccias from collapse of caldera walls and transport of dome breccia, sediments derived from erosion of caldera walls, and intracaldera pyroclastic rocks commonly contribute to the filling of the caldera (Henry and Price, 1984). Collapse is commonly a trapdoor mechanism and leads to differential subsidence (Henry and Price, 1984; Lipman, 1984); however, collapse of some calderas is apparently piston-like (Aramaki, 1984).

The stratigraphic succession in the northwest segment of the Karsakuwigamak Block has some features and stratigraphic sequences similar to those associated with caldera formation. These include, 1) a thick early accumulation of lava flows and monolithic breccia, 2) eruption of a thick ash-flow ignimbrite, 3) repeated eruptions of ash-flow ignimbrites, 4) repeated extrusion of lava flows, and 5) upward changes in composition and volcanic processes. On the other hand, several features that are common to calderas (Hildreth, 1979; Lipman, 1984; Smith, 1979) are apparently absent in the Karsakuwigamak Succession. These include, 1) compositional zonation in ash-flow ignimbrites, 2) caldera wall collapse breccias and sediments derived from intracaldera pyroclastic rocks, and 3) absence of welding in ignimbrites.

The oldest rocks in the northwest segment of the Karsakuwigamak Block comprise a 1.35 km thick sequence of lava flows, block-and-ash flow ignimbrites and lesser tephra fallout. This sequence probably represents precaldera volcanism because the lava flows are thicker than the associated ignimbrites. In documented calderas elsewhere, early caldera lava flows and ignimbrites are apparently about half the thickness of ignimbrites associated with collapse (Yoshida, 1984), but in the Karsakuwigamak Block, the early lava flows and ignimbrites are much thicker than the ash-flow ignimbrites which may be associated with collapse. However, early caldera lava flows and ignimbrites appear to be the least understood part of the calderas.

The first occurrence of a thick ash-flow ignimbrite occurs in pyroclastic unit B. The unit is 170 to 360 m thick, occurs as a sheet and is composed of numerous flow units. Thus, it is suggested that this unit is a caldera-fill ash-flow ignimbrite that was ponded in the caldera. The sheet-like geometry of the unit and the numerous flow units are similar to other caldera associated ash-flow ignimbrites (Smith, 1960). Intracaldera ash-flow tuffs are commonly much more than 200 m thick whereas extracaldera ash flow tuffs are commonly less than 200 m thick (Busby-Spera, 1984). Caldera-fill ignimbrites are typically welded (Smith, 1960). Welding textures and structures have not been positively identified in any of the Karsakuwigamak ignimbrites. However, pumice in pyroclastic unit B ignimbrites is elliptical and vesicles have not been observed in the pumice fragments. The features could be the result of welding or partial welding and associated vapour phase recrystallization.

Following the deposition of pyroclastic unit B the style of volcanism changed from Plinian to Vulcanian and Vulcanian breccias were deposited from debris flows. Volcanism ceased with extrusion of lava flows. Following the deposition of these lava flows, there was a hiatus in volcanism and a regolith developed at the surface of the lava flow sequence. Deposition of the flow was probably the end of a phase of caldera formation because extrusion of lava flows commonly occurs at that time (Elston, 1984; Lipman, 1967, 1984; Smith and Bailey, 1968). Pyroclastic unit B is thickest in the east suggesting subsidence in trapdoor fashion.

Thus, pyroclastic unit B probably signifies collapse of a volcanic substrate and deposition of caldera-filling ignimbrite. This caldera-forming phase closed with lava flow extrusion that was followed by a period of erosion and weathering.

Following the hiatus in volcanism and deposition after emplacement of lava flows, pyroclastic volcanism recommenced with eruptions that resulted in debris flow deposition followed by ash-flow ignimbrites interspersed with hot air fall deposits and extrusion of lava flows. This was followed by deposition of ash-flow ignimbrites, debris flows and lava flows that form a sequence that is much thicker in the east than in the west, suggesting differential subsidence in trapdoor fashion.

Following a second period of erosion and weathering after emplacement of flow unit E lava flows and pyroclastic unit E, renewed pyroclastic volcanism was dominated by formation of Vulcanian breccias that resulted in deposition of debris flow deposits with interspersed block-and-ash flow ignimbrites, ash-flow ignimbrites, lava flows, and debris flows composed of rounded volcanic material probably transported from a nearby highland or the caldera walls (Baldwin, 1987). The ash-flow ignimbrites in this sequence are very thin, and are probably unrelated to caldera subsidence, although the ash-flow ignimbrites in pyroclastic unit G are eroded and original thickness of the deposit is unknown. However, the ash-flow units in the pyroclastic unit are separated by co-ignimbrite ash-fall deposits suggesting slow accumulation.

The complex nature of the caldera fill following emplacement of pyroclastic unit B is not common in calderas associated with felsic volcanism unless some of the fill is from a source separate from the caldera and some of the felsic deposits are an integral part of caldera formation. Many of the deposits stratigraphically above pyroclastic unit B are proximal, primary volcanic deposits and thus probably resulted from intracaldera eruptions (Baldwin, 1987).

The magma from which the volcanic products were erupted may have been zoned from felsic composition at the top of the magma chamber to intermediate and mafic in the lower part of the chamber. In the volcanic succession there is considerable compositional variation from aphyric to phyric felsic rocks, as well as variations in the quartz and plagioclase contents of phyric rocks (Baldwin, 1987). These features may also be the result of compositional zonation in the magma chamber.

There is a sharp decrease in the phenocryst abundance of primary volcanic rocks following the deposition of some ignimbrites (Baldwin, 1987). In addition, the volcanic sequence emplaced following the deposition of pyroclastic unit C ignimbrites includes mafic to intermediate debris flows and aphyric to phenocryst-poor felsic primary volcanic rocks. These marked decreases in phenocryst abundance may be due to draining of the magma chamber during the ignimbrite-forming eruptions. The mafic volcanism that resulted in the mafic debris flows could have been a consequence of a drained magma chamber, following emplacement of these ignimbrites. The increase in the phenocryst abundance from the bottom to the top of the lower group may indicate there was an increase in the phenocryst abundance downwards in the magma chamber.

Caldera wall collapse breccias most commonly accumulate near caldera margins (Busby-Spera, 1984; Henry and Price, 1984). Proximal volcanic deposits occur at several stratigraphic levels in the Karsakuwigamak succession. Thus, the absence of recognized collapse breccias suggests that the preserved stratigraphic succession in the northwest segment of the Karsakuwigamak Block is a section through a part of the caldera that was close to the centre of the caldera, and the full lateral extent of the caldera is not preserved.

There is only limited evidence of erosion in the Karsakuwigamak succession. These are major unconformities. The absence of additional erosional surfaces and erosional products suggests that between these periods of major erosion the deposition of volcanic material was rapid. Two of the periods occur after deposition of a sequence of rocks that are similar to sequences associated with caldera subsidence (Baldwin, 1987). This suggests that periods of rapid subsidence were interspersed with periods of major deposition. During these depositional periods, accumulation of the caldera fill was apparently rapid, and thus there was little time for erosion of the pyroclastic deposits and accumulation of eroded products.

The attitude of the preserved section of volcanic rocks relative to that of the caldera is unknown and thus the limits of the caldera are unknown. Fault 1 (Fig. 2) truncates opposite-facing volcanic sequences in the Ruttan Block and displaces the boundaries between volcanic and plutonic rocks. In addition, neither caldera collapse breccias nor numerous normal and reverse faults are exposed in the stratigraphic sequence in the northwest segment of the Karsakuwigamak Block. Thus, it is more likely that Fault 1 is a late, regional, major fault rather than a reactivated caldera. Other than the differences in the distribution of lithologies in the Karsakuwigamak Block and the Eastern Block, the geological relationships of Fault 2 (Fig. 2) are unknown. The volcanic rocks to the southeast and east of Fault 4 (Fig. 2) are very poorly exposed and, as a result, the distribution of lithologies is largely unknown. However, the rocks in this part of the Karsakuwigamak Block include felsic lava flows, felsic heterolithic breccia that could be debris flows, and felsic monolithic lapilli-tuff that could be ignimbrites. Thus the felsic volcanic sequence in the Karsakuwigamak Block may have a lateral extent from Fault 1 to Fault 2. Therefore, it is possible that the caldera diameter was more than 10 km, the distance between the exposed sequence and Fault 2.

The fault block model cannot be dismissed as a possible explanation for the preservation of the felsic volcanic succession in the northwest segment of the Karsakuwigamak Block because of the complex geometrical relationships of the fault blocks in the Rusty Lake metavolcanic belt. However, preservation of such a thick, largely subaerial pyroclastic and flow succession and the occurrence of volcanic sequences that can be related to caldera formation support the caldera model rather than the fault block model.

ECONOMIC GEOLOGY

The reader is referred to Manitoba Department of Energy and Mines, Mineral Resources Division Open File Report OF81-4 (Baldwin, 1982) for the documentation of mineral occurrences in the map area.

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APPENDIX: TABLES 1 TO 11

Table 1.
Summary of Stratigraphy in Northern Block

Lithologic Units in Stratigraphic Order	Thickness (m)	Main Lithologic Features	Lateral and Vertical Variations
Greywacke, siliceous sulphide facies iron-formation	1600	*Greywacke* is fine- to medium-grained with minor siltstone interbeds. *Iron-formations* are 30 to 40 m thick, occur as two units in lower 400 m of the formation and comprise bedded quartz-rich sandstone, bedded chert with 5 to 35% pyrrhotite and minor pyrite and greywacke beds that locally contain 10 to 15% sulpide. Locally massive pyrrhotite zones a few metres thick are present.	Greywacke maintains uniform composition and texture laterally for about 30 km. Iron-formations exposed only in the west and can be traced laterally for 25 km by geophysical methods and have been encountered in diamond drill cores in the east.
Feldspathic greywacke, polymictic conglomerate	800 - 1600	*Feldspathic greywacke* forms medium grained and normally graded and massive beds. *Polymictic conglomerate* contains volcanic and plutonic pebbles and cobbles in a lithic sandstone matrix comprising volcanic, plutonic, quartz and plagioclase sand grains and granules and recrystallized granoblastic quartz, plagioclase, biotite and amphibole. 20 to 50% of the clasts are plutonic rock.	Formation thins westward, but can be traced for about 25 km laterally. Rock types are interbedded. Feldspathic greywacke becomes finer grained and thinner bedded upward but bed thickness also increases eastward. Conglomerate beds are thicker and coarser at the base of the unit and in the west. Upward and eastward they progressively thin, become finer grained and less abundant.
Polymictic volcanogenic conglomerate, sandstone and siltstone, mafic flows	3500	*Polymictic conglomerate* contains only volcanic material. Matrix is mafic to intermediate in composition and clasts have mafic, intermediate and felsic compositions. Clasts are commonly reversely to normally graded. *Sandstone* is medium- to fine-grained and organized into partial Bouma Cycles. It has mafic to intermediate compositions. *Siltstone* is thin bedded and commonly laminated. It has mafic to intermediate compositions. *Mafic flows* have pillowed and brecciated facies and locally 10 to 15 cm thick interflow tuff beds.	Base of formation is truncated by Fault 3, but upper parts of formation can be traced laterally for 25 km. Upward and eastward, bed thickness, clast size in, and abundance of conglomerate decrease; thickness of sandstone beds decreases but abundance increases; and the abundance of siltstone increases, but siltstone bed thickness remains constant. Primary structures in sandstone and siltstone include graded bedding, crossbedding (except in Bouma cycles), flame structures, rip-ups, load casts and soft sediment folding. Mafic flow sequences occur near the top and base of the formation and have a lateral extend of 3.5 to 5 km. They thin and change from a dominantly pillowed facies to dominantly brecciated facies eastward.

Table 2.
Summary of Stratigraphy in Ruttan Block (north domain)

Lithologic Units in Stratigraphic Order	Thickness (m)	Main Lithologic Features	Lateral and Vertical Variations
Mafic flows	0 to 2000	Aphyric to plagioclase- and hornblende-phyric. Massive, pillowed and brecciated facies with minor interflow tuff. Flow thickness ranges from 3 to 15 m. Thicker flows are dominantly flow breccia.	True thickness of unit is not known because the top is truncated by a granitic intrusion. Sparse outcrop prohibits documentation of lateral and vertical variations. Unit has a lateral extent of 9 km.
Volcanogenic conglomerate with minor sandstone and siltstone	150 to 400	*Conglomerate* is massive bedded; clasts are mainly felsic volcanic, up to cobble size, and locally display normal size grading. *Sandstone* is interbedded with conglomerate and comprises felsic volcanic sand grains and granules, and quartz and plagioclase sand grains. *Siltstone* is thin bedded to laminated and is greywacke to arkose in composition.	Unit occurs only in west part of the fault block. Conglomerate and interbedded sandstone form a central lens up to 400 m thick and 4 km long that is flanked on either end by siltstone wedges. Conglomerate beds fine and thin upwards in the upper half of the unit. Siltstone becomes more arkosic, thinner bedded and finer grained upward.
Felsic flows	100 to 325	Plagioclase-phyric to plagioclase- and sparsely quartz-phyric. Flows are largely massive and flow layered with minor fragmental facies.	Unit thins westward and can be traced for 5 km laterally.
Mafic flows	1200	Hornblende-phyric massive with minor breccia.	Unit present only in east part of fault block and is truncated to the west by an intrusion. Flow thicknesses are unknown and lateral and vertical variations are not known due to lack of outcrop.
Volcanogenic sandstone and minor volcanogenic polymictic conglomerate	200 to 700	*Sandstone* is arkose to greywacke in composition and contains felsic and mafic volcanic grains and granules and quartz and/or plagioclase sand grains. Beds are massive to normally graded and some have a thin siltstone cap. These latter beds display partial Bouma cycles. *Conglomerate* contains mafic to felsic volcanic pebbles to boulders in a greywacke matrix. Most beds have reverse coarse-tail grading.	Unit thins westward because of truncation by an intrusion. Conglomerate beds most abundant at base of the unit and they fine upward and eastward. Upper 500 m of the unit is entirely sandstone. Unit can be traced for 9 km laterally.
Mafic flows	0 to 700	Plagioclase- and hornblende-phyric and 3 to 10 m thick. They commonly have a lower massive zone, a middle brecciated zone and thin interflow tuff beds.	Unit thins westward but is laterally continuous for 7 km. The abundance of flow breccia increases upward and eastward. Flow subdivisions are better developed in the east and locally near the top of the unit in west where flows are all less than 4 m thick.
Volcanogenic polymictic conglomerate, volcanogenic greywacke	0 to 120	*Conglomerate* comprises mafic, intermediate and felsic volcanic pebbles to cobbles in a greywacke matrix. Most beds are massive but some have reverse coarse-tail grading. Beds are up to 25 m thick. *Greywacke* beds most commonly have normal grading and some have partial Bouma cycles. Forms units 30 to 75 m thick.	Unit occurs in west part of fault block and can be traced eastward for 2 km before wedging out. Conglomerate and greywacke are interbedded but greywacke increases in abundance eastward. Primary features in greywacke include rip-ups, scours, flame structures and load casts.

Table 2.
Summary of Stratigraphy in Ruttan Block (north domain) (continued)

Lithologic Units in Stratigraphic Order	Thickness (m)	Main Lithologic Features	Lateral and Vertical Variations
Siliceous siltstone, sandstone, minor chert	20 to 30	*Siltstone* is thin bedded to laminated and also commonly forms thin caps on sandstone beds. *Sandstone* is fine- to medium-grained, generally massive bedded but some beds are normally graded. Sandstone composition ranges from greywacke to arkose. Chert is massive bedded.	From east to west the quartz content in siltstone and sandstone increases and sandstone becomes finer grained. Unit is laterally continuous for 9 km, but chert is present only at the Ruttan Mine where it is laterally continuous for 1.5 km.
Massive sulphide "Ruttan Mine"	0 to 100	Coarse- to fine-grained pyrrhotite, pyrite, sphalerite and chalcopyrite.	Copper-zinc metal zoning. Lateral extent of 550 m.
Volcanogenic polymictic conglomerate	350 to 700	*Conglomerate* is felsic in composition, poorly bedded and beds are massive; felsic volcanic pebbles and cobbles in a greywacke matrix. Some beds also contain clasts with intermediate composition.	Appears to be laterally and vertically homogeneous; unit is thickest at Ruttan Mine and thins eastward and westward; can be traced laterally for 5.2 km; eastward it interdigitates with the underlying unit of mafic flows; westward it is truncated by a granitic pluton. Contains hydrothermal alteration zone to the Ruttan Mine.
Mafic flows	0 to 900	Aphyric, plagioclase- and hornblende-phyric. Massive, pillowed and brecciated facies with minor interflow tuff.	Unit is confined to the central part of fault block, has a lateral extent of 4 km and is truncated to the northeast by Fault 3 and to the west by a granitic pluton. Dominantly massive facies with an eastward increase in the abundance of flow breccia and tuff. In the east the unit includes abundant gabbroic and dioritic sills and dykes.

Table 3.
Summary of Stratigraphy in Ruttan Block (south domain)

Lithologic Units in Stratigraphic Order	Thickness (m)	Main Lithologic Features	Lateral and Vertical Variations
Mafic flows	250 to 450	Hornblende-phyric, massive and differentiated, with minor breccia and interflow tuff.	Unit thickness and lateral extent (3.5 km) are minimum values because the top of the unit is truncated by a pluton. No apparent lateral or vertical variations.
Siltstone, volcanogenic polymictic conglomerate	100	*Siltstone* is thin bedded to laminated and is arkosic in composition. *Conglomerate* contains felsic and intermediate volcanic clasts in a feldspathic greywacke matrix.	Unit is uniform in thickness, fines eastward and has a known lateral extent of 2.5 km.
Mafic flows	175 to 350	Aphyric to plagioclase- and hornblende-phyric. Massive, pillowed and brecciated facies.	Unit thins eastward, there are no apparent vertical or lateral facies changes and it can be traced laterally for 3.5 km.
Siltstone	0 to 200	Thin bedded to laminated and composed of a fine grained granular aggregate of plagioclase, quartz, biotite, muscovite and minor epidote.	Unit thins eastward and forms a lens 4.3 km long.
Felsic flows	200	Plagioclase-phyric to plagioclase- and sparsely quartz-phyric; massive.	Unit has a uniform thickness and appears to be uniform in composition and texture; can be traced laterally for 4 km.
Volcanogenic greywacke	0 to 250	Massive bedded, medium- to fine-grained.	Unit thins both eastward and westward and forms a lens 2 km long.
Mafic flows	100	Hornblende-phyric; massive.	No observed vertical or lateral variations; can be traced for 5 km.
Silicified greywacke and oxide-facies iron formation	50	*Silicified greywacke* contains sillimanite, anthophyllite, andalusite and staurolite. *Iron formation* is 1 to 2 m thick and comprises magnetite layers up to 20 cm thick interlayered with chert and siliceous greywacke.	Unit exposed sporadically for 1 km but can be traced laterally by geophysical techniques for 3.5 km.
Mafic flows	120 to 400	Hornblende-phyric, massive and differentiated with minor breccia and interflow tuff.	Unit thins eastward and westward, flows are thinner and more brecciated eastward and flow sequence can be traced laterally for 5.5 km.
Volcanogenic lithic greywacke and sandstone	300	*Lithic greywacke* is medium- to fine-grained, and massive bedded with mafic, intermediate and minor felsic volcanic grains and plagioclase crystal grains in a granular mosaic of plagioclase, biotite, amphibole and minor quartz. *Siltstone* is thin bedded to laminated and is composed of a fine grained granular mosaic of plagioclase, biotite and minor quartz.	Unit is uniform in thickness laterally, but siltstone beds thicken and increase in abundance eastward; can be traced laterally for 6 km.
Mafic flows	75 to 650	Hornblende-phyric, massive and differentiated, with minor flow breccia and interflow tuff.	Unit thins eastward, flows are thinner and more brecciated in the east and flow sequence can be traced laterally for 6 km.

Table 3.
Summary of Stratigraphy in Ruttan Block (south domain) (continued)

Lithologic Units in Stratigraphic Order	Thickness (m)	Main Lithologic Features	Lateral and Vertical Variations
Volcanogenic lithic greywacke and siltstone	200	*Lithic greywacke* is medium- to fine-grained and massive bedded with mafic and intermediate volcanic grains and plagioclase and quartz crystal grains in a granular mosaic of plagioclase, biotite, amphibole and minor quartz. *Siltstone* has greywacke composition and is thin bedded to laminated.	No apparent change in unit thickness laterally; siltstone beds thicken and increase in abundance eastward and unit can be traced laterally for 6 km.
Mafic flows	0 to 1500	Hornblende-phyric, massive and differentiated, with minor flow breccia and interflow tuff.	Unit thins eastward, flows thin and abundance of flow breccia increases westward; its base is truncated by intrusive rocks and flow sequence can be traced laterally for 5 km.

Table 4.
Summary of Stratigraphy in Eastern Block

Lithologic Units in Stratigraphic Order	Thickness (m)	Main Lithologic Features	Lateral and Vertical Variations
Mafic rocks	200	Plagioclase- and hornblende-phyric, massive, fine- to medium-grained, and sparsely amygdaloidal; local monolithic breccia.	Thickness is minimum because top of unit is truncated by Fault 3; no known vertical or lateral variations; unit can be traced laterally for 3 km. Probably extrusive origin.
Felsic flows	100 to 250	Plagioclase-phyric, massive and autoclastic breccia facies are layered and have the same composition and same phenocryst population. Flow layering occurs in the massive facies. Locally flow material appears to have intruded autoclastic breccia.	Unit thins westward, no known lateral or vertical variations and can be traced laterally for 3 km.
Mafic rocks	75 to 150	Plagioclase- and hornblende-phyric, massive and fine- to medium-grained.	Unit thins westward, has no known lateral or vertical variation and can be traced laterally for 3 km. Probably extrusive origin.
Volcanogenic polymictic pebble conglomerate	25 to 100	3 to 7 mm diameter, angular to subrounded, mafic to intermediate clasts in a fine-grained sandstone matrix of intermediate composition. Appears to be massive bedded.	Unit occurs in the east of the fault block and wedges out westward; no known lateral or vertical variation; can be traced laterally for 1.3 km.
Mafic rocks	475 to 900	Plagioclase- and hornblende-phyric, massive, fine- to medium-grained, and sparsely amygdaloidal.	Unit thins eastward, has no known lateral or vertical variation and can be traced laterally for 5 km. Probably extrusive origin.
Volcanogenic polymictic conglomerate	40	Unsorted; appears to be massive bedded and contains mafic, intermediate and felsic volcanic clasts that are subangular to rounded. Clasts are in a fine grained mafic sandstone matrix.	Occurs in the east part of the fault block, wedges out westward, has no known vertical or lateral variation and can be traced laterally for 2 km.
Felsic flows	100 to 225	Plagioclase-phyric, interlayered massive and autoclastic breccia facies that have the same composition and phenocryst content. Flow layering occurs in the massive facies. Locally massive flow material appears to have intruded autoclastic breccia.	Unit thins eastward, has no vertical or lateral variation and can be traced laterally for 5 km.
Mafic rocks	100 to 800	Plagioclase- and hornblende-phyric, generally massive but locally brecciated, fine- to medium-grained and locally amygdaloidal.	Unit thins westward, has no known vertical or lateral variation and can be traced laterally for 5 km. Probably extrusive origin.
Siltstone, volcanogenic polymictic conglomerate	260	*Siltstone* is thin bedded to laminated and has an intermediate composition. *Conglomerate* is unsorted, clasts are subangular to rounded and are felsic to intermediate in composition. Clasts are in a lithic sandstone matrix that has an intermediate composition.	Thickness remains constant, has no vertical or lateral variations and can be traced laterally for 5 km.
Mafic rocks	375	Plagioclase- and hornblende-phyric, massive and fine- to medium-grained.	Thickness is minimum because of lack of outcrop, has no known vertical or lateral variations and can be traced laterally for 5 km. Probably extrusive origin.

Table 5.
Summary of Stratigraphy in Northwest Segment of Karsakuwigamak Block

*Lithologic units in stratigraphic order	Thickness (m)	Lithology	Exposed Lateral Extent	Comments
		UPPER GROUP		
Pebble conglomerate, lithic greywacke, siltstone. (Mass sediment flows)	500 (min)	The sedimentary sequence comprises 50 to 60% conglomerate, 30 to 40% lithic greywacke and 10% siltstone. Bed sets of conglomerate are interlayered with bed sets of lithic greywacke. Siltstone occurs as fine grained tops on many lithic greywacke beds. *Conglomerate* is grey, with 20 to 35%, matrix-supported, rounded, non-vesicular, pebbles and cobbles of fine grained felsic, intermediate and rare mafic volcanic rock; clasts have phyric and aphyric texture. Conglomerate matrix is lithic greywacke. Beds range in thickness from 0.3 to 2 m and form bed sets 5 to 40 m thick. Beds are generally massive but some have coarse-tail grading. *Lithic greywacke* is light to medium grey and fine- to coarse-grained; it consists of 20 to 30% lithic grains, 5 to 10% of each plagioclase and quartz crystal grains and 50 to 70% matrix composed of a fine grained recrystallized aggregate comprising biotite, muscovite, plagioclase and quartz. Beds range in thickness from 15 to 50 cm and form bed sets 2 to 30 m thick. Beds are massive to normally graded and some have a well sorted, coarse grained basal zone 5 to 8 mm thick. *Siltstone* is dark grey and consists of a fine grained, recrystallized aggregate composed of 35% biotite and subequal amounts of muscovite, plagioclase and quartz. It forms 5 to 10 cm thick tops on many normally graded sandstone beds.	2.3 km	Base of formation is not exposed and top is truncated by younger intrusion in the west and is not exposed in the east. Upward conglomerate abundance and bed thickness decreases; lithic greywacke abundance increases and bed thickness decreases. From east to west there is no change in abundance of bed thickness of either conglomerate or lithic greywacke.
		Contact not exposed.		
Rhyolite tuff (co-ignimbrite ash fall)	0.15	*Rhyolite tuff* is white to buff, fine grained and normally graded. The unit comprises a 5 cm thick basal zone containing 25%, non-vesicular, aphyric, angular, rhyolite fragments, 0.25 to 3 mm in diameter and 7% euhedral and broken pyrogenic quartz and plagioclase crystals, 0.25 to 1 mm in diameter in a fine grained, recrystallized quartzofeldspathic aggregate. This is overlain by a 6 to 7 cm thick zone that contains 3 to 4% pyrogenic crystals in fine grained, recrystallized, quartzofeldspathic aggregate. The upper 4 cm of the unit consists of only quartzofeldspathic aggregate.	Exposed in only the east part of the formation where unit can be traced laterally for 150 m.	
		Contact is sharp to gradational.		
Rhyolite lapilli-tuff (ignimbrite)	3 to 4	*Rhyolite lapilli-tuff* is white buff and consists of 5 to 50% elliptical, 0.5 to 3 cm long pumice lapilli containing 2 to 3%, plagioclase phenocrysts, 1.5 to 2 mm long and 2%, quartz phenocrysts, 1 to 2 mm in diameter and, 7 to 10% of each plagioclase and quartz, euhedral and broken pyrogenic crystals in a fine grained, recrystallized, quartzofeldspathic aggregate. The lapilli-tuff also contains 5 to 10% angular, non-vesicular, aphyric, rhyolite fragments, 2 to 4 mm in diameter. Pumice lapilli are reversely to normally size graded; the largest lapilli are concentrated in a 15 to 20 cm thick zone, the top of which occurs about 55 to 60 cm from the top of the unit.	Exposed discontinuously for 225 m in east of formation and after a 1.5 km gap in outcrop unit is exposed discontinuously for 150 m in west of formation.	
		Sharp planar contact.		

Table 5.
Summary of Stratigraphy in Northwest Segment of Karsakuwigamak Block (continued)

*Lithologic units in stratigraphic order	Thickness (m)	Lithology	Exposed Lateral Extent	Comments
Rhyolite tuff (ground surge)	0.5 to 1.3	*Rhyolite tuff* is white to buff, very fine grained and is composed of 2 to 3 cm thick beds, some of which contain 2 to 4 mm thick laminations. Beds are composed of a very fine grained recrystallized, quartzofeldspathic aggregate, with or without, 0.25 to 0.5 mm plagioclase and quartz pyrogenic crystals; maximum pyrogenic crystal content is 5%. Bedding parallels unit boundaries; beds are generally planar but, some pinch and swell; and beds are defined by abrupt changes in colour and/or changes in the grain size of the recrystallized quartzofeldspathic aggregate. Laminations consist of 20%, angular, non-vesicular, rhyolite fragments, 0.25 to 1 mm in diameter, and 5 to 10%, plagioclase and quartz pyrogenic crystals, 0.25 to 0.5 mm in diameter in the recrystallized, quartzofeldspathic aggregate. Laminations are oblique to and truncated by bedding. In some beds, lenses with similar constituents as laminations, 3 to 10 cm in length, occur parallel or oblique to bedding; oblique lenses are not truncated by bedding.	Exposed only in east part of formation where it can be traced discontinuously for 150 m.	
		Sharp planar contact.		
Siltstone (lacustrine)	2.0	*Siltstone* is black, very fine to fine grained, recrystallized aggregate composed of 50% biotite and equal amounts of plagioclase and quartz; it consists of 1 to 4 cm thick beds that are internally laminated.	Exposed for 100 to 170 m in the east and west extremities of the formation.	
		Contact is sharp and conformable.		
Heterolithic volcanic breccia (debris flow)	6 to 20	*Heterolithic volcanic breccia* is buff to light grey and comprises 50%, felsic to intermediate, 2 mm to 25 cm diameter, volcanic fragments in a matrix consisting of 40% fine grained recrystallized plagioclase-quartz-mica aggregate, 35% felsic lithics and 25%, euhedral and broken plagioclase crystal grains. 80% of the fragment population is felsic, angular, equant to tabular, non-vesicular, aphyric, quartz- and plagioclase-phyric and plagioclase-phyric. The remaining fragments are felsic to intermediate, subrounded to rounded, non-vesicular to 20% vesicular, aphyric, quartz- and plagioclase-phyric and plagioclase-phyric; these fragments have a maximum size of 3 cm. The unit is a single, generally upward-fining bed that is reversely graded for 20 to 25 cm at the base; this is followed by a 2 to 8 m thick ungraded zone overlain by a normally graded zone. The long axis of tabular fragments is parallel to unit boundaries.	2.0 km	Unit thins westward; no lateral change in maximum fragment size, fragment abundance or fragment distribution within the unit.
		Sharp, planar, conformable contact.		
Lithic greywacke, siltstone, pebble conglomerate, pebbly sandstone (fluvial).	0 to 80	Unit consists of 80 to 90% lithic greywacke and minor interbedded siltstone, pebble conglomerate and pebbly sandstone, most of which occur in the upper 3 to 7 m of the unit. Pebble conglomerate also forms discrete dish-shaped lenses in the lower 15 m of the unit. *Lithic greywacke* is generally massive bedded and structureless but local 0.5 mm thick concentrations of mica define bedding planes. The rock comprises 35 to 40%, subrounded, equant to elliptical, 0.25 to 2.5 mm diameter, felsic volcanic fragments and, 10% combined, angular, euhedral and broken, and subrounded plagioclase and	2.0 km	Thickens westward because of thinning of massive lithic greywacke. The upper interbedded sequence does not change in the range of the thickness from east to west in the member.

Table 5.
Summary of Stratigraphy in Northwest Segment of Karsakuwigamak Block (continued)

*Lithologic units in stratigraphic order	Thickness (m)	Lithology	Exposed Lateral Extent	Comments
		quartz crystal grains, 0.25 to 1.5 mm in diameter in a 1/1 ratio, in a fine grained recrystallized aggregate composed of 65%, combined plagioclase and quartz, 25% biotite and 10% muscovite. *Siltstone* is buff to light grey, massive to thinly laminated and generally forms beds 5 to 40 cm thick but, locally is 1 m thick. It consists of a fine grained recrystallized aggregate similar in composition to the recrystallized aggregate in lithic greywacke. *Pebble conglomerate* differs from lithic greywacke in that most commonly 25 to 30% of the rock is composed of rounded pebbles of felsic volcanic rock that have a maximum size of 1 cm. Pebble conglomerate that forms the dish shaped lenses in lithic greywacke is composed of 60 to 70% subrounded to rounded, equant pebbles that are all 3 to 4 mm in diameter. The matrix is similar to but finer grained than lithic greywacke. *Pebbly sandstone* is similar to lithic greywacke but contains 5 to 15%, rounded, equant to elliptical, pebbles of felsic volcanic rock that have a maximum size of 1 cm. The lithic greywacke component of pebbly sandstone is finer grained than the generally massive lithic greywacke. In the upper 3 to 7 m of the member pebble conglomerate, pebbly sandstone and lithic greywacke form normally graded beds and massive beds, 7 to 13 cm thick. Massive pebbly sandstone or lithic greywacke fill scours in siltstone, and siltstone occupies scours in pebbly sandstone.		
		Erosional Unconformity.		
Massive, flow-layered and brecciated rhyolite and dacite (flows), rhyolite tuff (ignimbrites and co-ignimbrite ash fall).	50 to 220 (min)	Rhyolite and dacite flow sequence composed of 4 flow units is overlain by pyroclastic deposits. The pyroclastic deposits have an aggregate thickness of 10 m and consist of interlayered ignimbrite and co-ignimbrite ash falls. *Felsic flows* are rhyolite and dacite, range in thickness from 0 to 50 m and are massive or are composed of a massive zone with either or both flow layered zones and breccia zones. Massive rhyolite is composed of 0 to 3% plagioclase phenocrysts, 1 to 3 mm long and 1 to 4%, quartz phenocrysts 1 to 2 mm, across in a very fine grained recrystallized groundmass of plagioclase and quartz with minor muscovite and biotite and accessory apatite, zircon, epidote, carbonate and Fe-Ti oxide granules. Massive dacite is aphyric or contains 1 to 2% plagioclase phenocrysts, 1 to 3 mm long in a very fine grained recrystallized groundmass similar to the groundmass in rhyolite but biotite is more abundant than muscovite. Flow-layered zones are 1.5 m thick and consist of millimetre to centimetre thick layers of differing colour with or without 1 to 2 mm diameter spherulites. Breccia zones are 3 to 7 m thick and consist of an intact to disrupted framework of angular, blocks and lapilli of massive rhyolite or dacite, or a disrupted framework of subrounded to rounded and rarely subangular blocks and lapilli of rhyolite pumice in a matrix similar to the groundmass of the associated massive zones. Lapilli and blocks range from 0.2 to 25 cm across and compose 30 to 65% of the material in breccia zones. *Rhyolite tuff* is white to buff and consists of interlayered coarse- and fine-grained tuff that have an aggregate thickness of 10 m. Coarse grained tuff forms layers 4 to 4.5 m thick and consists of 15% pumice lapilli and 8 to 12% pyrogenic crystals in a fine-grained recrystallized, quartzofeldspathic aggregate. Pumice lapilli are elliptical, 5 to	Formation is exposed for 2.0 km. Upper 2 felsic flow units and pyroclastic rocks are exposed only in the east of the formation where they can be traced for 320 m.	Base of formation is truncated by a younger intrusion.

Table 5.
Summary of Stratigraphy in Northwest Segment of Karsakuwigamak Block (continued)

*Lithologic units in stratigraphic order	Thickness (m)	Lithology	Exposed Lateral Extent	Comments
		15 mm across and contain 2 to 4%, euhedral, plagioclase phenocrysts, 1 to 2 mm across and 2 to 4%, euhedral, quartz phenocrysts, 1 to 1.5 mm across. Pyrogenic crystals comprise 4 to 6%, euhedral and broken plagioclase, 0.25 to 2 mm across and 4 to 6%, euhedral and broken quartz, 0.25 to 1.5 mm across. The recrystallized, quartzofeldspathic aggregate consists of 90 to 95% combined plagioclase and quartz with minor muscovite, biotite, epidote and rare Fe-Ti oxide granules. Fine grained tuff forms layers 0.5 m thick that have sharp to gradational contacts with underlying coarse grained tuff but, sharp contacts with overlying coarse grained tuff. Fine grained tuff is composed of 2% combined pyrogenic crystals of plagioclase and quartz that are euhedral and broken and, range in size from 0.25 to 0.5 mm in a fine grained, recrystallized, quartzofeldspathic aggregate similar to that in coarse grained tuff.		
		Contact is largely a younger intrusion and elsewhere it is not observed.		
Heterolithic breccia, lithic greywacke, siltstone (debris flows).	190 to 450	Formation consists of 60% heterolithic breccia interbedded with 25% lithic greywacke and 15% siltstone. *Heterolithic breccia* is poorly stratified and consists of massive beds, 1 to 6 m thick. Beds comprise 40 to 50% mafic and intermediate volcanic fragments supported in a lithic greywacke matrix. Fragments are angular to subrounded, equant and rarely elliptical, largely non-vesicular, but some contain 30% vesicles and are 0.2 to 4 cm across. Fragments with mafic composition compose 75 to 90% of the fragment population and those with intermediate composition 10 to 20%. Mafic fragments are hornblende- and plagioclase-phyric and aphyric and intermediate fragments are plagioclase-phyric to aphyric. The matrix of heterolithic breccia comprises 50%, fine grained, recrystallized, hornblende-plagioclase aggregate; 40%, equant to elliptical, mafic and intermediate lithic fragments, 0.5 to 2 mm in diameter; 3 to 5%, euhedral plagioclase crystal grains, 1 to 3 mm across; and, 3 to 5%, barrel shaped, chlorite pseudomorphs after pyroxene crystal grains, 2 to 3 mm across. *Lithic greywacke* forms beds 20 to 60 cm thick that are generally massive but, some are normally graded; it is similar to the matrix in heterolithic breccia. *Siltstone* forms 5 to 7 cm thick beds and also forms fine grained tops on some lithic greywacke beds; it is similar to the recrystallized hornblende-plagioclase aggregate in the matrix of heterolithic breccia.	3.2 km	Lateral continuity of formation is interrupted by younger intrusion.
		Contact not exposed.		
Rhyolite lapilli-tuff (ignimbrite).	45 to 50	*Rhyolite lapilli-tuff* is salmon pink to white and consists of 5 to 40%, pumice lapilli, 0 to 10% lithic lapilli and 14 to 20%, pyrogenic crystals in a fine grained, recrystallized, quartzofeldspathic aggregate. Pumice lapilli are elliptical, non-vesicular, 0.5 to 3 cm across and contain 3%, quartz phenocrysts, 0.5 to 1.5 mm in diameter and 4%, plagioclase phenocrysts, 1 to 2 mm in diameter. Lithic lapilli are angular to subrounded, non-vesicular, aphyric and 0.5 to 1.5 mm across. Pyrogenic crystals are euhedral and broken and comprise 7 to 10%, quartz crystals, 0.25 to 1.5 mm across and 7 to 10% plagioclase crystals, 0.25 to 2 mm across. The recrystallized aggregate consists of 90 to 95%, plagioclase and quartz with minor muscovite, biotite,	500 m in east of formation	

Table 5.
Summary of Stratigraphy in Northwest Segment of Karsakuwigamak Block (continued)

*Lithologic units in stratigraphic order	Thickness (m)	Lithology	Exposed Lateral Extent	Comments
		epidote and rare Fe-Ti oxide granules. Pumice lapilli are reversely to normally graded and locally occur in pumice swarms in the upper 30 m of the unit. Lithic lapilli are normally graded and most abundant in lower 10 m of unit.		
		Younger intrusion separates members.		
Dacite tuff-breccia, lapilli-tuff (ignimbrite). Massive, flow-layered and brecciated dacite (flows).	0 to 200	Dacite tuff-breccia and lapilli-tuff are interlayered and compose 75% of the exposed rock in the member. Commonly tuff-breccia grades upward into lapilli-tuff forming layers 12 to 15 m thick in which lapilli-tuff forms one third the thickness of the layer. *Tuff-breccia* is light to medium grey, monolithic and forms layers 9 to 12 m thick. It consists of 40 to 60%, angular, non-vesicular aphyric, dacite fragments, 0.5 to 15 cm in diameter and 2 to 5%, angular, non-vesicular, dacite fragments, 0.2 to 0.5 m across that contain 1% plagioclase phenocryst in a fine grained, recrystallized, quartzofeldspathic aggregate comprising 85 to 90% plagioclase and quartz with minor biotite and rare muscovite, epidote, carbonate and Fe-Ti oxide granules. In tuff-breccia, block size material composes 30 to 50% of the rock and lapilli 5 to 20%. *Lapilli-tuff* is similar to tuff-breccia except block size material composes about 12 to 17% of the rock and lapilli 30 to 40%; it forms layers 3 to 5 m thick. *Dacite flows* consist of massive, flow-layered and brecciated material; the number of flows in the sequence is unknown. Massive zones range in thickness from 0 to 40 m and are composed of 1% plagioclase phenocrysts in a fine-grained recrystallized quartzofeldspathic aggregate comprising 85 to 90% plagioclase and quartz with minor biotite and rare muscovite, epidote, apatite and Fe oxide granules. Flow-layered zones are 0.3 to 2 m thick and consist of millimetre to centimetre thick layers of different colour and grain size of the recrystallized aggregate. Breccia zones are up to 10 m thick and consist of an intact to disrupted framework of 50 to 65%, angular to subrounded, blocks and lapilli and some rounded lapilli that range from 0.3 to 15 cm in diameter. Breccia fragments and matrix have the same texture and mineralogical composition as massive flow material. Breccia zones compose 10% of the sequence.	Pyroclastic rock exposed for 1.3 km. Flows exposed for 600 m.	Flows occur in the east of the member and the pyroclastic rocks are a westward stratigraphic equivalent of the flows. Flows and pyroclastic rocks are separated by an 800 m gap of no outcrop. Member is thinner in east than in west.
		Contact not exposed but in part is a younger intrusion.		
Heterolithic breccia (debris flow).	0 to 200	*Heterolithic breccia* is well stratified and consists of massive beds 0.7 to 2 m thick defined by sharp breaks in fragment abundance or by bed to bed variations in the abundance of different fragment types. The rock comprises 20 to 35%, mafic and intermediate fragments of volcanic rock supported in a siltstone matrix. Fragments are rounded to subrounded, equant, non-vesicular and 0.2 to 10 cm in diameter. Mafic fragments are aphyric and intermediate fragments are aphyric and hornblende- and plagioclase-phyric. In the breccia unit mafic and intermediate fragments are present in subequal amounts but, from bed to bed, mafic and intermediate fragments each make up from 30 to 70% of the fragment population; however, all fragment types are present in all beds. The matrix comprises 90%, fine-grained, recrystallized aggregate of plagioclase, hornblende, chlorite and quartz and 7%, equant to elliptical, mafic and intermediate fragments 0.5 to 2 mm in diameter and, 3%, rounded plagioclase crystal grains 0.5 to 1.5 mm in diameter.	1.1 km	Thins westward. This heterolithic breccia and the heterolithic breccia described immediately previous in the stratigraphic order are stratigraphically equivalent.
		Contact not exposed.		

Table 5.
Summary of Stratigraphy in Northwest Segment of Karsakuwigamak Block (continued)

*Lithologic units in stratigraphic order	Thickness (m)	Lithology	Exposed Lateral Extent	Comments
Heterolithic breccia, lithic greywacke, pebbly sandstone (debris flows).	0 to 375	Heterolithic breccia composes about 85% of the rock in the member. Lithic greywacke and pebbly sandstone are present in subequal amounts and are interbedded with heterolithic breccia. *Heterolithic breccia* forms reversely to normally graded beds, reversely graded beds and massive beds, 1 to 2.2 m thick. It is composed of 40 to 60% felsic and intermediate volcanic rock fragments in a lithic greywacke matrix. Felsic fragments are angular, equant to tabular, non-vesicular to rarely vesicular with 30% vesicles, plagioclase-phyric dacite, and aphyric to quartz- and plagioclase-phyric rhyolite, 0.2 to 20 cm across and compose 90% of the fragment population. Intermediate fragments are subrounded to rounded, elliptical, non-vesicular to 20% vesicles, aphyric and hornblende-phyric, 5 to 10 cm across, and compose 10% of the fragment population. The matrix comprises 70%, fine grained, recrystallized, plagioclase, quartz, muscovite, biotite aggregate and 25%, angular, equant, felsic fragments, 0.5 to 2 mm in diameter and, 5% euhedral and broken plagioclase crystal grains 0.5 to 2.5 mm across. *Lithic greywacke* forms massive beds, 5 to 15 cm thick and consists of 60 to 65% combined sand-size, felsic volcanic particles and plagioclase crystal grains and, 35 to 40% fine grained, recrystallized, plagioclase-quartz-biotite-muscovite aggregate. *Pebbly sandstone* is similar to lithic greywacke except it contains 10 to 15%, angular, felsic fragments 3 to 7 mm in diameter.	3.2 km	Thins eastward.
		Unconformity.		
		MIDDLE GROUP		
Massive and brecciated dacite (flows); dacite tuff (ignimbrite).	0 to 280	Massive and brecciated dacite compose 90% of the rock in the formation. Dacite tuff occurs between two massive dacite units in upper 75m of formation. *Dacite flows* are light grey to salmon pink, aphyric, non-vesicular and consist of massive and brecciated zones. Massive dacite and dacite breccia fragments consist of a very fine grained, recrystallized aggregate of plagioclase, quartz, biotite, muscovite, epidote, and carbonate, with accessory apatite and Fe-Ti oxide granules. Massive zones are 0 to 70 m thick. Breccia zones are 0 to 10 m thick and are a disrupted to intact framework of 40 to 65%, angular to subangular, equant blocks and subangular to subrounded lapilli, 0.3 to 30 cm in diameter, in a fine grained recrystallized matrix similar in composition to massive dacite, blocks and lapilli, and contain a few millimetre size fragments. Flow thicknesses are unknown except for the lowermost flow in the sequence; it is 0 to 80 m thick and comprises a lower 0 to 10 m thick breccia, a central 0 to 60 m thick massive zone and an upper 0 to 10 m thick breccia zone. *Dacite tuff* is light grey and forms a 3 to 7 m thick layer consisting of 0.5 to 2.5 m thick zones composed of pumice-bearing tuff that alternate with 0.1 to 0.5 m thick pumice-free zones. Pumice-bearing zones contain 10 to 15%, subrounded, aphyric, vesicular pumice (60% vesicles), 0.5 to 1 cm in diameter in a fine grained, recrystallized aggregate of plagioclase, quartz, biotite, and muscovite, with minor epidote and Fe-Ti oxide granules. Pumice-free zones are composed of the recrystallized	Formation and flows can be traced for 600 m; pyroclastic rock for a maximum of 100 m.	Formation occurs only in the east of northwest segment of Karsakuwigamak Block because of younger intrusion and unconformity. A regolith occurs at the top of the sequence.

Table 5.
Summary of Stratigraphy in Northwest Segment of Karsakuwigamak Block (continued)

*Lithologic units in stratigraphic order	Thickness (m)	Lithology	Exposed Lateral Extent	Comments
		aggregate. Contacts between the zones are generally gradational but, locally some are sharp.		
		Contact is in part a younger intrusion and in part an unconformity.		
Heterolithic breccia (debris flows).	0 to 310	*Heterolithic breccia* forms massive beds, 20 to 60 cm thick defined by bed to bed variation in fragment abundance. The breccia consists of 30 to 40%, mafic and intermediate fragments in a greywacke matrix. Fragments are angular to subrounded, equant, non-vesicular to containing 20 to 25% vesicles, aphyric, plagioclase-phyric and 0.2 to 1.5 cm in diameter. Intermediate fragments compose 60% of the fragment population and mafic fragments 40%. The matrix comprises 70% fine grained, recrystallized aggregate of hornblende and plagioclase and 15% of each angular to subrounded, mafic and intermediate fragments 0.5 to 2 mm in diameter.	1.3 km	Thins westward.
		Contact is for the most part planar and conformable but is locally unconformable.		
Rhyolite lapilli-tuff (ignimbrite and pumice falls).	0 to 170	*Rhyolite lapilli-tuff* is white to buff and is composed of two distinct lithological types based on abundance of pumice lapilli. Lapilli-tuff composed of 15 to 40%, subrounded, equant to elliptical, non-vesicular to vesicular (60% vesicles), pumice lapilli, 0.3 to 7 cm across and 3 to 10%, angular to subrounded, equant, non-vesicular, lithic fragments, 0.3 to 0.7 cm across and 4 to 10%, euhedral and broken pyrogenic quartz crystals, 0.25 to 2 mm across and, 3 to 7%, euhedral and broken pyrogenic plagioclase crystals, 0.25 to 3 mm across, in a fine grained, recrystallized, quartzofeldspathic aggregate, that form layers estimated to be 10 to 20 m thick, compose all but 30 cm of the member thickness. Pumice lapilli contain 3 to 5%, quartz phenocrysts, 0.5 to 2 mm across and 1 to 3%, plagioclase phenocrysts, 1 to 3 mm across. In the lower 100 m of the member pumice lapilli are non-vesicular and elliptical. Upwards the vesicularity increases to a maximum of 60% and the lapilli are equant. Boundaries between these lapilli-tuff layers are diffuse and layer thickness is estimated from changes in pumice abundance and lithic fragment distribution. Lithic fragments are normally graded whereas pumice is reversely to normally graded or ungraded; locally within layers pumice forms 0.5 to 1 m thick concentrations where pumice abundance increases rapidly but gradationally from 25 to 40%. The fine grained, recrystallized aggregate consists mainly of plagioclase and quartz with minor muscovite, biotite and lesser epidote, carbonate and Fe-Ti oxide granules. In the lower 85 m of the member there are two similar lapilli-tuff layers, 10 to 15 cm thick, that have sharp upper and lower boundaries. These lapilli-tuff layers are composed of 65 to 70%, elliptical, non-vesicular pumice lapilli, 4 to 7 cm long, and rare, angular, non-vesicular lithic fragments 0.5 to 1.5 mm across, and 4 to 5% combined, euhedral and broken quartz and plagioclase pyrogenic crystals, 0.25 to 1 mm across in a fine grained, recrystallized, quartzofeldspathic aggregate similar to that in thicker more abundant lapilli-tuff layers. Pumice lapilli contain 3 to 5%, quartz phenocrysts, 0.5 to 1 mm in diameter and 1 to 3% plagioclase phenocrysts, 1 mm in diameter. Pumice lapilli are densely packed but, are each separated by 3 to 4 mm of the recrystallized mosaic.	Member is exposed for 2.8 km laterally. The thin pumice-rich lapilli-tuff layers are only exposed in eastern most part of the member.	Member forms a westward gradually thickening sheet.
		Contact is sharp and planar.		

Table 5.
Summary of Stratigraphy in Northwest Segment of Karsakuwigamak Block (continued)

*Lithologic units in stratigraphic order	Thickness (m)	Lithology	Exposed Lateral Extent	Comments
Heterolithic breccia (debris flow).	0 to 3	Unit forms a single reversely to normally graded bed that has sharp upper and lower boundaries. *Heterolithic breccia* is very light grey to light pink and consists of 15 to 40%, largely angular, equant to tabular and lesser subrounded and elliptical, non-vesicular, plagioclase- and quartz-phyric and aphyric rhyolite fragments, 0.2 to 7 cm diameter, in a siltstone matrix comprising 80%, fine grained, recrystallized, mica-plagioclase-quartz aggregate, 10 to 15%, equant, sand-size rhyolite grains and 5 to 10% combined, euhedral and broken, plagioclase and quartz crystal grains, 0.5 to 2 mm across.	Exposed for 300 m of strike length in eastern part of Formation.	
		Contact is sharp and planar.		
Massive, flow-layered and brecciated dacite and, massive and brecciated rhyolite (flows).	0 to 70	Member consists of two flows of similar maximum thickness that are stratigraphic equivalents. *Dacite flow* is 0 to 70 m thick, light grey to pink, consists of aphyric, massive, flow layered and breccia zones. Massive dacite and breccia fragments are composed of a fine grained, recrystallized, aggregate of plagioclase and quartz with minor biotite and muscovite, accessory epidote, carbonate and apatite and, rare Fe-Ti oxide and Fe-sulphide granules. Flow-layered zones are similar to massive dacite but, flow layering is defined by slight color change reflecting variations in the grain size of the recrystallized aggregate. Breccia matrix is also a fine grained, recrystallized aggregate but, is coarser grained than the aggregate composing breccia fragments. The massive zone is 0 to 70 m thick and contains 1 to 5 m thick flow layered zones. The breccia zone occurs at the top of the flow, is 0 to 4 m thick and consists of a disrupted framework of 45 to 55%, angular to subangular blocks and lapilli, 0.3 to 10 cm in diameter. *Rhyolite flow* is white to light pink, 0 to 70 m thick and consists of a 0 to 70 m thick massive zone and a 70 m thick marginal breccia. Massive rhyolite and breccia fragments consist of 2 to 3% euhedral quartz phenocrysts and 3 to 4% euhedral and tabular plagioclase phenocrysts in a fine grained, recrystallized, aggregate of plagioclase and quartz with minor muscovite and biotite, accessory apatite and epidote and rare Fe-Ti oxide granules. Some blocks and lapilli contain a few, 1 to 2 mm, rounded structures occupied by a granoblastic mosaic of plagioclase and quartz. These structures are spherulites. Breccia matrix is similar in composition to massive rhyolite but is slightly coarser grained and contains a few 0.5 to 2 mm crystals of plagioclase and quartz and 1 to 2 mm rhyolite fragments.	Rhyolite flow is exposed for 300 m of strike length in extreme east of Member and the dacite flow has a lateral exposed extent of 2.2 km.	Variation in thickness is due to a younger intrusion in the east and west of the member as well as westward thinning of the dacite flow. The contact between the flows is not exposed.
		Contact not exposed but, parallel primary planar structures on either side suggest it is planar and probably conformable.		
Rhyolite lapilli-tuff and tuff (tephra-fall).	0 to 50	Bedded lapilli-tuff units composing 65% of the member are interlayered with bedded tuff units that compose 35% of the member. Lapilli-tuff and tuff units thin westward, as well, the maximum size of lapilli decreases from 10 cm to 5 mm in this same direction. Upwards in the member the maximum lapilli size decreases from 10 cm to 1 cm. Upwards in lapilli-tuff units the maximum lapilli size decreases from 10 cm to 1 cm. Upwards in lapilli-tuff units the maximum lapilli size decreases but the abundance can be normally or reversely graded.	2.0 km	Thins westward; eastward the unit is truncated by fault 4.

Table 5.
Summary of Stratigraphy in Northwest Segment of Karsakuwigamak Block (continued)

*Lithologic units in stratigraphic order	Thickness (m)	Lithology	Exposed Lateral Extent	Comments
		Rhyolite lapilli-tuff is light pink to greyish white and composes bedded units 1.15 to 18 m thick; bedding is not observed in outcrop but, on etched slabs, it is 5 to 15 cm thick. The rock is composed of 20 to 60%, oblate to spherical, concentrically layered lapilli, 0.2 to 10 cm long or in diameter and 3 to 11%, euhedral and broken, plagioclase pyrogenic crystals, 0.5 to 4 mm long and, 3 to 4%, euhedral and broken, quartz pyrogenic crystals, 0.25 to 2 mm across in a fine grained, recrystallized, quartzofeldspathic aggregate comprising 95% plagioclase and quartz in a 1/1 ratio and 5% combined muscovite, biotite, chlorite, Fe-oxide and pyrite. The lapilli are composed of a fine grained granoblastic mosaic of equal amounts of quartz, plagioclase and microcline, and rare flakes of muscovite, biotite and chlorite, rounded granules of Fe-oxide and euhedral pyrite and contain 0 to 6%, euhedral and broken, pyrogenic plagioclase crystals, 1 to 4 mm long and 0.7 to 3.3%, euhedral and broken, pyrogenic quartz crystals, 0.25 to 2 mm across. Concentric layering is defined by layers that have differing grain size of the quartz and feldspar granoblastic mosaic, as well as layers with similar mineralogy that have a fibrous texture and, layers and lunate-shaped lenses composed of polycrystalline quartz. In cross section the lapilli have features common to accretionary lapilli as well as spherulites and lithophysae. *Rhyolite tuff* is light pink to light grey and forms bedded units 1 to 1.75 m thick; beds are 3 to 10 cm thick. Tuff is composed of 97 to 98% fine grained recrystallized, quartzofeldspathic aggregate similar to that in lapilli-tuff and 2 to 3% combined, euhedral and broken, pyrogenic quartz and plagioclase crystals, 0.25 to 0.5 mm across. Bedding is defined by abrupt changes in colour.		
		Contact is planar and conformable.		
Rhyolite tuff (ignimbrite).	5 to 15	*Rhyolite tuff* is pale pink and consists of single tuff layer that is reversely to normally graded. The rock contains 5 to 30%, elliptical, non-vesicular pumice lapilli that contain 3%, quartz phenocrysts, 1 mm in diameter and 3%,plagioclase phenocrysts, 1 to 3 mm long and 5 to 7%, euhedral and broken, pyrogenic quartz crystals, 0.25 to 1 mm across and 5 to 7%, euhedral and broken, pyrogenic plagioclase crystals, 0.25 to 3 mm long, in a fine grained, recrystallized, quartzofeldspathic aggregate comprising 90 to 95% combined plagioclase and quartz and 5 to 10% combined muscovite, biotite, epidote, chlorite and rare Fe-Ti oxide granules. Pumice lapilli are reversely size and abundance graded in the lower 3 to 10 m of the tuff layer and normally size and abundance graded in the upper 2 to 5 m.	2.0 km	Thins westward. Eastward the unit is truncated by fault 4.
		Contact is planar and conformable.		
Rhyolite lapilli-tuff and tuff (tephra falls).	0 to 30	Member consists of 60%, bedded lapilli-tuff units interlayered with 40%, bedded tuff layers. Lapilli-tuff and tuff units thin westward. Maximum lapilli size decreases from 1.0 to 0.5 cm westward and upward in the member. In lapilli-tuff units, lapilli are normally size graded but, are both normally and reversely abundance graded. *Rhyolite lapilli-tuff* is light grey to white and composes bedded units 10 to 75 cm thick; beds are 5 to 15 cm thick on etched slabs but, beds are not observed in outcrop. The rock comprises 30 to 40% oblate, concentrically layered lapilli, 0.5 to 1 cm long and 7 to 10% combined, broken and euhedral, plagioclase and quartz	2.0 km	Thins westward. Eastward the unit is truncated by fault 4.

Table 5.
Summary of Stratigraphy in Northwest Segment of Karsakuwigamak Block (continued)

*Lithologic units in stratigraphic order	Thickness (m)	Lithology	Exposed Lateral Extent	Comments
		pyrogenic crystals in a 1/1 ratio, in a fine grained, recrystallized quartzofeldspathic aggregate composed of 90% plagioclase and quartz in a 1/1 ratio and 10% combined muscovite, biotite, chlorite and Fe-Ti oxide granules; pyrogenic quartz crystals are 0.25 to 1.5 mm across and pyrogenic plagioclase crystals are 0.25 to 4 mm across. The lapilli are composed of a fine grained, granoblastic mosaic of equal amounts of quartz, plagioclase and microcline and, rare flakes of muscovite, biotite and chlorite and, contain 3 to 4% combined, euhedral and broken pyrogenic crystals of quartz 0.25 to 1.5 mm across, and plagioclase 0.25 to 4 mm across. Concentric layering is defined by layers that have differing grain size of the quartz and feldspar granoblastic mosaic, as well as layers with similar mineralogy that have a fibrous texture, and layers and lunate-shaped lenses of polycrystalline quartz. In cross-section the lapilli have features common to accretionary lapilli as well as spherulites and lithophysae. *Rhyolite tuff* is light grey to white and forms bedded units 10 to 50 cm thick comprising beds 3 to 10 cm thick. The rock is composed of 97 to 98% fine grained, recrystallized, quartzofledspathic aggregate similar to that in lapilli-tuff and 2 to 3% combined pyrogenic crystals of quartz, 0.25 to 0.5 mm across, and plagioclase, 0.25 to 1 mm across. Bedding is defined by abrupt colour change and locally by variations in the grain size of the quartzofeldspathic aggregate.		
		Contact is planar and conformable		
Dacite tuff (ignimbrite).	27 to 60	*Dacite tuff* is light grey to white and consists of a single layer in which pumice lapilli are reversely size and abundance graded in the lower 10 to 35 m, and ungraded in the upper 17 to 25 m; the boundary between graded and ungraded zone is gradational. The rock consists of 5 to 20%, subrounded, equant, vesicular (60 to 70%), pumice lapilli, 1 to 7 cm in diameter, containing 1 to 2% combined, plagioclase phenocrysts, 1 to 2.5 mm in diameter, and quartz phenocrysts 1 mm in diameter, and 7%, angular, equant, non-vesicular, felsic, lithic fragments, 0.5 to 3 cm in diameter and, 1 to 2% of each plagioclase and quartz pyrogenic crystals, 0.25 to 2.5 mm and 0.25 to 1 mm in diameter respectively, in a fine grained, recrystallized, quartzofeldspathic aggregate composed largely of plagioclase and quartz, and lesser biotite, muscovite, epidote and rare Fe-Ti oxide granules.	700 m	Thins westward. Eastward the unit is truncated by fault 4.
		Contact is planar and conformable.		
Heterolithic breccia and pebbly sandstone (debris flows).	0 to 100	Two bedded heterolithic breccia sequences separated by pebbly sandstone. Pebbly sandstone also occurs at the top of the member. *Heterolithic breccia* is light-grey to buff, composed of volcanic material, forms reversely to normally and ungraded to normally graded beds, 0.2 to 5.5 m thick, that compose 95% of the rock in the member. All breccia beds have a basal sandstone zone that is between 2 to 8 cm in thickness. The rock consists of 35% felsic volcanic fragments, 0.2 to 20 cm in diameter, supported in a feldspathic greywacke matrix that composes 65% of the rock, comprising 69%, fine grained, recrystallized aggregate of quartz, plagioclase, muscovite and biotite, and 15%, equant, felsic rock fragments, 0.5 to 2 mm in diameter and, 16% combined, euhedral and broken	Discontinuous for 2.8 km	Thins westward. Eastward the unit is truncated by fault 4.

Table 5.
Summary of Stratigraphy in Northwest Segment of Karsakuwigamak Block (continued)

*Lithologic units in stratigraphic order	Thickness (m)	Lithology	Exposed Lateral Extent	Comments
		plagioclase and quartz crystal grains in equal amounts that are 0.5 to 3 mm in diameter. The felsic volcanic fragment population includes; 60%, largely angular to lesser rounded, equant to tabular and rarely elliptical, non-vesicular to poorly vesicular, plagioclase-phyric dacite; 20%, angular, equant to tabular, non-vesicular aphyric, felsic fragments that are probably dacite; and, 20%, angular to subrounded, equant to tabular, non-vesicular to poorly vesicular, plagioclase- and quartz-phyric rhyolite that have a maximum size of 10 cm. *Pebbly sandstone* is light-grey, composed of volcanic material, forms normally graded beds, 8 to 13 cm thick and composes 5% of the rock in the member. It comprises 10%, angular, equant, non-vesicular, felsic volcanic fragments, 0.5 to 2.5 cm in diameter and 7 to 10% of each plagioclase and quartz crystal grains 0.5 to 3 mm in diameter, in a fine grained, recrystallized aggregate similar to that in the heterolithic breccia matrix.		
		Unconformity		
Massive, flow-layered and brecciated dacite (flows).	80 to 300	Interlayered sequence of massive and brecciated dacite zones; flow-layered zones are contained in massive dacite. Breccia zones compose 20% of the rock in the member and 80% is composed of massive plus flow layered dacite. Contacts between massive and brecciated dacite are poorly exposed to unexposed thus the number and thickness of flow units is unknown. However, based on distribution of massive and brecciated dacite, flow thickness is estimated to be 50 to 100 m. *Massive dacite* consists of 2 to 3%, euhedral, equant to tabular plagioclase phenocrysts in a groundmass comprising a fine-grained, recrystallized aggregate of 85 to 90% plagioclase and quartz and 10 to 15% combined biotite, muscovite, chlorite, epidote, carbonate and Fe-Ti oxide granules. *Flow-layered* dacite occurs in massive dacite and consists of millimetre to centimetre thick layers with differing colour and differing grain size of the groundmass that form zones 20 to 50 cm thick. Massive plus flow-layered zones form layers 50 to 100 m thick. *Brecciated dacite* consists of 50 to 60%, angular to subrounded and rarely rounded, equant, blocks and lapilli, 0.3 to 40 cm in diameter that are mineralogically the same as massive dacite, in a matrix similar to but coarser grained than the recrystallized groundmass of breccia fragments. Breccia zones have a disrupted to locally intact framework texture and are up to 20 m thick. At the very top of the member there are 0 to 4 m of black, magnetite-rich fine grained rock that contains rounded to subrounded, lapilli, and blocks of jointed dacite that have an internal concentric layering and/or show various degress of progressive alteration from dacite to the black, fine grained, magnetite-rich rock. This zone is considered to be a regolith.	3.7 km	Thickest in west; thins toward central part of member and thickens eastward. In the east the upper surface of the member is uneven and locally has 60 m relief. In the east the member is truncated by fault 4.
		Contact is not exposed.		

Table 5.
Summary of Stratigraphy in Northwest Segment of Karsakuwigamak Block (continued)

*Lithologic units in stratigraphic order	Thickness (m)	Lithology	Exposed Lateral Extent	Comments
Heterolithic breccia (debris flows).	0 to 60	*Heterolithic breccia* is light grey to pale pink, composed of volcanic material and forms a bedded sequence in which bed thickness ranges from 0.6 to 5 m. Beds are generally massive and have a disrupted framework texture but, some are reversely to normally graded. The rock consists of 40 to 60%, angular to subrounded, equant, non-vesicular felsic volcanic fragments, 0.2 to 20 cm in diameter, in a lithic greywacke matrix composed of 40%, fine grained, recrystallized plagioclase, quartz, muscovite, biotite aggregate, 40%, angular, equant, felsic volcanic fragments, 0.25 to 2 mm in diameter and, 20% combined, euhedral and broken, plagioclase and quartz crystal grains in equal amounts, 0.25 to 2 mm in diameter. The felsic volcanic fragment population includes: 50%, plagioclase-phyric, non-vesicular dacite that are largely angular; 25%, aphyric, non-vesicular dacite with angular to subrounded shapes present in equal amounts; and 25%, quartz- and plagioclase-phyric, non-vesicular rhyolite with angular and subrounded shapes present in equal amounts. At the base of the heterolithic breccia unit there are laterally separated, 2 to 3 m thick, 30 to 50 m long lenses comprising 50 to 60%, subrounded to rounded, dacite and rhyolite fragments, 20 to 60 cm in diameter, in a matrix similar to that in the overlying breccia beds. Fragments in the lenses show vertical coarse tail grading and locally the rock has an intact framework texture.	1.8 km	Thicker in central part of member and thins east and west.
		Contact is sharp and planar where exposed.		
		LOWER GROUP		
Dacite lapilli-tuff and tuff (ignimbrite and tephra fall).	4 to 7	Member consists of a lower 2 to 5 m thick unit comprising interbedded lapilli-tuff and tuff in which bed thicknesses range from 5 to 30 cm and lapilli are normally graded and, an upper lapilli-tuff unit 2 m thick that has a homogeneous distribution of lapilli. *Dacite lapilli-tuff* in the upper lapilli-tuff unit consists of 45 to 50%, subrounded, 0.3 to 4 cm diameter pumice lapilli with 50% vesicles and contains 5%, plagioclase phenocrysts, 1 to 1.5 mm in diameter, and 5 to 10%, subangular, non-vesicular, aphyric, lithic fragments, 0.3 to 1 cm in diameter and, 10 to 15%, euhedral and broken, plagioclase pyrogenic crystals 0.25 to 1.5 mm in diameter, in a fine grained, recrystallized, quartzofeldspathic aggregate composed largely of plagioclase and quartz with minor biotite and muscovite and accessory epidote, carbonate, apatite and Fe-Ti oxide granules. *Dacite lapilli-tuff* in the lower unit consists of 20 to 60%, circular to elliptical, non-vesicular, concentrically layered lapilli, 2 to 5 mm in diameter containing a few 0.25 to 2 mm diameter, euhedral and broken plagioclase crystal grains and, 5 to 10%, euhedral and broken, pyrogenic plagioclase crystals, in a fine grained recrystallized, quartzofeldspathic aggregate consisting of 95% plagioclase and quartz in subequal amounts, and subequal amounts of biotite and sericite and, rare Fe-Ti oxide granules. The rock forms beds 5 to 30 cm thick. Lapilli have features common with accretionary lapilli. *Dacite tuff* generally consists of 3 to 5%, euhedral and broken, pyrogenic plagioclase crystals, 0.25 to 2 mm in diameter and 95 to 97% fine grained, recrystallized, quartzofeldspathic aggregate similar to that in lapilli-tuff. Some beds contain 10% pyrogenic crystals and some are devoid of these crystals. Parallel laminations 1 to 3	Both units exposed for 1.0 km	The lower, interbedded lapilli-tuff and tuff unit thins westward. Eastward the member is truncated by fault 4.

Table 5.
Summary of Stratigraphy in Northwest Segment of Karsakuwigamak Block (continued)

*Lithologic units in stratigraphic order	Thickness (m)	Lithology	Exposed Lateral Extent	Comments
		mm thick are also defined by abrupt changes in pyrogenic crystal content. Tuff beds are 8 to 10 cm thick.		
		Contact is sharp, planar and conformable.		
Dacite lapilli-tuff (ignimbrite, tephra fall).	23.3	Member consists of two distinctly different lapilli-tuff units in sharp and conformable contact. The lower unit is 20 to 30 cm thick and contains a greater abundance of and larger lapilli than the upper 23 m thick unit. *Dacite lapilli-tuff* in the upper unit comprises 30 to 45%, elliptical, poorly vesicular (5 to 10%), pumice lapilli, 0.3 to 1 cm across that contain 5%, plagioclase phenocrysts 1 to 2 mm in diameter, and 5 to 7%, angular, non-vesicular, lithic fragments, 2 to 5 mm in diameter and, 10%, euhedral and broken, plagioclase pyrogenic crystals, 0.25 to 2 mm in diameter, in a fine grained, recrystallized, quartzofeldspathic aggregate comprising largely plagioclase and quartz and minor biotite, muscovite, epidote and rare Fe-Ti oxide granules and chlorite. Lithic fragments are most abundant in the lower 5 m of the unit and pumice and pyrogenic crystals are uniformly distributed. *Dacite lapilli-tuff* in the lower unit comprises 45 to 60%, angular to subrounded, polygonal, equant to tabular, plagioclase-phyric, non-vesicular, dacite fragments, 0.1 to 24 cm across that contain 2 to 3%, plagioclase phenocrysts 2 to 3 mm in diameter, and rare 1 to 2 mm, plagioclase crystal grains, in a fine grained, recrystallized, quartzofeldspathic aggregate consisting of 80 to 90% plagioclase and quartz in a 2/1 ratio and 10 to 20%, submillimetre, angular, lithic fragments. Although lapilli and blocks compose 45 to 60% of the rock, lapilli form 75% of this population. In the easternmost outcrops, lapilli are normally graded and blocks have a maximum size of 24 cm and are randomly distributed. In the western outcrops lapilli are the same size and have the same distribution as in the east but, blocks are rare and have a maximum size of 8 cm.	1.8 km	Eastward the member is truncated by fault 4.
		Contact is sharp, planar and conformable.		
Dacite lapilli-tuff (ignimbrite).	150 to 350	Thick accumulation of lapilli-tuff in which there are few sharp boundaries between lapilli-tuff units. Locally variations in lapilli abundance define a crude stratification on a scale of 1 to 25 m. As well, there are local 20 to 50 cm thick concentrations of lapilli. *Dacite lapilli-tuff* is pale pink to greyish white and consists of 15 to 30%, elliptical, non-vesicular, pumice lapilli, 0.4 to 5 cm across that contain 2 to 5%, plagioclase phenocrysts, 2 to 3 mm in diameter, and 5 to 10%, angular to subangular, non-vesicular, lithic fragments, 0.3 to 3 cm across that contain 2 to 3%, plagioclase phenocrysts, 2 to 3 mm in diameter, and 5%, angular, non-vesicular, aphyric, lithic fragments, 0.3 to 3 cm in diameter and, 2 to 13%, euhedral and broken, plagioclase pyrogenic crystals 0.25 to 3 mm in diameter, in a fine grained recrystallized, quartzofeldspathic aggregate comprising 85 to 90% plagioclase and quartz in a 2/1 ratio and lesser biotite, muscovite, epidote and rare carbonate and Fe-Ti oxide granules.	4 km	Thins westward; eastward it is truncated by fault 4.
		Contact unexposed.		

Table 5.
Summary of Stratigraphy in Northwest Segment of Karsakuwigamak Block (continued)

*Lithologic units in stratigraphic order	Thickness (m)	Lithology	Exposed Lateral Extent	Comments
Massive, flow-layered and brecciated dacite (flows); dacite tuff-breccia, lapilli-tuff and tuff (ignimbrite).	200 to 400	Interlayered sequence of 25% massive plus flow-layered and brecciated dacite and, 75% dacite pyroclastic rocks; pyroclastic rocks also overlie massive and brecciated dacite. Massive, flow-layered and brecciated dacite form three flow units ranging in thickness from 0 to 240 m. One flow is composed of only massive dacite containing flow-layered zones and two flows consist of a massive core enveloped by breccia. Brecciated dacite composes 0 to 55% of flow thickness. Tuff-breccia grades upwards into lapilli-tuff forming flow units 14 to 35 m thick that have sharp upper and lower boundaries. Locally tuff overlies lapilli-tuff with a sharp to gradational contact. Where tuff-breccia overlies tuff the contact is always sharp. In pyroclastic flow units, tuff-breccia forms 75 to 80% and lapilli-tuff 20 to 25% of the unit thickness. Tuff layers are rare and compose 0.5 to 1% of the thickness of the unit that they occur in. *Massive dacite* consists of 0 to 3%, plagioclase phenocrysts in a groundmass of fine grained, recrystallized, quartzofeldspathic aggregate comprising 90% plagioclase and quartz in about a 2/1 ratio and 10% combined biotite, muscovite, epidote and rare chlorite and Fe-Ti oxide granules. Massive dacite, including flow-layered, dacite forms layers 0 to 125 m thick. *Flow-layered dacite* is similar to massive dacite but, is defined by millimetre to centimetre thick colour bands that form zones 0.5 to 2 m thick in massive dacite. *Brecciated dacite* consists of 40 to 60%, angular to subrounded blocks and subrounded lapilli of massive dacite, 0.3 to 20 cm in diameter, in a matrix consisting of a fine grained, recrystallized, quartzofeldspathic aggregate similar to but, coarser grained than the groundmass of massive dacite, and contains a few 0.5 to 1.5 mm plagioclase crystals. Breccia zones are 0 to 100 m thick and envelop two of the three flows in the sequence. Adjacent to massive dacite, brecciated dacite has an intact framework and is composed largely of blocks; this grades outwards into a disrupted framework composed of blocks and lapilli. *Dacite tuff-breccia and lapilli-tuff* are compositionally similar and differ only in thickness and the proportions of block- and lapilli-sized fragments. The rocks are composed of 30 to 65%, angular to subangular, non-vesicular 0.5 to 15 cm diameter, dacite fragments that contain 2 to 3%, plagioclase phenocrysts, 1 to 2 mm in diameter, and 5%, angular, aphyric, non-vesicular, lithic fragments, 0.5 to 3 cm in diameter and, 2 to 3%, plagioclase crystals, 1 to 2 mm in diameter, in a fine grained, recrystallized, quartzofeldspathic aggregate comprising 85 to 90% plagioclase and quartz and 10 to 15% combined biotite, muscovite and minor epidote, carbonate and Fe-Ti oxide granules. Tuff-breccia layers are 5 to 25 m thick and lapilli-tuff layers are 2 to 10 m thick. *Dacite tuff* is similar to the fine grained, recrystallized aggregate in tuff-breccia and lapilli-tuff and contains 2 to 3%, plagioclase crystals, 1 to 2 mm in diameter and, rare angular, non-vesicular, dacite fragments, 0.5 to 1 cm in diameter, some of which contain a few plagioclase phenocrysts 1 to 2 mm in diameter. Tuff layers are 5 to 30 cm thick and always occur in sharp to gradational contact with lapilli-tuff.	Formation and pyroclastic rocks exposed for 3.0 km. Flows exposed for 1.9 km in central and east part of formation.	Formation is truncated in the west and east by younger intrusions. Flows most abundant in west and central part of formation and thin eastward. Eastward, pyroclastic rocks increase in abundance and in east compose total thickness of the formation. Pyroclastic flow units thin eastward.

Contact not exposed.

Table 5.
Summary of Stratigraphy in Northwest Segment of Karsakuwigamak Block (continued)

*Lithologic units in stratigraphic order	Thickness (m)	Lithology	Exposed Lateral Extent	Comments
Dacite lapilli-tuff and tuff (tephra fall).	200 to 400	Interlayered sequence composed of 55% lapilli-tuff that forms bedded units 5 to 27 m thick consisting of 0.15 to 5 m thick beds, and 45% tuff that forms bedded units 0 to 60 m thick consisting of 0.03 to 1.2 m thick beds. Contacts between lapilli-tuff and tuff units are sharp and bedding planes within units are sharp and defined by abrupt changes in abundances and/or sizes of rock components. *Dacite lapilli-tuff* is pale pink to white and consists of 35 to 65%, angular, blocky to serrate, equant to tabular, non-vesicular to poorly vesicular (1 to 2% vesicles), dacite fragments, 0.01 to 1.7 cm in diameter, some of which contain 2 to 4%, combined, plagioclase and quartz phenocrysts, 2 mm in diameter, and 2 to 3% combined, euhedral and broken, pyrogenic plagioclase and quartz crystals in a fine grained, recrystallized, quartzofeldspathic aggregate consisting almost entirely of plagioclase and quartz and minor biotite, muscovite and Fe-Ti oxide granules. *Dacite tuff* is pale pink to white and consists of 10 to 50%, angular, blocky and serrate, equant to tabular, non-vesicular, aphyric, dacite fragments 0.1 to 5 mm in diameter, and 2 to 5% combined euhedral and broken, pyrogenic plagioclase and quartz crystals, 0.5 to 2 mm in diameter, in a fine grained, recrystallized quartzofeld-spathic aggregate similar to that in lapilli-tuff.	1.8 km	East and west boundaries are younger intrusions. From west to east and from bottom to top the abundance of lapilli-tuff decreases and tuff increases. Formation thickens eastward but, lapilli-tuff unit thickness decreases and tuff unit thickness increases in this direction.
		Contact observed at only one locality and here it is sharp, planar and appears to be conformable.		
Dacite lapilli-tuff and tuff (ignim-brite).	0 to 375	Interlayered sequence composed of 70 to 80% lapilli-tuff and 20 to 30% tuff. Lapilli-tuff zones 12 to 20 m thick grade upward into tuff zones about 5 m thick and together they form flow units 17 to 25 m thick that where exposed have sharp upper and lower contacts. Some lapilli-tuff zones have coarse-tail grading from bottom to top of the zone. *Dacite lapilli-tuff and tuff* are compositionally similar and differ in thickness and in the abundance of lapilli-size fragments. The rocks are light grey and consist of 20 to 40%, angular to subrounded, non-vesicular to poorly vesicular (1 to 2% vesicles), aphyric fragments, 0.2 to 5 cm in diameter, in a fine grained, recrystallized aggre-gate of mainly plagioclase and quartz and minor biotite, muscovite, epidote and Fe-Ti oxide granules. In tuff zones lapilli-size fragments have a maximum diameter of 1.5 cm.	1.0 km	Member thins eastward. Eastward and westward the member is truncated by younger intrusions.
		Contact not exposed.		
Massive and brecciated dacite (flows).	175 to 274	Massive dacite forms 90 to 95% of the rock in the member and brecciated dacite 5 to 10%. Massive zones range in thickness from 70 to 90 m and breccia zones from 0 to 6 m. Flow thickness is unknown but, it is estimated to be 75 to 100 m. *Massive dacite* is grey, aphyric and consists of a fine grained, recrystallized, quartzofeldspathic aggregate of 90% plagioclase and quartz and 10% combined biotite, muscovite, epidote and minor Fe-Ti oxide granules. *Brecciated dacite* is grey and consists of 45 to 50%, angular to subrounded, and rare rounded, aphyric, blocks and lapilli of massive dacite, 0.3 to 15 cm in diameter that form a disrupted framework in a matrix that is compositionally similar to but, coarser grained than massive dacite.	1.4 km	Member thins westward. Eastward and westward the member is truncated by younger intrusions.
		Contact not exposed.		

Table 5.
Summary of Stratigraphy in Northwest Segment of Karsakuwigamak Block (continued)

*Lithologic units in stratigraphic order	Thickness (m)	Lithology	Exposed Lateral Extent	Comments
Massive, flow-layered and brecciated rhyolite and dacite (flows).	210 to 440	Formation consists of 60% rhyolite that forms two flows and 40% dacite that forms one flow. Rhyolite flows are 0 to 180 m thick; one of these is composed only of massive plus flow-layered rhyolite and the other of massive, flow-layered and brecciated rhyolite. Brecciated rhyolite has a maximum thickness of 7 m and forms 4% of the flow thickness. Flow-layered zones are 0.3 to 1 m thick. The dacite flow is 70 to 140 m thick and is composed of only massive dacite. *Massive rhyolite* is pink and consists of 2 to 4% quartz phenocrysts and 0 to 3% plagioclase phenocrysts in a recrystallized groundmass consisting of a fine grained aggregate of 95% plagioclase and quartz and 5% combined muscovite and biotite and rare Fe-Ti oxide granules. *Flow-layered rhyolite* consists of millimetre to centimetre thick layers of differing colours of massive rhyolite. *Brecciated rhyolite* comprises an intact to locally disrupted framework of 60 to 65%, angular to subangular and rare subrounded, blocks and lapilli of massive rhyolite, 0.2 to 15 cm in diameter, in a fine grained, recrystallized, quartzofeldspathic aggregate that is similar to but, coarser grained than the recrystallized groundmass of massive rhyolite but, also contains a few 0.5 to 1.5 mm quartz crystals. Upwards in the breccia zone the maximum block size decreases. *Massive dacite* is light grey and consists of 3 to 5%, plagioclase phenocrysts in a recrystallized groundmass composed of a fine grained, quartzofeldspathic aggregate of 90% plagioclase and quartz and 10% combined biotite, muscovite epidote and rare Fe-Ti oxide.	1.0 km	Thickness variation is due to younger intrusions that form the west, south and east boundaries of the formation.

*Rock types listed in order of abundance.

Table 6.
Megascopic Features of Basalt Flow Sequences.

The characteristics of flow types in flow sequences are described in the table under Flow Texture and Structure. The number of flows in a sequence are unknown.

Fault Block	Flow Sequence	Sequence Thickness (m)	Flow Thickness (m)	Flow Texture and Structure: aphyric	pg-phyric	pg-hb-phyric	hb-phyric	<10% vesicles	10-40% vesicles	massive	pillowed	differentiated	breccia	interflow tuff	Lateral and Vertical Variations
Northern Block	A	0 - 350	3 - 15	X				X			X		X	X	Unit thins eastward. Flows are thinner toward top of unit. Porphyritic flows most abundant in lower 175 m of unit. Massive flows only present in west. Abundance of breccia and interflow tuff increases eastward.
			5 - 10		X			X			X		X	X	
			5 - 10		X			X		X			X	X	
			1 - 25	X				X		X			X	X	
	B	0 - 325	1 - 15	X				X		X			X	X	Unit thins eastward. Pillowed flows occur most commonly in east and about 100 m from base of unit, and have a total thickness of 35 m. Flow breccia in pillowed flows contains amoeboid pillows. Pg-phyric basalt compose about 20% of the unit thickness. In massive aphyric flows, breccia increases in abundance eastward.
			3 - 7		X			X		X			X		
			3 - 7		X			X			X		X	X	
Ruttan Block (North)	A	150 - 950	4 - 20	X				X		X					Unit thins westward. Pg-hb-phyric flows only present in upper 60 - 80 m in the east.
			4 - 20	X				X		X			X	X	
			4 - 20	X				X			X		X		
			1 - 10			X		X			X		X	X	
	B	0 - 850	3 - 6			X		X		X			X	X	Unit thins eastward. Upward and eastward breccia abundance increases. In the east the unit comprises 85% breccia. In the west flows are locally interbedded with heterolithic basalt breccia.
	C	1200	Unknown			X	X		X				X	X	Unknown.
	D	0 - 2000	Largely			X		X		X			X		Lateral variation in thickness obscured by intrusive rocks. Vertical change from dominantly massive, hb-phyric basalt to aphyric and pg-hb-phyric basalt. Thicker flows appear to be predominantly breccia.
			unknown,			X	X		X			X			
			locally	X				X		X			X		
			3 - 15	X				X			X		X	X	
Ruttan Block (South)	A	0 - 1500	3 -15				X	X		X	X	X	X		Units thins eastward. In the east flows are thinner and contain higher proportion of breccia than in the west.
	&						X	X		X			X		
	B	75 - 650													
	C	120 - 400	3 - 6				X	X				X		X	Unit thins westward and eastward. Breccia present in minor amounts but increase in abundance eastward. Flows are generally thinner eastward.
	D	100	3 - 6				X	X				X		X	Lateral and vertical variations are unknown.
	E	175 - 350	Largely	X				X		X			X		Unit thins eastward. No apparent lateral or vertical variation. Pillowed flows compose less than 15% of the unit.
			unknown,			X				X			X		
			locally	X				X			X		X		
			5 - 10			X		X			X		X		

Table 6.
Megascopic Features of Basalt Flow Sequences. (continued)
The characteristics of flow types in flow sequences are described in the table under Flow Texture and Structure. The number of flows in a sequence are unknown.

Fault Block	Flow Sequence	Sequence Thickness (m)	Flow Thickness (m)	Flow Texture and Structure: aphyric	pg-phyric	pg-hb-phyric	hb-phyric	<10% vesicles	10-40% vesicles	massive	pillowed	differentiated	breccia	interflow tuff	Lateral and Vertical Variations
	F	250 - 450	Largely unknown, locally 5 -10				X	X				X	X		No apparent variations.
Karsakuwigamak Block	A	300	10 - 20		X			X			X		X	X	Limited outcrop precludes documentation of variations; however, flows appear to be thicker in upper 100 m of unit.
			10 - 30	X				X			X		X	X	
			10		X			X		X			X	X	
			10	X				X		X			X	X	
Eastern Block	A	0 - 350	Unknown			X			X	X					Base of unit covered by glacial deposits.
	B	100 - 800	Unknown			X			X	X					Unit thins westward.
	C	450 - 875	Unknown			X		X		X					Unit thins eastward.
	D	75 - 150	Unknown			X		X		X					Unit thins westward.
	E	200	Unknown			X		X		X					Unit truncated by fault.

Footnotes

: Flow types in each basalt unit are listed in order of abundance.

: Basalt unit designation (A) in each fault block corresponds to unit designation in Figure 5. Units are thereby designated for descriptive purposes only.

Table 7.
Megascopic Features of Felsic Flows

Fault Block	Rhyolite Flows	Thickness (m)	Flow Thickness (m)	aphyric	pg-phyric	pg-qtz-phyric	vesicles	massive	flow layered	top breccia	bottom breccia	vol. % pg-phenocrysts	vol. % qtz-phenocrysts	Lateral and Vertical Variations
				Flow Texture and Structure										
Ruttan Block (North)	A	300	20 - 40	X			X	X	X	X		0	0	Westward stratigraphic equivalents of rhyolite pyroclastic flow deposits. Aphyric flows in upper 200 m.
			50 - 60			X	X	X	X	X		5-7	3-5	
Ruttan Block (South)	A	200	20 - 50	X			X	X	X			0	0	Sparse outcrop; no apparent variation.
Karsakuwigamak Block	A	950	70 - 100		X		X	X		X		0	3-5	Aphyric flows in upper 650 m.
			50	X				X				0	0	
	B	725	50 - 100	X			X	X	X	X	X	0	0	None.
	C	715 - 815	120 - 250			X	X	X	X	X		2-3	3-5	Aphyric flows in upper 175-275 m. Flows form an eastward thinning wedge but aphyric flows thin westward. Flow layering commonly flow folded.
			75 - 100	X			X	X		X	X	0		
	D	0 - 380	0 - 240		X			X		X	X	2-3	0	Breccia envelopes massive rhyolite and is coarsest proximal to massive rhyolite. Aphyric rhyolite in lower 125 m. Flows from eastward thinning wedge.
			0 - 125	X				X	X			0	0	
	E	80 - 300	50 - 100		X		X	X	X	X	X	2-3	0	None.
	F	0 - 70	0 - 70	X				X	X	X		0	0	Locally flow layering is oblique to flow boundaries; breccia fragments are either massive or flow layered.
	G	65	65			X						3-4	2-3	Flow is entirely breccia; some fragments are spherulitic. Lateral stratigraphic equivalent of flow F.
	H	80 - 200	50 - 100	X			X	X		X	X	0	0	Thin intercalated pyroclastic flow deposits in upper 140 m. Thins westward.
			30 - 40		X		X	X		X		1.0	0	
	I	220	35 - 50			X	X	X	X	X		3	1-3	Pumice breccia at the top of one quartz-plagioclase-phyric flow; other flow top breccia contain non-vesicular fragments plagioclase-quartz- phyric flows locally spherulitic.
					X		X	X		X		1.0	0	
Eastern Block	A	100 - 220	30 - 40		X			X	X	X	X	3-4	0	Massive rhyolite is flow layered and forms pods enveloped by autoclastic breccia.
	B	100 - 250	30 - 40		X			X	X	X	X	3-4	0	Massive rhyolite is flow layered and form pods enveloped by autoclastic breccia.

Table 8.
Megacopic Features of Ignimbrites

Pyroclastic Unit	Ignimbrite Thickness (m)	Flow Unit Thickness (m)	Flow Unit or Ignimbrite Contacts		Internal Variations		*Pumice, Dense Juvenile, Cognate and Accessory Pyroclasts						Phenocrysts		Pyrogenic Crystals			Comments
			Upper	Lower	Thickness (m)	Type, Special Features	%	Size (mm)	Shape	Vesicularity	Type	Type	%	Size (mm)	Type	%	Size (mm)	
ASH FLOWS																		
B	2	2	sharp	sharp		not present	45-50 5-10	3-40 3-10	subrounded subangular	50% none	pumice cognate	pg not present	5	1 -1.5	pg.	10-15	1.15-1.5	Pyrogenic crystals are broken.
B	23	23	sharp	sharp		not present	30-45 5-7	3-10	elliptical angular	poor none	pumice cognate	pg. not present	5	1 -2	pg.	10	0.25-2	Pyrogenic crystals are broken.
B	150-350	unknown	sharp (Ignimbrite) Flow unit boundaries that are exposed are sharp	unknown (Ignimbrite)	1-25	Changes in pumice content between flow units; local 0.2-0.5 m thick pumice concentrations in flow units	15-30 5-10 5	4-50 3-30 3-30	elliptical angular to subrounded angular	none none none	pumice dense juvenile cognate	pg. pg. not present	2-5 2-3	2 -3 2 -3	pg. pg.	23	0.25-3	Pyrogenic crystals are broken.
C	27-60	27-60	sharp	sharp	10-35	Upper zone containing pumice and rare lithics; lower zone containing pumice and lithics	5-20 7	10-70 5-30	subrounded angular	60-70% none	pumice dense juvenile and/or cognate	pg. qtz variable pg. and qtz. phenocryst content	1-2 combined	1 -2.5 1	pg. qtz.	12 1	0.25-2.5 0.15-1	Locally pumice is indistinguishable from the fine grained quartzo-feldspathic aggregate. Pyrogenic crystals are broken.
C	5-15	5-15	unknown	sharp		Variation in pumice content and size	5-30	3-10	elliptical	none	pumice	qtz. pg.	3 3	1 1 -3	qtz. pg.	57 57	0.25-1 0.25-3	Pyrogenic crystals are broken.
D	0-170	10-20	unconformity (ignimbrite) Exposed flow unit contacts are sharp.	sharp (ignimbrite) contacts		Variation in pumice content	15-40 3-10	3-70 3- 7	subrounded and equant in upper half of ignimbrite; in lower half angular to subrounded equant	60% elliptical none	pumice cognate or accessory	qtz. pg. not present	3-5 1-3	0.5-2	qtz.	4-10	0.25-2	Pyrogenic crystals are broken; thickness variation due to unconformity at top of Member and younger intrusion at east end of member. Ignimbrite sheet contains two air-fall deposits that have sharp boundaries with adjacent ignimbrite flow units.
E	3-7	3-7	sharp	sharp	0.5- 2.5	Pumice concentrations	0-15	5-10	subrounded	60%	pumice	not present						
F	45-50	45-50	sharp	younger intrusion		Variation in pumice and lithic abundance. Local 0.3 0.5 m pumice concentrations.	5-40 0-10	5-30 5-15	elliptical angular to subrounded	none none	pumice cognate or accessory	qtz. pg. not present	3 4	0.5-1.5	qtz.	7-10	0.25-1.5	Pyrogenic crystals are broken. Western and eastern boundaries are a younger intrusion.
G	10	4	gradational (flow units) Upper boundary of ignimbrite is an erosional unconformity; basal contact is sharp.	sharp (flow units)	4-45	Reverse size grading of pumice	15	5-15	elliptical	none	pumice	pg. qtz.	2-4 2-4	1 -2 1 -1.5	pg. qtz.	45 45	0.25-2 0.25-1.5	Pyrogenic crystals are broken.

Table 8.
Megacopic Features of Ignimbrites (continued)

Pyro-clastic Unit	Ignim-brite Thickness (m)	Flow Unit Thickness (m)	Flow Unit or Ignimbrite Contacts Upper	Lower	Internal Variations Thickness (m)	Type, Special Features	*Pumice, Dense Juvenile, Cognate and Accessory Pyroclasts %	Size (mm)	Shape	Vesicu-larity	Type	Phenocrysts Type	%	Size (mm)	Pyrogenic Crystals Type	%	Size (mm)	Comments
H	3-4	3-4	sharp	sharp	1.5-3	Reverse grading, concentration of pumice in upper 1.5-2 m of flow unit.	30	5-30	elliptical	none	pumice	pg.	2-3	1.5-2	pg.	7-10	0.25-2	Pyrogenic crystals are broken.
												qtz.	2	1 -2	qtz.	7-10	0.25-2	
							5 -10	24	angular	none	cognate and/or accessory	not present						
BLOCK-AND-ASH FLOWS																		
A	0-375	17-25	Ignimbrite and flow unit boundaries not exposed.		0.4 -6	Variations in pyroclast content.	20-40	0.5-50	angular to subrounded	none to poor and/or	dense juvenile cognate	not present			not present			Interlayered lapilli-tuff and tuff.
B	200-400	5-35	Exposed flow unit boundaries are sharp. Ignimbrite boundaries are not exposed.		5 -15	Variations in pyroclast content. Normal size grading	30-65	5	angular to subangular	none	dense juvenile	pg.	2-3	1 -2	pg.	2 -3	1 -2	Same as EM-1.
							5	5 -30	angular	none and/or accessory	cognate	not present						
F	100-200	12-15	Exposed flow unit boundaries are sharp. Ignimbrite boundaries are not exposed.		3 -12	Interlayered tuff-breccia and lapilli-tuff.	40-60	5 -150	angular	none	dense juvenile	not present			not present			Tuff-breccia interlayered with lapilli-tuff. Associated with massive dacite flows.
							2-45	0 -40	angular	none	cognate or accessory	pg.	1	1 -2				

Table 9:
Megascopic Features of Pyroclastic Fall Deposits.

Deposits are listed according to genetic type. In each genetic type the deposits are listed sequentially from oldest to youngest.

Pyro-clastic Unit	Deposit Thickness (m)	*Lithologic Unit Thickness (m)	Contacts Upper	Contacts Lower	Thickness (m)	Internal Stratification Type: Special Features	%	**Recognizable juvenile, cognate and accessory components. Size (mm)	Shape	Vesicularity %	Type	Phenocrysts Type	Phenocrysts %	Phenocrysts Size (mm)	Pyrogenic Crystals Type	Pyrogenic Crystals %	Pyrogenic Crystals Size (mm)	Comment
LAPILLI-AND-ASH FALL																		
A	200 - 400	5 - 27	sharp	sharp	0.3 - 5	Bedded lapilli tuff	35 - 60	0.1 - 17.5	Angular-blocky to serrate, equant to tabular	none to poor	juvenile	pg qtz	2 - 4 combined	2 2	pg qtz	2 - 3 combined	0.5 - 2 0.5 - 2	Pyrogenic crystals are broken. Interlayered, bedded lapilli-tuff and tuff. Lapilli-tuff units and beds thin and decrease in abundance upwards and eastward. Tuff units vary sympathetically in thickness and abundance with lapilli-tuff.
		0 - 60	sharp	sharp	0.03 - 1.2	Bedded tuff	10 - 50	0.1 - 5		none	juvenile	——not present——			pg qtz	2 - 5 combined	0.5 - 2 0.5 - 2	
B	2 - 5	0.05 - 3.0	sharp	sharp	0.05 - 3.0	Bedded; interbedded lapilli tuff and tuff. Normally graded accretionary lapilli.	0 - 60	2 - 5	Circular to elliptical in section	none	accretionary lapilli	——not present——			pg	0 - 10	0.25 - 2	Pyrogenic crystals are broken and occur in accretionary lapilli and in fine grained recrystallized vitric component. Unit thins westward. westward.
BLOCK-AND-ASH FALL																		
B	0.2 - 0.3	0.2 - 0.3	sharp	sharp		Normally graded lapilli in a lapilli-tuff unit composed of one bed.	45 - 60	1 - 240	Angular to subrounded equant to tabular	none	cognate	pg	2 - 4	2 - 4	pg	rare	2 - 3	Unit thins and maximum fragment size decreases westward.
HOT AIR FALL																		
C	0 - 30	0.1 - 0.75	sharp	sharp	0.05 - 0.15	Bedded lapilli-tuff; accretionary lapilli.	30 - 40	5 - 10	Oblate	none	accretionary lapilli	pg qtz	3 combined	0.5 - 4 0.25 - 1.5	pg qtz	7 - 10 combined	0.25 - 4 0.25 - 1.5	Pyrogenic crystals are broken. The 0.25 to 4 mm crystals listed as phenocrysts are in fact pyrogenic crystals contained in accretionary lapilli; they are described in the table as phenocrysts to illustrate the differences between the lapilli and the fine grained recrystallized aggregate comprising the material surrounding the lapilli. Units thin and maximum lapilli size decreases westward.
C	0 - 18	1.15 - 18	sharp	sharp	0.05 - 0.15	Bedded lapilli-tuff. Normally size graded accretionary lapilli.	20 - 60	2 - 100	Oblate to spherical	none	accretionary lapilli	pg qtz	0 - 6 0.7 - 3.3	1 - 4 0.25 - 2	pg qtz	3 - 11 3 - 4	0.5 - 4 0.25 - 2	Same as C.
PUMICE FALL																		
D	0.1 - 0.15	0.1 - 0.15	sharp	sharp		Lapilli-tuff unit composed of one bed.	65 - 70	4 - 7	Elliptical	none	pumice	pg qtz	1 - 3 3 - 5	1 0.5 - 1	pg qtz	4 - 5 combined	0.25 - 1 0.25 - 1	Pyrogenic crystals are broken. Two similar units occurring in an ignimbrite sequence.
							Rare	0.5 - 1.5	Angular	none	dense juvenile or cognate	——not present——						

Table 9:
Megascopic Features of Pyroclastic Fall Deposits. (continued)

Deposits are listed according to genetic type. In each genetic type the deposits are listed sequentially from oldest to youngest.

Pyro-clastic Unit	Deposit Thickness (m)	*Lithologic Unit Thickness (m)	Contacts: Upper	Contacts: Lower	Internal Stratification: Thickness (m)	Internal Stratification: Type: Special Features	**Recognizable juvenile, cognate and accessory components: %	Size (mm)	Shape	Vesicularity %	Type	Phenocrysts: Type	Phenocrysts: %	Phenocrysts: Size (mm)	Pyrogenic Crystals: Type	Pyrogenic Crystals: %	Pyrogenic Crystals: Size (mm)	Comment
ASH FALL																		
G	0.5	0.5	sharp	gradational		Tuff unit composed of one bed.	not present								pg qtz	2 combined	0.25 - 0.5 0.25 - 0.5	Pyrogenic crystals are broken. Two similar units occurring in an ignimbrite sequence. Units overlie each flow units.
H	0.15	0.15	unexposed	sharp to gradational	0.04 - 0.07	Normally graded tuff. Variation in pyrogenic crystal and lithic content.	0 - 25	0.25 - 3	Angular	none	dense juvenile or cognate	not present			pg qtz	0 - 7 combined	0.25 - 1 0.25 - 1	Pyrogenic crystals are broken. Unit overlies an ash flow unit.
C	1 - 1.75	1 - 1.75	sharp	sharp	0.03 - 0.10	Bedded tuff.	not present								pg. qtz.	2 - 3 combined	0.25 - 0.5 0.25 - 0.5	Pyrogenic crystals are broken. Ash fall inter-layered with hot air-fall deposits.
C	0.5 -1.0	0.5 - 1.0	sharp	sharp	0.03 - 0.10	Bedded tuff.	not present								pg. qtz.	2 - 3 combined	0.25 - 1.0 0.25 - 1.0	Pyrogenic crystals are broken. Ash-fall inter-layered with hot air-fall deposits.

* Lithologic unit is defined as a unit composed of one lithology that composes all or part of a deposit; it can consist of a single bed or multiple beds.

** The components listed are those that can be readily recognized. The remainder of the rock is a fine grained recrystallized aggregate interpreted to be recrystallized fine vitric ash.

Abbreviations: pg - plagioclase; qtz - quartz.

Table 10.
Megascopic Features of Pyroclastic Surge Deposit

Pyro-clastic Unit	Deposit Thickness (m)	Contacts: Upper	Contacts: Lower	Internal Stratification: Thickness (m)	Internal Stratification: Type: Special Features	*Recognizable juvenile, cognate and accessory components: %	Size (mm)	Shape	Vesicularity %	Type	Phenocrysts: Type	Phenocrysts: %	Phenocrysts: Size (mm)	Pyrogenic crystals: Type	Pyrogenic crystals: %	Pyrogenic crystals: Size (mm)	Comments
H	0.5 - 1.3 0.02 - 0.05	Sharp	Sharp	0.02 - 0.05	Bedded tuff; parallel and oblique stratification; parallel lamination.	0 - 20	0.25 - 1	angular	none	Juvenile and/or cognate	——not present——			pg qtz	0 - 10 combined	0.2 - 0.5 0.2 - 0.5	Pyrogenic crystals are broken. Unit includes ash-flow ignimbrite.

*The components listed are those that can be readily recognized. The remainder of the rock is a fine grained recrystallized quartzofeldspathic aggregate interpreted to be recrystallized fine vitric ash.

Abbreviations: pg - plagioclase; qtz - quartz.

Table 11.
Megascopic Features of Heterolithic Breccia (Debris Flow Deposits)

Fault Block	Breccia Unit	Thickness (m) Bed Thickness (m)	Stratification	Rock Components: Fragments % of Rock	Rock Components: Fragments Size Range (mm)	Rock Components: Matrix (<2 mm) % of Rock	Fragment Descriptions: Composition	angular	subangular	subrounded	rounded	aphyric	pg-phyric	qtz-phyric	hb-phyric	vesicularity %	% fragment populations	max. size (mm)	Matrix Description: Composition	Shape	% of Matrix	Comments
Karsakuwigamak	A	0 - 60	Beds generally massive; some reversely graded. 20% variation in fragment content from bed to bed. Bedding planes are generally gradational.	40 - 60	2 - 200	40 - 60	dacite	X	X	X			X			0	50	200	pg-qtz-aggregate		40	2 to 3 m thick, 30 to 50 m long lenses at base of unit comprising 50 to 60%, angular to subrounded, 200 to 600 mm, dacite and rhyolite fragments. Matrix is sandstone with a composition similar to matrix in heterolithic breccia. Lenses are coarse-tail graded. Westward the lenses become finer grained.
		0.6 - 3.0					dacite	X	X	X		X				0	25	200	dacite	equant	30	
							rhyolite	X	X	X			X	X		0	25	200	rhyolite	equant	10	
																			pg-crystals	euhedral	10	
																			qtz-crystals	euhedral	10	
	B	0 - 100	75% of beds are reversely to normally graded; 25% ungraded to reversely graded. All beds have basal sand zone grading upwards into breccia.	35	2 - 200	65	dacite	X					X			0	25	200	qtz-pg-aggregate		69	Minor interbedded sandstone with same composition as heterolithic breccia.
		0.20 - 5.5					dacite			X	X		X			0	25	200	dacite	equant	10	
							dacite	X				X				0	20	200	rhyolite	equant	5	
							dacite	X	X	X			X			2-3	10	200	pg-crystals	euhedral	8	
							rhyolite	X	X	X			X	X		0	10	100	qtz-crystals	euhedral	8	
							rhyolite		X				X	X		2-3	10	100				
	C	0 - 310	Massive bedded. Thin silt layers between breccia beds are common. Bedding planes are sharp.	30 - 40	2 - 15	60 - 70	basalt	X	X	X		X				25	20	15	amph-pg			
		0.2 - 0.6					basalt	X	X	X		X				0	20	15	aggregate		70	
							andesite	X	X	X			X			0	20	15	basalt	equant to		
							andesite	X	X	X		X				20	20	15		elliptical	15	
							andesite	X	X	X		X				0	20	15	andesite	equant to		
																				elliptical	15	
	D	100 - 435	Reversely to normally graded, reversely graded and massive beds.	55 - 65	2 - 200	35 - 45	dacite	X					X			0	50	200	pg-qtz-aggregate		70	Minor interbedded pebbly sandstone with same composition as heterolithic breccia.
		1 - 2.2					rhyolite	X				X				0	20	200	dacite	equant	25	
							rhyolite	X					X	X		0	20	200	pg-crystals	euhedra	5	
							andesite			X	X	X				20	5	100	rhyolite	equant	rare	
							andesite			X	X				X	0	5	100				
	E	190 - 450	Massive bedding. Changes to fragment content from one bed to another. Bedding plane relationships are largely unknown but locally contacts are sharp.	40 - 50	2 - 40	50 - 60	basalt	X	X	X			X		X	0	25-	40	amph-pg		50	Minor interbedded sandstone and siltstone with same composition as breccia.
		2 - 6															30		aggregate			
							basalt	X	X	X		X				0	25-	40	basalt	equant	35	
																	30		andesite	equant	5	
							basalt			X		X				30	25-	40	pg-crystals	euhedral	3-5	
																	30		chl-pseudomorphs	euhedral	3-5	
							andesite	X	X	X			X			0	5-	40	of pyroxene			
																	10		crystals			
							andesite	X	X	X		X				0	5-	40				
																	10					
	F	6 - 20	Single bed comprising basal sand zone in turn grading into normally graded zone. Upper and lower contacts are sharp and planar.	50	2 - 250	50	rhyolite	X						X	X	0	25	250	pg-qtz-aggregate		40	Fragment content increases to 65 and 75% at west extremity of the unit.
							rhyolite	X				X				0	25	250	rhyolite	equant	25	
							dacite	X				X				0	15	150	pg-crystals	euhedral	25	
							dacite	X					X			0	15	150	dacite	equant	10	
							rhyolite		X	X			X	X		20	8	10				
							dacite			X	X		X			2-3	8	10				
							andesite			X	X	X				0	4	30				

Table 11.
Megascopic Features of Heterolithic Breccia (Debris Flow Deposits) (continued)
Fragment Description

Fault Block	Breccia Unit	Thickness (m) / Bed Thickness (m)	Stratification	Rock Components: Fragments % of Rock	Fragments Size Range (mm)	Matrix (<2 mm) % of Rock	Fragment Descriptions: Composition	angular	subangular	subrounded	rounded	aphyric	pg-phyric	qtz-phyric	hb-phyric	vesicularity %	% fragment populations	max. size (mm)	Matrix Description: Composition	Shape	% of Matrix	Comments
Eastern	A	0 - 100 0.3 - 2.0	Massive bedding. Changes in fragment content from one bed to another.	50 - 60	2 - 200	40 - 60	andesite	X	X	X			X		X	0	30	200	amph-pg		70	Poorly exposed. Local indications of fine grained sandstone layers grading into breccia layers. Amph-pg aggregate contains accessory epidote and chlorite.
							andesite	X	X	X			X			10	20	200	aggregate			
							andesite	X				X				20	20	100	andesite	equant	20	
							dacite	X	X	X		X				10	20	100	pg-crystals	euhedral	5-10	
							dacite	X				X				0	10	100	dacite	equant	0-5	
																			carbonate			
																			epidote			
	B	0 - 120 0.4 - 3.0	Massive bedding. Changes in fragment content from one bed to another. Rare reverse to normal grading. Rare sandstone interbeds.	30 - 60	2 - 180	40 - 70	basalt	X	X			X				0	30	180	amph-pg		70	Amph-pg aggregate contains accessory epidote and chlorite with minor biotite and quartz.
							basalt	X	X	X	X		X		X	20	25	180	aggregate			
							basalt	X	X	X			X			0	25	100				
							andesite	X	X			X				10	10	60	basalt	equant	25	
							andesite		X	X			X		X	0	10	60	andesite	equant to elliptical	5	
							rhyolite									10	rare	7				
Ruttan (North)	A	0 - 650 1 - 4	Massive bedding. Changes in fragment from one bed to another.	30 - 60	2 - 150	40 - 70	rhyolite		X	X		X				0	40	150	pg-qtz-aggregate		55	Pg-qtz aggregate contains accessory muscovite, biotite, epidote. In upper 20 m of unit maximum fragment size is 25 mm.
							rhyolite		X	X			X	X		0	40	150	rhyolite	equant	20	
							dacite		X	X			X			0	10	150	pg-crystals	euhedra	15	
							dacite		X	X	X					0	5	150	qtz-crystals	euhedral	10	
							andesite		X	X			X			0	5	50				
	B	0 - 500 0.5 - 10.0	Massive bedded, reversely to normally rare sandy zones at base of beds grading upwards into breccia.	40 - 50	2 -1000	50 - 60	rhyolite		X				X	X		0	35	1000	qtz-plag aggregate		40	Fragments 1 m diameter and beds >6.0 m thick are rare and occur within the upper 50 m of the unit. Rhyolite and dacite fragments are generally less than 300 mm diameter.
							dacite		X				X			0	35	1000	rhyolite	equant	20-25	
							dacite		X			X				0	20	300	dacite	equant	20-25	
							andesite			X	X		X			5-10	10	100	qtz-crystals	euhedral	5-10	
																			plag-crystals	euhedral	5-10	
	C	0 - 300 5 - 7	Massive, reversely to normally graded, and and normally graded beds. Changes in fragment content and/or change in most abundant fragment type from one bed to another. Some beds have basal sandy zone.	30 - 50	2 - 200	50 - 70	rhyolite	X	X	X		X				0	20-50	200	pg-bt-qtz amph aggregate		80	
							rhyolite	X	X	X			X	X		0	20-30	200	rhyolite	equant	15-20	
							dacite	X	X	X		X				0	10-20	125	dacite	equant	5	
							dacite	X	X	X			X			0	10-20	125				
							andesite			X	X		X			5	10	75				
							basalt			X	X		X			5-10	10	65				