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Petrology and Tectonic Evolution of the Bowers Supergroup Northern Victoria Land, Antarctica

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Ray Robert, Jr.

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ANTARCTICA

by

Ray Robert, Jr.

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ABSTRACT

The Bowers Supergroup of northern Victoria Land, Antarctica is at least 6.5 km thick and consists of Solidarity, Molar, and Glasgow Formations of the Middle Cambrian Sledgers Group; Middle to late Cambrian Mariner Group; and Middle Ordovician Leap Year Group. The Solidarity Formation is at least Ø.4 km thick and consists of submarine tholeiites. The Molar Formation is up to 2.7 km thick and consists of slope-facies turbidites in its southwesternmost extent and shelf-facies sediments in its northeasternmost extent. Sediment provenance was the Glasgow Formation and a continental landmass lying northeast of the southwestern sloping Bowers basin. The Glasgow Formation is up to 2.7 km thick and consists of tholeiitic and calc-alkaline basalts to rhyolites erupted along a magmatic arc probably related to eastward subduction. The Mariner Group is a regressive marine sequence deposited during tectonic quiessence. The Leap Year Group rests unconformably on the Mariner and Sledgers Groups and consists of up to 2.5 km of molasse derived in part from the Granite Harbour Intrusives. The Bowers Supergroup was folded about N3Ø^{o}W axes, metamorphosed to the prehnite-pumpellyite facies, then tectonically juxtaposed by strike slip faults between the Wilson and

Robertson Bay terranes.

Deposition of the Leap Year Group, folding, metamorphism, and faulting occurred between 480 to 425 Ma and were the result of collision between the Wilson and Bowers terranes representing the Ross Orogeny in northern Victoria Land. Between 420 and 384 Ma, refolding about N60^{o}E axes, normal faulting, and the emplacement of the Admiralty Intrusives occurred during the Borchgrevink Event by which time the terranes may have become stitched. The allochthonous nature of the rocks of the Bowers Supergroup may preclude their correlation with those of the Dundas Trough in Tasmania.

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I want to express my deepest love and appreciation to my wife Peggy for enduring along with me. Even though it was by long distance near the end, your support kept me going.

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INTRODUCTION

The Lower Paleozoic Bowers Supergroup lies along a 20-30 km wide belt that strikes N30°W across northern Victoria Land, Antarctica and is bounded by faults. On the west it is flanked by Wilson Group metamorphic rocks and associated Granite Harbour Intrusives, and on the east mainly by Robertson Bay Group metasediments. The present study area lies in the central Bowers Mountains between 71°S and 72°S Latitude and 162°E and 164°E Longitude near the Alt, Carryer, and Sledgers Glaciers where the Bowers Supergroup is well exposed. Field data were collected during the 1981-1982 USARP and the 1974-1975 NZARP expeditions. The locations of traverses during both expeditions are shown in figure 1.

Field and petrologic studies are combined to interpret the stratigraphy, structure, and petrogenesis of the Bowers Supergroup in terms of its geologic history and plate tectonic environment of deposition. Because the study area lies near the coast facing Australasia, it occupies an important position for the hypothetical pre-Cretaceous reconstruction of Gondwanaland, a subject of much debate (Craddock, 1972; Laird et al., 1977; Grindley and Davey, 1982).

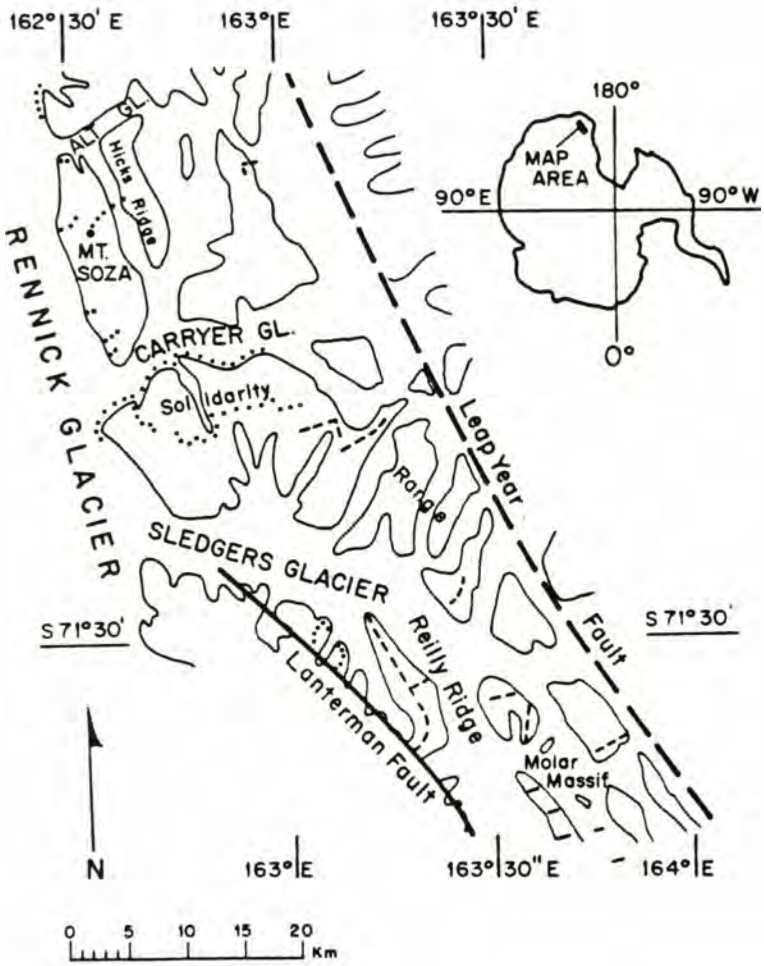


Figure 1. Study area in northern Victoria Land showing location of traverses. Dashes and dots indicate 1974-1975 NZARP and 1981-1982 USARP expeditions respectively.

REGIONAL SETTING

Northern Victoria Land lies within West Antarctica close to the East Antarctic craton Boundary in the northern extent of the Transantarctic Mountains (Figure 2). Because of its location in Antarctica, northern Victoria Land occupies a position critical to determining the location of the Paleozoic Pacific margin of Gondwanaland.

Recently, Dalziel (1982) suggested that West Antarctica is composed of several discrete blocks or microcontinents. However, he considers northern Victoria Land to be a part of the East Antarctic craton. Gair (1967) recognizes three tectonic zones in northern Victoria Land. Included within these zones are the Wilson Group in the west, the Robertson Bay Group in the east, and the central Bowers Supergroup. Grindley and Oliver (1983) point out that these zones have different thermotectonic histories and suggest that they had been cratonized onto East Antarctica. Weaver et al. (1984) suggest the presence in northern Victoria Land of three separate terranes juxtaposed by strike-slip faulting. From west to east they are the Wilson, Bowers, and Robertson Bay terranes.

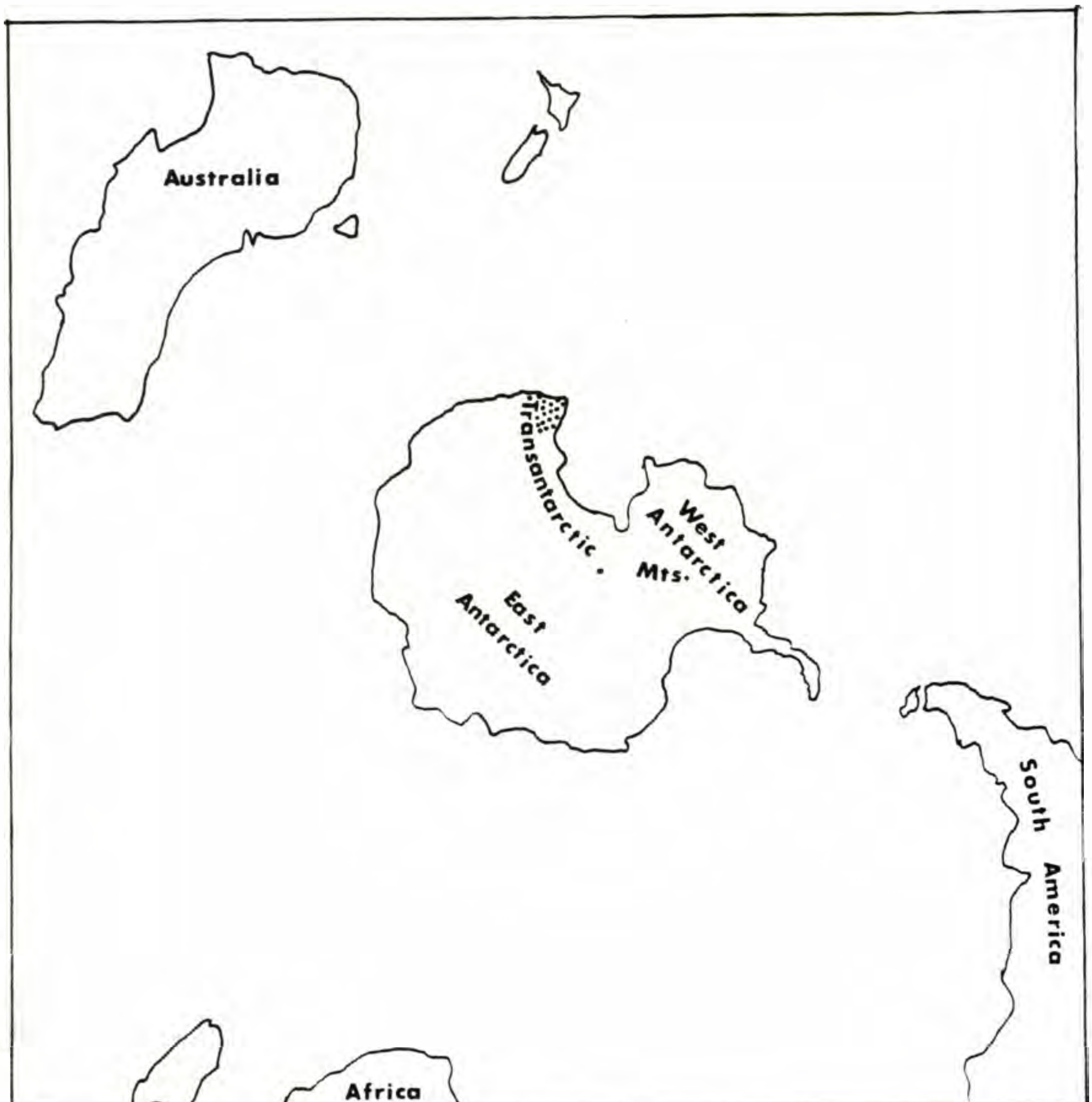


Figure 2. Location of Antarctica with respect to Australia, South America, and Africa. Northern Victoria Land shown as stippled area.

Wilson Terrane

The Wilson terrane lies to the west of the Bowers Supergroup in the Lanterman and Salamander Ranges and west of the Rennick Glacier in the USARP Mountains (Figure 3). In the Lanterman Range, the Wilson terrane consists of quartzo-feldspathic and pelitic gneisses, amphibolites, and stretched metaconglomerates of the Wilson Group all of which have been metamorphosed to the amphibolite facies (Wodzicki et al., 1982a). The gneisses have been folded at least twice about northwest-striking axes (Bradshaw et al., 1982). Northwest and southeast plunging F_1 and F_2 axes were recorded during the 1974-1975 NZARP expedition (Wodzicki and Robert, in press). These axes define a northwest-striking great circle, possibly suggesting a later folding event about northeast-southwest trending axes. Locally, the gneisses have been intruded by granites of the Granite Harbour Intrusives (Tessensohn et al., 1981). K-Ar biotite and hornblende ages reported by Adams et al. (1982) range from 451-483 Ma and probably record uplift.

The Morozumi Range, which may not be part of the Wilson terrane, lies between the Lanterman and Daniels Ranges (Figure 3). Here greenschist facies quartzo-feldspathic turbidites have been intruded by

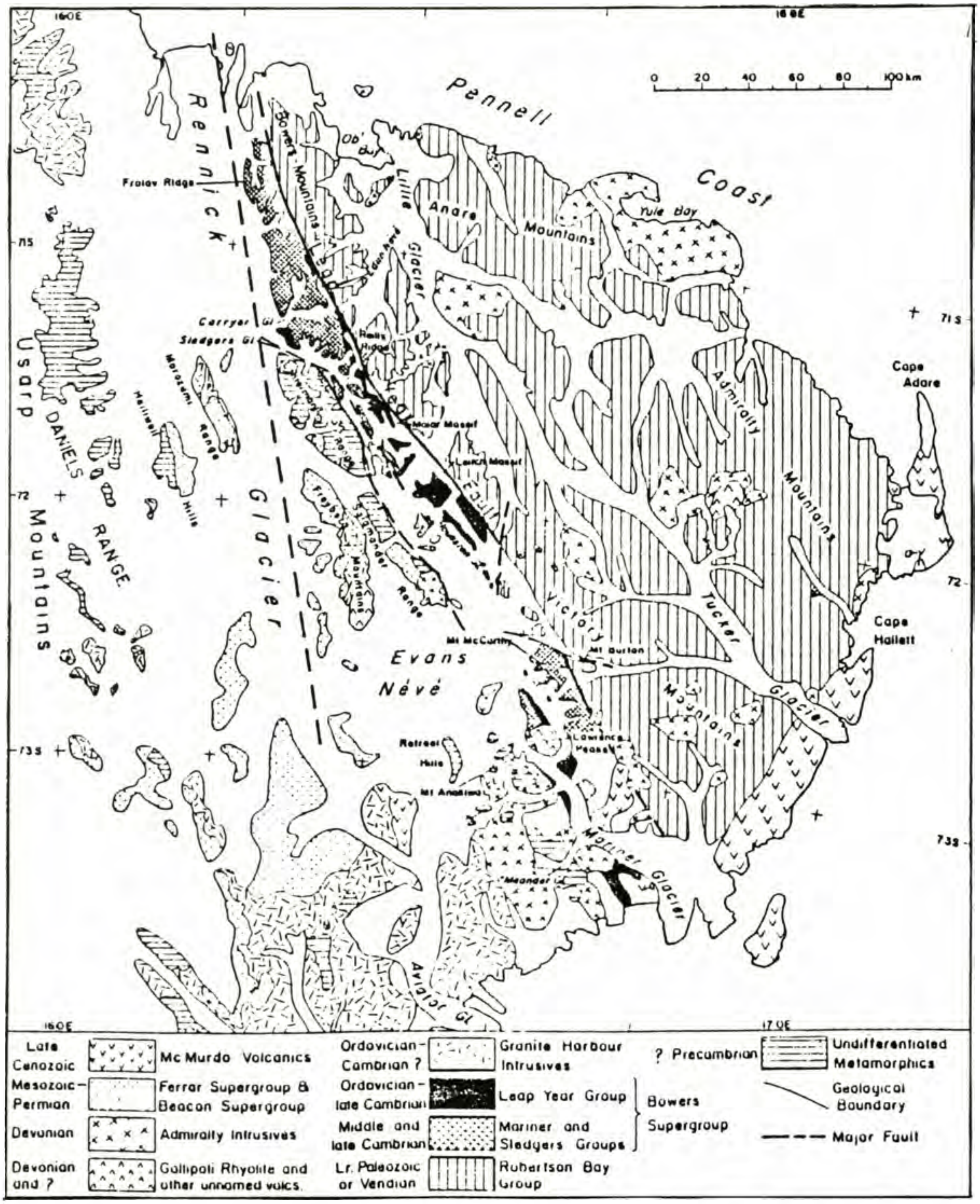


Figure 3. Geologic map of northern Victoria Land modified from Bradshaw et al. (1983).

Morozumi Adamellite. On the basis of similarities in sedimentological features, these sediments have been correlated with the Robertson Bay Group by Sturm and Carryer (1970), Dow and Neall (1974), Wright (1981), and Tessensohn et al. (1981).

In the Daniels Range of the USARP Mountains, Plummer et al. (1983) mapped the Rennick Schist, the Wilson Gneiss, and the Granite Harbour Intrusives. The Rennick Schist, according to Plummer et al. (1983), consists of psammo-pelitic to pelitic schists of amphibolite facies. The Wilson Gneiss is a migmatitic, two-mica, S-type granitoid. Babcock et al. (in press) describe the Wilson Gneiss (Complex) as heterogeneous, syntectonic, granitic rocks that are intimately associated with high-grade metamorphic rocks. They recognize two distinctive magmatic rock types: xenolithic/xenocrystic leucogranites to leucotonalites; and leucogranites to granodiorites that show a conspicuous layering defined by biotite, or rarely garnet-rich zones of variable thickness. According to the Rb-Sr and U-Pb dating of Adams (in press), the Rennick Schist protolith was deposited prior to the Early Cambrian and was metamorphosed at 530 ± 15 Ma. The Wilson Gneiss was probably derived by partial melting of the Rennick Schist, is an early phase of the Granite Harbour Intrusives, and was emplaced at 496 ± 24 Ma. The Granite

Harbour Intrusives proper intrude the Rennick Schist and the Wilson Gneiss (Plummer et al., 1983) and are predominantly two-mica, S-type granitoids (Vetter et al., 1983). Locally, they are epizonal granophyres and megacrystic granites (Plummer et al., 1983). Babcock et al. (in press) also note the presence of minor amounts of I-type tonalite to diorite intrusives.

Robertson Bay Terrane

The Robertson Bay terrane lies east of the Bowers Supergroup. It has been subdivided by Findlay and Field (1983) into the Millen Range Schist, which lies near the boundary with the Bowers Supergroup, and the Robertson Bay Group, which extends eastward to the coast. The Millen Range Schist has been metamorphosed locally to greenschist facies (Wodzicki et al., 1982a). It has undergone synmetamorphic nappe-like folding and post-metamorphic folding along gently plunging axes that strike northwest (Bradshaw et al., 1982; Findlay and Field, 1983). Northwest and southeast plunging L_1 lineations were recorded during the 1974-1975 NZARP expedition (Wodzicki and Robert, in press). The lineations define a northwest-striking great circle suggesting later folding about northeast-southwest trending axes.

The sedimentology of the Robertson Bay Group has been studied by Field and Findlay (1983) who consider that deposition took place in a submarine fan environment, and sediment transport was to the north and northwest. The sediments are quartz-rich and have a continental provenance. They consist of turbidites with minor amounts of debris flow deposits and pelagic sediments. Trace fossils suggest a late Precambrian age (Wright, 1981). Recently, Wright et al. (1984) report finding within turbidites, shallow-water limestone olistoliths that contain fossils from the Cambrian-Ordovician boundary.

The Robertson Bay Group has been folded about northwest-striking axes with deformational style similar to the post-metamorphic folds in the Millen Range Schist (Findlay and Field, 1983). According to Field and Findlay (1983), the schist may form the basement to part of the Robertson Bay Group. Whole rock K-Ar ages of the Millen Range Schist and Robertson Bay Group pelitic lithologies are interpreted to range from 502 to 477 Ma (Adams et al., 1982) and probably record metamorphism, folding, and uplift of these rocks.

PREVIOUS WORK

LeCouteur and Leitch (1964) were first to map and describe rock units in the Bowers Trough (terrane). During the 1962-1963 field season of the New Zealand Federated Mountain Club, they discovered subaerial quartzites and conglomerates in the Leitch Massif area (Figure 3) and designated these as the Camp Ridge Quartzite. In 1964, a brief helicopter reconnaissance into parts of the lower Rennick Glacier (Figure 3) was made by geologists of the U. S. G. S. (Crowder, 1968). Crowder named the Sledgers Formation for outcrops on either side of the upper Sledgers Glacier (Figure 3) of calcareous sandstone and siltstone, conglomerate, grit, and rare limestone, together with spillitized basic volcanic flows, flow breccias, and volcaniclastic sediments. In the summer of 1963-1964, the first major geological reconnaissance was made into the lower Rennick Glacier region (Sturm and Carryer, 1970). Sturm and Carryer proposed the name Bowers Group for a thick sequence of calcareous and volcaniclastic, shallow-water sediments exposed throughout the central and western Bowers Mountains (Figure 3). They include in this group the Sledgers Formation and the Camp Ridge Quartzite. In 1967-1968, a New Zealand Geological Antarctic expedition undertook regional mapping in the lower Rennick Glacier region (Dow and Neall, 1972). Dow and Neall describe a fault wedge of largely polymictic conglomerates along the Carryer Glacier (Figure 3) and name this formation the Carryer Conglomerate. They also divide the Bowers Group into three formations: the Carryer Conglomerate (oldest) the Sledgers Formation, and the Camp Ridge Quartzite (youngest). During the summer of 1974-1975, detailed mapping of the Bowers Group was carried out by the New Zealand Antarctic Research Program. Drastic revisions of the previously suggested stratigraphic succession resulted. Stratigraphy of the Bowers Group revised by Laird et al. (1976) now contain two major units: an older sequence which includes the Sledgers Formation and the Mariner Formation (Andrews and Laird, 1976), and a younger sequence which includes the Camp Ridge Quartzite and the Carryer Conglomerate.

Fossils collected from the Bowers Group by Cooper et al. (1976) indicate an age of Middle to Late Cambrian or Early Ordovician and that a significant unconformity separates the two major sequences. On the basis of field observations and paleontological studies, Laird et al. (1982) revised comprehensively the stratigraphy of the Bowers Group. The sequence now includes two important unconformities and accomodates four major units, the upper three forming the newly defined Bowers Supergroup. These units are from oldest to youngest: the Husky Conglomerate which rests unconformably on the Wilson Group; the Sledgers Group composed of the Glasgow and Molar Formations; the Mariner Group composed of the Edlin, Spurs, and Eureka Formations; and the Leap Year Group composed of the Camp Ridge Quartzite and the Carryer and Reilly Conglomerates.

Adams et al. (1982) report K-Ar whole-rock ages for the Bowers Supergroup. They show that in the Sledgers Group rocks, four ages fall in the range 467 to 441 Ma, but four others fall in the range 421 to 384 Ma. From this they conclude that K-Ar ages reflect two main metamorphic events: a Cambrian and a Siluro-Devonian regional metamorphism associated with the Ross and Borchgrevink Orogenies respectively. Bradshaw et al. (1982) describe the structural style and tectonic history in northern Victoria Land. They conclude that the structure of the Bowers Supergroup comprises a major syncline flanked to the west by a complex, faulted, anticline/sycline couplet. Wodzicki et al. (1982a) in a discussion of the petrology of the Bowers Supergroup, note that the rocks in the western part of the supergroup are metamorphosed at slightly higher temperatures than those in the eastern part. Additionally, the boundary between the prehnite-pumpellyite and the pumpellyite-actinolite facies lies just below the Leap Year-Mariner contact in the western part of the supergroup and 1000 to 2000 m below the contact in the eastern part. From this they conclude that the geothermal gradient was steeper in the western part of the Bowers Supergroup than in the eastern part. Tessensohn et al. (1981) compare the basement units of North Victoria Land and conclude that the Wilson Group, the Bowers Group (Supergroup), and the Robertson Bay Group are lateral equivalents exposed at different structural levels. Laird and Bradshaw (1983), based on sedimentological studies, conclude that the basin of deposition of the Sledegers and Mariner Groups was bordered by a landmass to the southwest, but an important source for the Sledgers Group also lay to the northwest. Stump et al. (1983) show that the Bowers graben extends the entire length of northern Victoria Land and is bounded on the east by the newly defined Leap Year Fault. Weaver et al. (1984) suggest that the Bowers terrane represents an allochthonous block juxtaposed against the Wilson and Robertson Bay terranes by strike-slip motion. Wodzicki and Robert (in press) abandon the term Husky Conglomerate and introduce the name Solidarity as a new formation of the Sledgers Group.

IMPETUS FOR THE PRESENT STUDY

The Bowers Trough of northern Victoria Land traditionally has been correlated with the Adelaide geosyncline of South Australia (Craddock, 1972). Laird et al. (1977) note the stratigraphy and structure of the Bowers Mountains correlate much better with the Dundas Trough of Tasmania. They note the youngest fossiliferous marine deposits in Antarctica and Tasmania (the Mariner and Dundas Groups respectively) are unconformably overlain by dominantly contintetal, coarse, quartzose sandstones and conglomerates of probably latest Cambrian or earliest Ordovician age (the Leap Year Group in Antarctica and the Owen Conglomerate in Tasmania). The marine deposits are underlain by unfossiliferous clastic sequences with interbedded mafic volcanic rocks (the Sledgers Group in Antarctica and the Crimson Creek Formation in Tasmania). The Cambrian sequences of both area are intruded by Devonian to Carboniferous granites. Futhermore, both area were affected similarly by tectonic activity during the Late Cambrian and Early Ordovician and were metamorphosed between 400-500 Ma.

Grindley and Davey (1982) note the apparent absence of equivalents of the Proterozoic Robertson Bay Group in Tasmania and equivalents of the Mount Read Volcanics of

Tasmania in northern Victoria Land. They suggest a plate reconstruction in which the Bowers Trough lines up with the "greenstone axial belt" in western Victoria, Australia. To the east of Tasmania however, a mica schist recovered from DSDP Site 281 on the South Tasman Rise was correlated by Ovenshine et al. (1974) with the Robertson Bay Group.

The presence of rhyolitic and granitic pebbles in the redeposited sediments of the Sledgers Group (Wodzicki et al., 1982a) shows that rocks similar to those present in the Mount Read Volcanics (Corbett et al., 1974) were close to the Bowers Trough. The Gallipoli Porphyries in Evans Neve' (Figure 3) near the Bowers Trough consist of rhyolitic flows and pyroclastic rocks (Dow and Neall, 1974) and are lithologically similar to the Mount Read Volcanics. This similarity suggests that they may be the source of the pebbles in the Sledgers Group. However, Rb-Sr dating by Faure and Gair (1970) shows the age of the Gallipoli Porphyries to be 382 $\pm$ 40 Ma (date corrected using new decay constant of 1.42×10^{-11}). This Late Cambrian to Early Ordovician age makes the Gallipoli Porphyries a highly unlikely source for the pebbles found in the Early Cambrian Sledgers Group. Wodzicki et al. (1982b), on the basis of field observations during the 1981-1982 USARP expedition and of previous work by Laird et al. (1977), tentatively correlate the Bowers and Dundas Troughs.

The present study was undertaken with the following purposes:

1) Determine the nature of the relationship of the Husky Conglomerate to the overlying Sledgers Group.

2) Petrographically describe and classify the rocks of the Bowers Supergroup.

3) Determine the tectonic provenance of the Glasgow Formation volcanics using geochemical discrimination diagrams.

4) Determine the tectonic provenance of the Sledgers and Leap Year Groups clastic deposits using sandstone comparison diagrams.

5) Develop a model for the tectonic evolution of the Bowers Trough.

6) Evaluate the Antarctic-Australia plate reconstruction of Laird et al. (1977) in light of this study.

GEOLOGY OF THE BOWERS SUPERGROUP

In the following sections the formations comprising the Bowers Supergroup are described from the point of view of their field occurrence and petrology. The stratigraphic nomenclature that is used is after Wodzicki and Robert (in press). The map and cross-sections in the Plate are taken from Wodzicki and Robert (in press) and show the geology of the Bowers Supergroup in the central Bowers Mountains. The geology of the upper Alt Glacier area is taken from Jordan (1981). Stratigraphic columns measured in the vicinity of Mt. Soza, lower Carryer Glacier-Mt. Gow, upper Carryer Glacier-Mt. Jamgroga, and the northern Molar Massif (Figure 4) are shown in figure 5.

Husky Conglomerate

The Husky Conglomerate was first described by Laird et al. (1982) at the type locality west of Reilly Ridge (Figure 4). There it is at least 370 m thick and consists of dark green conglomerate and breccia with basement derived amphibolite clasts interbedded with massive sandstone and mudstone. The basal breccia has been metamorphosed to the greenschist facies (Wodzicki et al., 1982a). The Husky Conglomerate is interpreted to rest

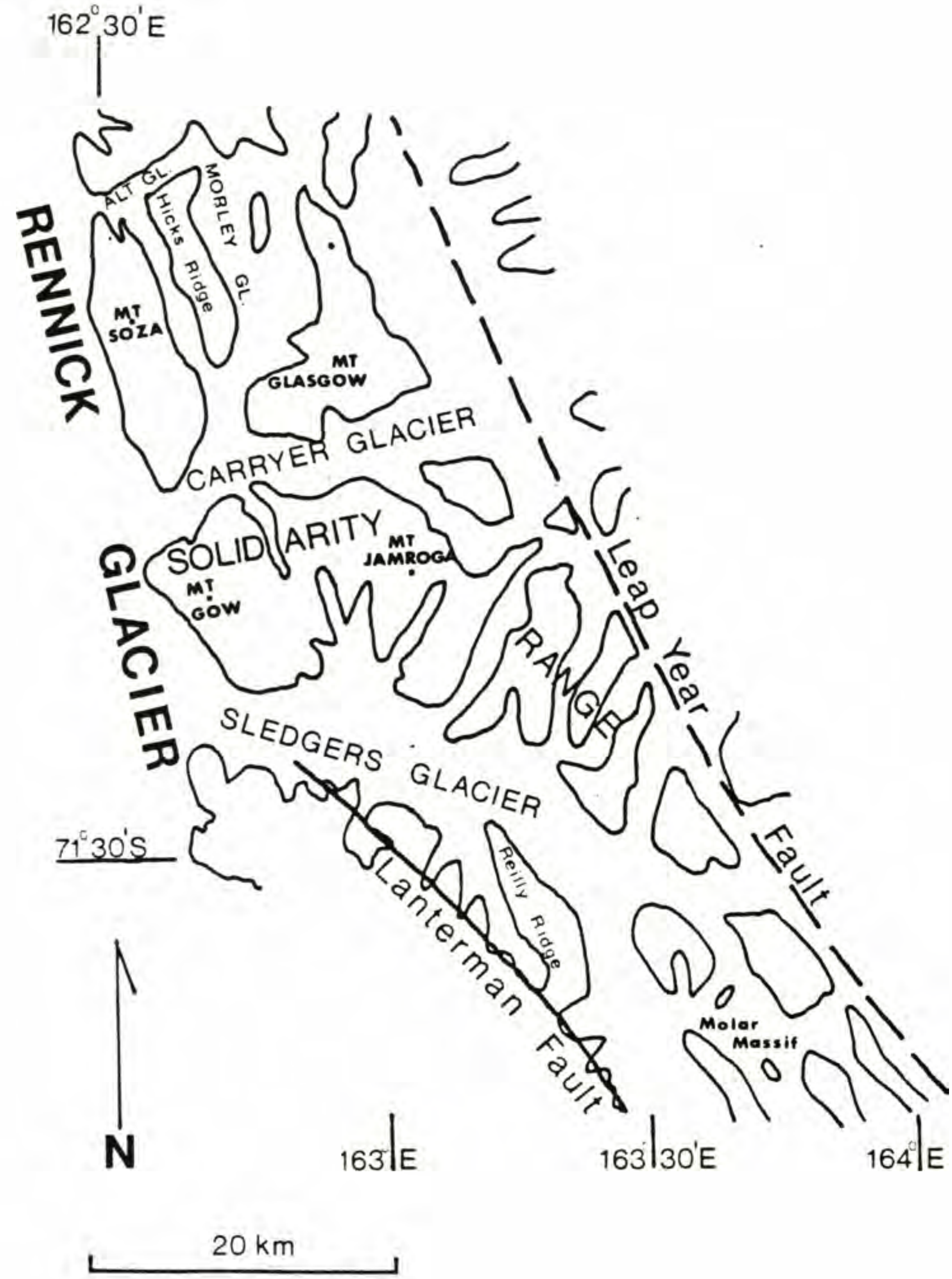


Figure 4. Sketch map of the study area showing important geomorphological features and major fault trends.

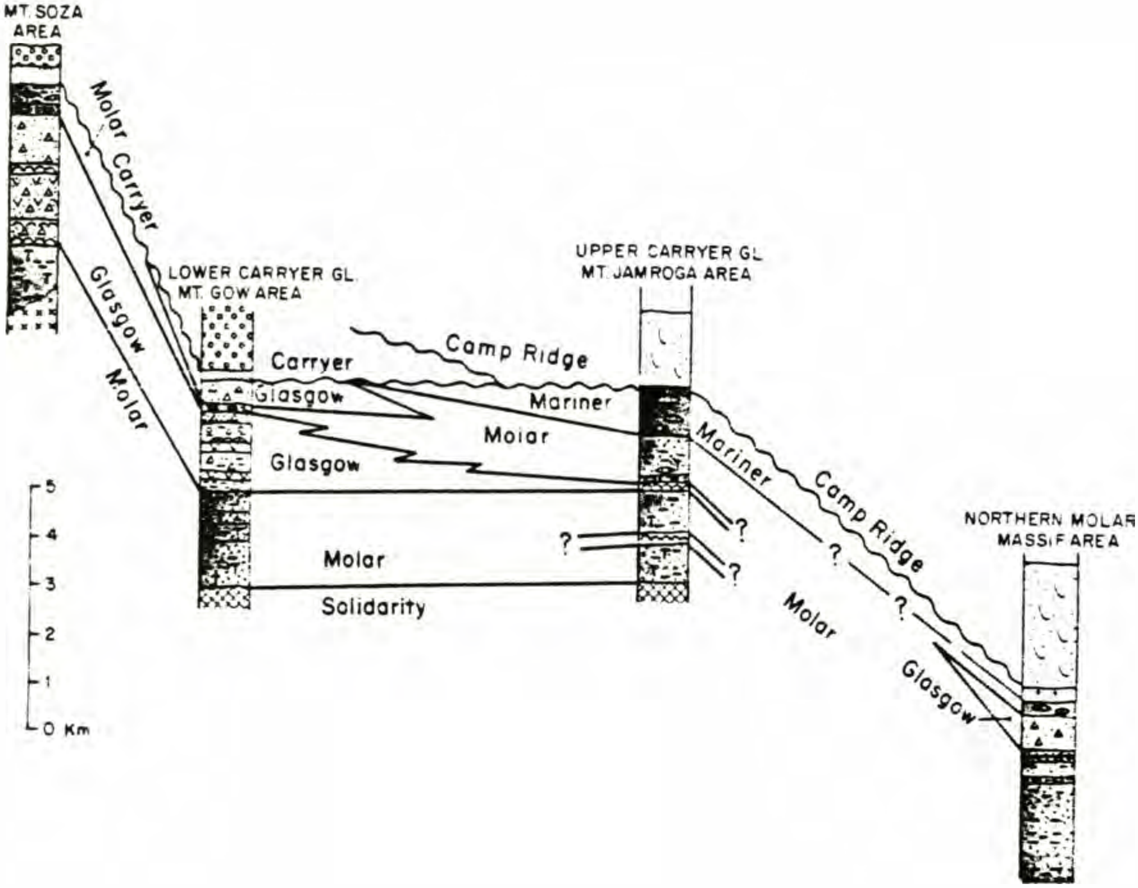


Figure 5. Stratigraphic columns at selected localities in the central Bowers Mountains (after Wodzicki and Robert, in press). Mt. Soza and the Molar Massif are located in the northwestern and southeastern extent of the map area respectively. The coeval Glasgow and Molar Formations interfinger, a feature best seen in the Carryer Glacier region. There is no correlation between vertical and horizontal scales.

unconformably on the Wilson Gneiss and to be in fault contact with Sledgers rocks. Kleinschmidt and Skinner (1981) disagree with this interpretation and consider the Husky Conglomerate a part of the Wilson Group basement. However, based on their description and photographs of lithologies (see Figures 14 and 15, Kleinschmidt and Skinner, 1981), the rocks they studied are almost certainly debris-flow deposits from the Glasgow Formation and meta-conglomerates from the Wilson Group basement rather than the Husky Conglomerate described by Laird et al. (1982; Wodzicki and Robert, in press). Laird and Bradshaw (1983) re-examined the Husky Conglomerate about 5 km northwest of the type locality. There they found refolded basement conglomerate (Wilson Group) in undulatory contact with 120 m of undeformed Husky Conglomerate containing clasts of the adjacent basement rocks. They inferred the presence of an unconformable contact with the basement and a fault contact with the nearby Molar Formation to the northeast.

The contact between the Sledgers and Wilson Groups has most recently been examined by Wodzicki and Robert (in press) at Latitude 71°31'S, Longitude 163°03'E and Latitude 71°32'S, Longitude 163°07'E. At both localities the Husky Conglomerate is in fault contact with the Molar Formation. In the northwestern locality a well-defined fault separates the Husky Conglomerate from the Wilson Group, but in the southeastern locality this contact is not well-exposed and appears gradational. The faults are marked by clay-rich pug zones up to 20 m wide. The Husky Conglomerate contains clasts, up to 3 m in diameter, of two-mica granite, quartzo-feldspathic gneiss, and calc-silicate gneiss. These lithologies are found in the nearby Wilson Group and Granite Harbour Intrusives, and the clasts are most likely derived from them. At the northwestern locality, knockers of quartz-talc-magnesite-fuchsite/mariposite up to 10 m long are present within the unit. This mineral assemblage is generally considered to result from hydrothermal metasomatism of ultramafic rock (Witkopp, 1980). Smaller clasts are augen-shaped and the Husky Conglomerate has an overall flaser structure imparting a weak foliation roughly parallel to the strike of the unit. Many augen are flanked by pressure shadows of coarser grained matrix minerals. The matrix is mafic to ultramafic in composition, consisting essentially of actinolite and chlorite with minor amounts of epidote and albite. Since some of the actinolite porphyroblasts cut the foliation and matrix/augen boundaries, it is inferred that the greenschist facies metamorphism, at least in part, post-dates cataclasis (Figure 6).

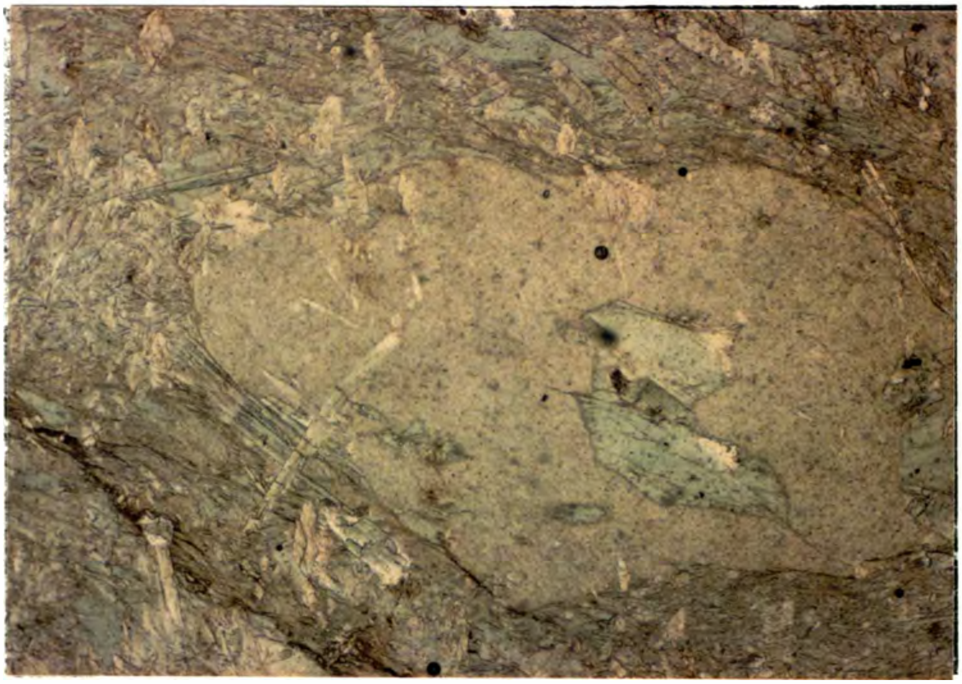


Figure 6. Photomicrograph of blastomylonitic matrix from the contact between the Sledgers and Wilson Groups. Note the chloritic augen and the actinolite pophyroblasts. Magnification is 4ØX.

In light of this evidence, the Husky Conglomerate is interpreted as a cataclastic rock formed along a major fault zone under greenschist facies conditions. Later movement resulted in the formation of a low-grade fault pug and juxtaposition of the Molar Formation and the Wilson Group (and possibly their interdigitation at Reilly ridge). It is proposed that the Husky Conglomerate be abandoned as a stratigraphic term.

Sledgers Group

The Sledgers Group (Figure 7) consists of the Solidarity Formation (Wodzicki and Robert, in press) overlain by the interfingering Molar and Glasgow Formations. The Solidarity and Glasgow Formations consist mainly of volcanic rocks, whereas the Molar Formation is sedimentary but locally contains a volcaniclastic component. The measured thickness of the Sledgers Group in the Mt. Soza and lower Carryer Glacier-Mt. Gow sections is 4.7 km; whereas, to the east and southeast, in the upper Carryer Glacier-Mt. Jamroga and northern Molar Massif sections, it is 3.5 km thick (Wodzicki and Robert, in press). These are minimum thicknesses because pre-Solidarity basement is not known in the study area.

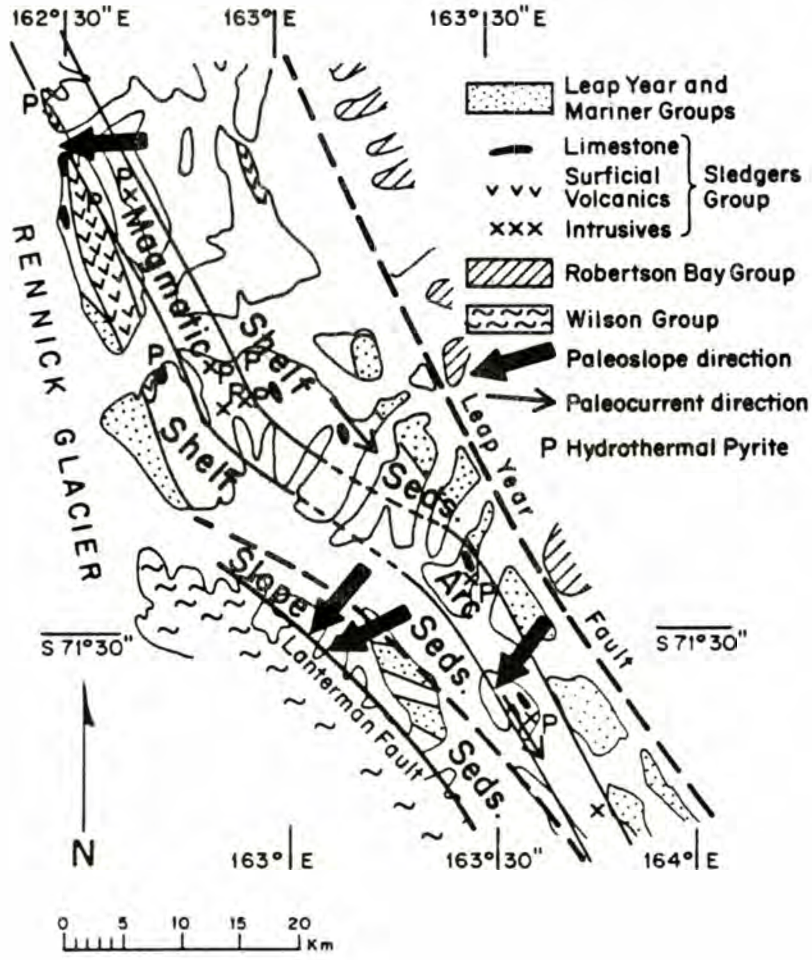


Figure 7. Sketch map of central Bowers Mountains showing some important geological features of the Sledgers Group (after Wodzicki and Robert, in press).

Solidarity Formation

The Solidarity Formation crops out in the west central Solidarity Range (Figure 4) and extends from the Carryer Glacier to the crest of the Solidarity Range and possibly southward to the Sledgers Glacier. Its type locality is along the crest of the Solidarity Range at Latitude 71°20'S, Longitude 162°50'E where it is at least 400 m thick; its base not exposed (Wodzicki and Robert, in press). It consists of pillow basalt and breccia intruded by dikes and sills of basaltic composition. Along the Carryer Glacier, minor amounts of chert and siliceous mudstone are interbedded with the volcanic rocks (Wodzicki and Robert, in press).

The basaltic lavas are porphyrytic with relict, subhedral plagioclase grains up to 0.3 mm long and anhedral, intergranular clinopyroxene and orthopyroxene grains up to 0.1 mm long. The plagioclase has been altered to albite and sericite and is replaced by chlorite. The clinopyroxene has been partly replaced by chlorite, calcite, sphene, quartz, and pumpellyite, and the orthopyroxene has been completely replaced by chlorite. The rock is cut by veinlets that contain chlorite, white mica, calcite, and prehnite (Figure 8).

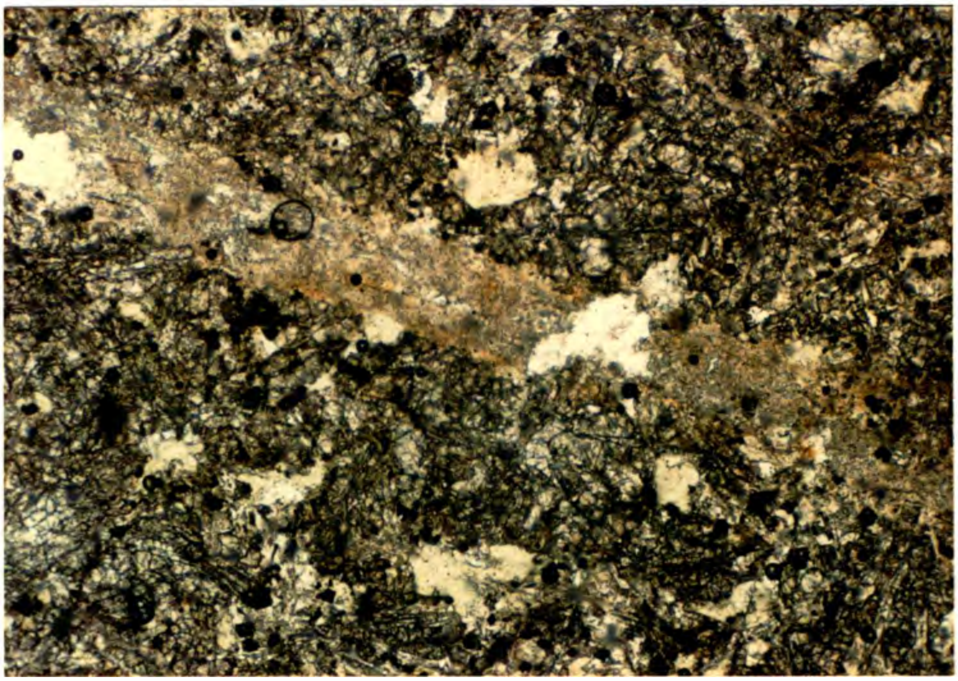


Figure 8. Photomicrograph showing prehnite veins within the Solidarity Formation basalts. Magnification is 40X.

The dikes and sills consist of clinopyroxene, plagioclase, and orthopyroxene. The clinopyroxenes are up to 1.5 mm long and have a sub-ophitic texture. The plagioclase occurs as laths up to 0.9 mm long. The relict orthopyroxene grains are anhedral to subhedral and up to 0.15 mm long. The pyroxenes are partly altered to chlorite, and the plagioclase is altered to albite. Fine grained sphene is disseminated throughout the rock.

This unit has been differentiated from the Glasgow Formation and named because it is separated from the main mass of Glasgow Formation by about 1 km of Molar Formation and because it is geochemically distinct from the Glasgow Formation.

Molar Formation

The Molar Formation crops out extensively and is volumetrically dominant in the structurally high core near the central part of the study area. In the central Solidarity Range it rests, apparently conformably, on the Solidarity Formation, but elsewhere the base is not exposed (Wodzicki and Robert, in press). Evidence indicates that the Molar Formation, at least in part, interfingers with the Glasgow Formation. In the Mt. Soza area about 1 km of Molar underlies and about 450 m rests above the Glasgow

Formation (Figure 5). In the lower Carryer Glacier-Mt. Gow area about 1.5 km of Molar underlies the Glasgow Formation, and in the upper Carryer Glacier-Mt. Jamroga area an additional 800 m of Molar interfingers with the Glasgow Formation. In the northern Molar Massif at least 2 km of Molar underlies the Glasgow Formation. Based on paleontological evidence, Cooper et al. (1983) have determined the Molar Formation is Middle Cambrian in age. Three lithologies are recognizable (Plate 1): tuffaceous sandstones and mudstones, sandstones and mudstones locally with limestone, and debris-flow deposits. A separate slope and shelf facies has been recognized (Figure 7).

The slope facies (Wodzicki and Robert, in press) is present mainly along the northwestern flank of the Lanterman Range and on Reilly Ridge. It consists almost entirely of a turbidite sequence with minor amounts of interbedded debris-flow deposits of the Glasgow Formation. Beds are graded from coarse sandstone to mudstone with the upper part locally convoluted. Flute and groove casts are very common and invariably indicate sediment transport and paleoslopes toward the southwest and west-southwest (Figure 7).

The sandstones are coarse to fine grained feldspathic to lithic wackes that are very poorly to moderately sorted and angular to subrounded. They typically contain 30-45%

quartz, 15-20% feldspar, 5-40% lithics, and 15-30% matrix. Minor constituents include biotite, muscovite, tourmaline, zircon, magnetite, sphene, garnet, and pyrite. Twenty to 40% of the total feldspar is K-feldspar. The matrix consists mainly of quartz, muscovite, and chlorite. Lithic grains include redeposited Molar sandstone, mudstone, and minor amounts of limestone; redeposited Glasgow volcanics; quartz-mica tectonites; tonalite; and biotite granite. The sandstones consist in part of redeposited Sledgers Group but have an important component with a granitic and metamorphic provenance. Secondary mineralization includes albitization and sericitization of feldspars, prehnite and chlorite development in volcanic lithics, hematite after magnetite, and cross-cutting veins of calcite and quartz.

The shelf facies of the Molar Formation (Wodzicki and Robert, in press) extends over most of the study area except for the south side of the Sledgers Glacier (Figure 7). The lower part of the sequence is characterized by finely laminated, dark mudstone interbedded with fine sandstone, massive sandstone, and locally graded sandstone. The upper part of the sequence is characterized by interbedded dark mudstone and fine sandstone, limestone, and near the top, debris-flow deposits. The massive and graded sandstones and locally the mudstones tend to be tuffaceous in the western part of the Solidarity Range and to the west of Morley Glacier (Figure 4). Tuffaceous units become less common eastward and southward. The uppermost part of the section does not contain tuffs suggesting that volcanism had ceased.

The mudstones consist mainly of quartz and feldspar in an orthomatrix of chlorite and muscovite. The clastic grains are subangular to subrounded and well sorted. The interbedded fine sandstones are also quartzo-feldspathic and well sorted. Locally they show ripple marks and current bedding indicating bottom current transport from northwest to southeast (Laird et al., 1982) (Figure 7). The sandstones are coarse to medium grained, angular to subrounded, poorly to moderately sorted, feldspathic arenites and wackes. Their range in constituent concentration is as follows: quartz 12-15%, feldspar 23-30%, lithics 10-40%, and matrix 10-25%. Minor amounts of clastic biotite, muscovite, magnetite, hornblende, clinopyroxene, apatite, tourmaline, zircon, sphene, and garnet are also present. The orthomatrix consists mainly of mica, chlorite, quartz, and calcite. The proportion of K-feldspar to total feldspar varies between 15 and 50%. Glasgow volcanics are the dominant lithic grains with minor amount of sandstone, mudstone, quartz-mica tectonites, and granitic clasts also present. The sandstones thus contain redeposited Sledgers Group and components of a granitic and metamorphic terrane. Secondary mineralization of sandstones include albitization and sericitization of feldspars; prehnite, pumpellyite, and chlorite development in volcanic clasts; hematite after magnetite; and cross-cutting veinlets of calcite.

Debris-flow deposits in the Molar Formation (Wodzicki and Robert, in press) are found along the western flank of Mt. Soza, along the lower Carryer Glacier, near Mt. Jamroga, and in the northern parts of the Molar Massif. The debris flow deposits are breccias with clasts up to 5 m in length set in a muddy matrix. At all locations these deposits lie near the upper part of the Molar Formation. Adjacent sandstones and mudstones locally show asymmteric folds probably related to the downslope emplacement of the debris flows. Along the Alt Glacier, westward paleoslopes are indicated; in the northern Molar Massif paleoslopes are to the southwest (Laird et al., 1982) (Figure 7). These directions are in excellent agreement with paleoslopes determined along the Sledgers Glacier using flute casts. Both support a westward to southwestward deepening of the basin of deposition.

In the western localities the clasts within the debris flows include sandstone, mudstone, limestone, mafic volcanics, and rhyolites. The sandstones and mudstones are typical Molar lithologies. The mafic volcanics consist of porphyrytic basalts composed of randomly arranged laths of relict plagioclase and clinopyroxene with minor amounts of magnetite and sphene set in a fine-grained matrix of albite, chlorite, and epidote. The rhyolite clasts are composed of fine- to medium-grained, relict plagioclase with medium-grained, interstitial quartz and minor amounts of pyrite in a fine-grained, albite, quartz, chlorite, and pyrite groundmass. The limestones, some of which are oolitic, are recrystallized and contain minor amounts of quartz, fine-grained volcanic lithics, and silty mudstone. The eastern locality lithologies are more varied and include clasts of intermediate to felsic porphyrytic volcanics, quartzo-feldspathic sandstones with minor amounts of calcite cement, limestones with minor amounts of ooids, mudstones, granophyres, tonalites, muscovite granites, and quartz-mica tectonites. The presence of oolitic limestone, rhyolite, granitic intrusives, and quartz-mica tectonites suggests a mixed shallow-marine/continental provenance. Futhermore, the dominance of continentally derived lithologies in the eastern localities suggests that a land mass existed to the east.

Glasgow Formation

The Glasgow Formation crops out mainly near the western and eastern margins of the study area, in the Mt. Soza-western Solidarity Range and in the Mt. Glasgow-northern Molar Massif areas respectively (Figure 4). The Glasgow and Molar Formations interfinger. Near the top of the Sledgers Group, 2.7 km of Glasgow Formation is found in the Mt. Soza area and 2.2 km in the lower Carryer Glacier area. Westward toward the Mt. Jamroga area, the Glasgow Formation thins. In the northern Molar Massif it is present as a Ø.8 km wedge near the upper part of the Sledgers Glacier (Figure 5). The age of the Glasgow Formation must lie within the range of the Molar Formation and is probably post-early Middle Cambrian and pre-late Middle Cambrian. On the geologic map and cross-sections in the Plate, the Glasgow Formation has been subdivided into flows, volcanic breccia, pillowed flows, volcanic breccia and conglomerate with a fine-grained matrix, and intrusive rocks.

Flows and volcanic breccias crop out mainly in a belt extending from the Alt Glacier through Mt. Soza to the lower Carryer Glacier. Massive, angular, monolithologic breccias and massive flows are the dominant lithologies, but welded tuffs occur locally (Wodzicki and Robert, in press). Mafic to felsic flows and breccias are present. Mafic varieties include intergranular and porphyrytic basalts. Intergranular basalts consist of randomly arranged albitized plagioclase laths up to Ø.12 mm in length with interstitial, anhedral to subhedral clinopyroxene, amphibole, and magnetite grains up to Ø.Ø9 mm long. The clinopyroxene is partially replaced by chlorite, the amphibole is completely replaced by chlorite and rimmed by magnetite, and the magnetite is altered to hematite which imparts a red color to the rocks. Minor amounts of sphene and veins of calcite are also present. Porphyrytic basalts consist of aligned, anhedral to euhedral, relict plagioclase laths from Ø.1 to 1.6 mm long, subhedral grains of clinopyroxene Ø.12 to 2.8 mm long, anhedral to subhedral grains of magnetite up to 1.8 mm long, and a fine-grained groundmass of albite, clinopyroxene, magnetite, and chlorite. Plagioclase is altered to albite and sericite and is replaced by chlorite. Clinopyroxene is partially altered to chlorite, and magnetite is altered to hematite.

Intermediate composition flows and breccias are porphyrytic and amygdaloidal and consist of subhedral to euhedral laths of sub-pilotaxitic, relict plagioclase up to 1.5 mm long; subhedral to euhedral amphibole grains up to 1.5 mm long; anhedral to subhedral clinopyroxene grains up to 3.Ø mm long; anhedral to subhedral magnetite grains up to Ø.7 mm long; and chlorite. Plagioclase is altered to albite and sericite and is replaced by calcite and chlorite. Amphibole is altered to muscovite, chlorite, albite, calcite, epidote, sphene, hematite, and quartz. Clinopyroxene is partially altered to chlorite, and magnetite is altered to hematite. Amygdales are commonly filled with various mineral combinations such as pumpellyite, prehnite, and quartz; pumpellyite, zoisite, and quartz; quartz and calcite; pumpellyite; and chlorite. Cross-cutting veins of quartz, epidote, and calcite; quartz, prehnite, and calcite; and quartz, epidote, and chlorite are common.

Felsic flows and breccias can be subdivided according to their distinct textures. Porphyrytic felsic volcanics from south of the Alt Glacier consist of partially resorbed, subhedral plagioclase grains up to 5.7 mm long; anhedral to subhedral, partially resorbed grains of quartz up to 3.5 mm long; anhedral to subhedral grains of amphibole up to 1.5 mm long; subhedral to euhedral magnetite grains up to Ø.45 mm long; and a ground mass of albite, quartz, magnetite, and chlorite. Plagioclase is altered to albite and sericite and is replaced by calcite and chlorite. Amphibole is rimmed by hematite and is altered to chlorite, quartz, epidote, and calcite.

Magnetite is altered to hematite. North of the Alt Glacier, fine- to medium-grained, hypidiomorphic granular, felsic flows are present (Wodzicki and Robert, in press). They consist dominantly of aligned laths of albitized plagioclase up to Ø.3 mm long and fewer euhedral grains of albitized plagioclase up to 1.2 mm long. Anhedral quartz grains occur interstitially and are up to Ø.3 mm long. Minor amounts of subhedral amphibole grains up to Ø.45 mm long are also present. The amphibole is altered to pumpellyite and chlorite. Veins of calcite, prehnite, and epidote are common.

Pyroclastic rocks from the Glasgow Formation include crystal and welded tuffs. The former are composed of relict shards with well preserved conchoidal fracture and relict crystals, possibly of clinopyroxene and amphibole, that are completely altered to chlorite. The matrix consists of muscovite and quartz. The latter are partially welded lapilli tuffs consisting of squashed, relict pumice fragments in an altered matrix of muscovite, quartz, calcite, prehnite, pumpellyite, and epidote.

Pillow lavas and associated breccias crop out mainly in a zone along the eastern flank of Mt. Soza and in the central Solidarity Range where they are associated with limestone encrustations and interbeds (Wodzicki and Robert, in press). Pillowed flows are mafic and porphyrytic and consist of subhedral to euhedral grains of aligned plagioclase up to 2.4 mm long; anhedral to euhedral grains of clinopyroxene up to 1.5 mm long; subhedral grains of orthopyroxene up to 2.5 mm long; flow-elongated amygdales up to Ø.1 mm long; and a fine-grained groundmass of albite microlites, clinopyroxene, and sphene. Less commonly, a vitrophyric groundmass that is completely altered to prehnite also occurs. Plagioclase is altered to albite and is replaced by calcite and chlorite. Clinopyroxene is partially altered to chlorite, prehnite, calcite, and quartz. Orthopyroxene is altered to chlorite. Amygdales are filled with chlorite and pumpellyite. Veins of quartz; and quartz, calcite, and muscovite are present.

Volcanic breccia with clasts up to 2Ø cm long set in a fine-grained matrix is the most common lithology in the Glasgow Formation (Wodzicki and Robert, in press). Conglomerates occur locally along the lower Carryer Glacier. Some of the breccias are polylithologic and contain granitic and sedimentary clasts in addition to the more common mafic to intermediate volcanic clasts. For instance, the conglomerate exposed along the lower Carryer Glacier contains 65% volcanic clasts, 3Ø% sandstone clasts, and traces of limestone, chert, and granite clasts (Wodzicki and Robert, in press). The breccias and conglomerates are characterized by a fine-grained, green, chloritic, foliated matrix. The matrix is interpreted as originally having been tuffaceous and muddy. The breccias are commonly interbedded with Molar sediments (Wodzicki and Robert, in press) and were deposited, at least locally, as submarine debris flows. The breccias grade into poorly sorted, tuffaceous, lithic wackes of the Molar Formation. Lithologies present in the debris flows include porphyrytic, mafic to intermediate Glasgow volcanics; medium-grained diabase; fine-grained, quartzo-feldspathic Molar sandstone and siltstone; recrystallized, oolitic limestone; indurated chert; medium-grained, tonalitic granite; and granodiorite. The matrix is very poorly sorted and consists of a very fine-grained, foliated, micaceous, quartzo-feldspathic sand with medium-grained quartz and volcanic lithic clasts.

Dikes and sills are locally associated with the Glasgow Formation pillow lavas and breccias north of the Alt Glacier, in the southern Solidarity Range, and in the northern Molar Massif (Figure 7). These mafic to intermediate intrusions are similar in composition to the associated volcanics and may represent feeder dikes for them. Mafic dikes consist of clinopyroxene, plagioclase, orthopyroxene, and magnetite and have a diabasic texture. Subophitic clinopyroxene grains, that are partially altered to chlorite, are up to 2 mm long and exhibit a dendritic morphology indicative of rapid crystallization. Plagioclase grains are subhedral, up to 1.5 mm long, and are altered to albite and replaced by calcite and chlorite. Orthopyroxene grains are subhedral, up to 1.9 mm long, and are altered to spherulitic phrenite with some crystals exhibiting fine dustings of magnetite along their edges. Fine-grained sphene and calcite veins are also present. Sills, intermediate in composition, are porphyrytic and consist of subhedral plagioclase grains up to 1.8 mm long; subhedral to euhedral clinopyroxene grains up to 3.0 mm long; and a fine-grained groundmass of albite, sphene, and chlorite. Plagioclase is altered to albite and sericite and is replaced by chlorite. Clinopyroxene is partially altered to chlorite, pumpellyite, and quartz.

A hypabyssal intrusion is located on Hicks Ridge between Mt. Soza and Morley Glacier (Figure 7). The intrusion is at least 0.8 km in diameter, but no contact with older rocks has been observed (Wodzicki and Robert, in press). Numerous xenoliths are incorporated into the intrusive rock. They comprise about 60% of the total rock in the west decreasing eastward to about 10% (Wodzicki and Robert, in press). The intrusion consists of fine- to medium-grained plagioclase, amphibole, and quartz phenocrysts; quartz xenocrysts; amphibole-feldspar porphyry inclusions; and xenoliths of porphyrytic, felsic volcanics, slate, sandstone, and quartzite, in a fine-grained quartz-feldspar mesostasis. Plagioclase phenocrysts are anhedral to subhedral and completely altered to albite and sericite. Amphibole phenocrysts are anhedral to subhedral, commonly show resorption features, and are altered to chlorite along crystal fractures. Quartz phenocrysts are all anhedral and embayed. Xenocrysts of quartz are commonly broken and angular and show evidence of resorption. Xenoliths of felsic volcanics are commonly angular. Slate xenoliths occur as thin and elongated schlieren which are deformed around more competent grains. Amphibole-feldspar porphyry inclusions consist of subhedral grains of medium-grained plagioclase with megacrysts of plagioclase reaching 9.0 mm in length; subhedral grains of hornblende up to 2.5 mm long and aligned laths up to 0.2 mm long; minor amounts of quartz and apatite grains up to 0.1 mm long; and a fine-grained groundmass of quartz, albite, and chlorite. Plagioclase is completely altered to albite and sericite and exhibits resorption features. Hornblende grains are embayed and altered to chlorite along crystal fractures.

The foliation of the fine-grained xenoliths parallels the regional trend suggesting that the intrusion pre-dates folding and metamorphism in the area (Wodzicki and Robert, in press). Even though the contact of the intrusion has not been observed, the high xenolith content suggests that the roof was not far above the present level of exposure. Furthermore, the high proportion of volcanic xenoliths and the presence of similar lithologies in the overlying Glasgow Formation suggest that the intrusive may be subvolcanic.

All the intrusive rocks in the study area lie along a linear zone that is slightly oblique to the regional trend of the Bowers Supergroup (see Figure 5). If the dikes and sills indeed represent feeders for the volcanics and the hypabyssal intrusive is a subvolcanic pluton, then the zone of intrusions may represent the axis of a Middle Cambrian magmatic arc (Figure 7).

The paleogeography during Molar and Glasgow time is depicted schematically in figure 9 and can be summarized as follows. A chain of volcanic islands with subvolcanic intrusions lay to the southwest of a continental landmass. The basin of deposition sloped to the southwest. Volcanics and shelf sediments were deposited in the northeastern part of the basin, whereas turbidites were deposited in the deeper part of the basin to the southwest. The provenance of the sediments was the magmatic arc and the continental landmass.

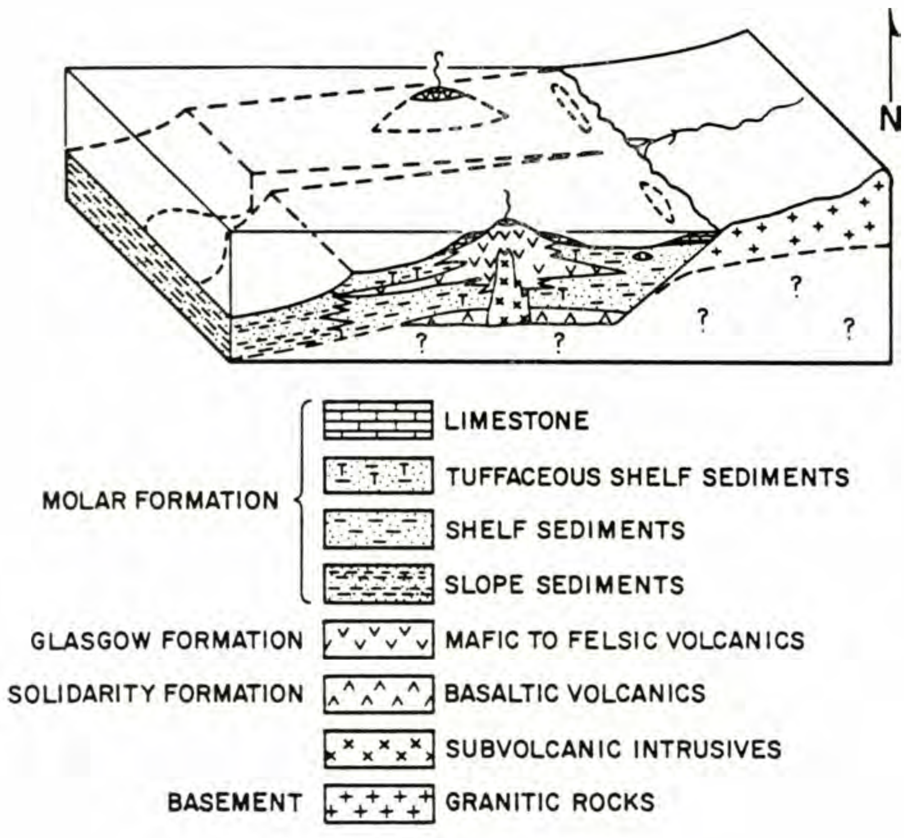


Figure 9. A schematic reconstruction of the paleogeography during Sledgers time (after Wodzicki and Robert, in press).

Mariner Group

The Mariner Group crops out near the eastern margin of the study area where the Spurs Formation is present. The Mariner Group was not investigated during the 1981-1982 USARP expedition, but Laird et al. (1982) and Laird and Bradshaw (1983) describe it as a regressive sequence and the Spurs Formation, one of its members, as mudstone with minor lenses and layers of fossiliferous limestone with increasing proportions of sandstone toward the top of the formation. In the Mt. Jamroga area the Spurs Formation is about Ø.9 km thick and rests conformably on the Molar Formation. The Spurs Formation thins to the west and is not present in the lower Carryer Glacier region. Near the Alt Glacier, lithologies similar to those present in the Spurs Formation were noted not far below the Carryer Conglomerate. No fossils were found at this location however, and the rocks were tentatively mapped as the upper part of the Molar Formation (Wodzicki and Robert, in press). Based on paleontological evidence, Cooper et al. (1983) consider that the Mariner Group was deposited between late Middle Cambrian and Late Cambrian.

Sediment transport, according to Laird and Bradshaw (1983), was to the northeast and northwest. Sandstones within the Spurs Formation contain clastic quartz, plagioclase, biotite, muscovite, and chlorite; are largely of granitic provenance; and contain no volcaniclastic material (Wodzicki et al., 1982a).

Leap Year Group

The Leap Year Group rests unconformably on the Sledgers and the Mariner Groups and consists of the Carryer Conglomerate, the Camp Ridge Quartzite, and the Reilly Conglomerate. The Carryer Conglomerate crops out mainly in the western part of the study area and the Camp Ridge Quartzite lies in the eastern part. At Reilly Ridge, northwest of the Molar Massif (Figure 4), Reilly Conglomerate rests on Carryer Conglomerate with an erosional contact.

Carryer Conglomerate

The Carryer Conglomerate is the oldest formation in the Leap Year Group. It crops out along the western margin of the study area between the Alt and Sledgers Glaciers. It rests unconformably on the Molar Formation near Mt. Soza, and on the Mariner Group at Reilly Ridge. Along the lower Carryer Glacier, the underlying Glasgow Formation is enriched in hematite and white mica suggesting a paleo-weathered horizon below the contact (Wodzicki and Robert, in press). Laird et al. (1982) report that in the lower Carryer Glacier area the dominant paleocurrent direction was toward the northeast.

Wodzicki and Robert (in press) describe the Carryer Conglomerate as a basal sandstone overlain by a thick conglomerate. The basal sandstone varies in thickness between 150 and 400 m. It consists mainly of red and green sandstones that are locally cross-bedded and contain well preserved ripple marks. The sandstones are interbedded with minor amounts of polymictic conglomerate and red mudstone. Sandstones are subangular to subrounded, poorly to moderately sorted, medium- to coarse-grained, feldspathic and lithic wackes. They typically contain 50-65% quartz, 5-20% feldspar, 5-20% lithics, and 15-25% matrix. Minor constituents include biotite, muscovite, zircon, tourmaline, magnetite, hornblende, and garnet. A trace to 70% of the total feldspar is K-feldspar, and the matrix consists mainly of muscovite, chlorite, and quartz. Lithic grains include redeposited sediments and volcanics from the underlying Sledgers and Mariner Groups, quartz-mica tectonites, muscovite schists, and chert. Secondary minerals include chlorite after biotite, tourmaline, and garnet; albite, sericite, and calcite after plagioclase; sericite after K-Feldspar; hematite after magnetite; patches and veinlets of epidote, prehnite and pumpellyite; and minor amounts of calcite and limonitic cement. Reddish colored sandstones contain an abundance of hematite stained lithics and limonitic cement, whereas greenish sandstones contain few stained lithics, minor amounts of limonitic cement, and more matrix.

The overlying conglomeratic unit consists mainly of polymictic conglomerate with minor amounts of interbedded sandstone and local mudstone which are more common toward the top. The conglomerate is well rounded with boulders up to 30 cm in diameter, has a sandy matrix, and is stained red. Pebble counts at nine, approximately equally spaced, stratigraphic horizons show that the percentage of different lithologies varies as follows: sandstone 5-10%, mudstone trace-10%, polycrystalline quartz trace-5%, volcanics 5-10%, and granite 5-25% (Wodzicki and Robert, in press). There appears to be no systematic change in the proportion of clast lithologies over the 1.1 km of section studied.

The clast sandstones are subangular to subrounded, very poorly to moderately sorted, very coarse- to fine-grained, reddish, feldspathic and lithic wackes. Typically they contain 45-75% quartz, 5-20% feldspar, trace to 25% lithics, and 15-35% matrix. Minor constituents include biotite, muscovite, tourmaline, zircon, magnetite, and garnet. A trace to 80% of the total feldspar is K-feldspar, and the matrix consists mainly of muscovite, chlorite, quartz, and calcite. Lithic fragments include volcanics, sandstones, and quartz-mica tectonites. The sandstones are similar to those found in the Molar Formation and were probably derived from them. The mudstone clasts are red and foliated and were probably derived from similar lithologies found in the Spurs and Molar Formations. Polycrystalline quartz clasts include hydrothermal quartz and chert.

The volcanic clasts are andesitic breccias and porphyrytic dacites. Breccia clasts are hematite-stained and consist of aligned, relict plagioclase microlites and pumpellyite, quartz, and chlorite filled amygdales. The dacites consist of fine- to medium-grained plagioclase, quartz, magnetite, and hornblende grains in a fine-grained albite, quartz, magnetite groundmass. Plagioclase grains are dominantly subhedral and altered to albite and sericite, and replaced by chlorite. Quartz grains are anhedral and often embayed. Magnetite grains are anhedral to subhedral and altered to hematite. Hornblende grains are anhedral to subhedral and completely altered to chlorite and hematite. Wodzicki et al. (1982a) report the presence of pyroxene andesite and hornblende dacite clasts in the Carryer Conglomerate. All recorded volcanic lithologies are similar to those found in the underlying Glasgow Formation.

The granitic clasts consist of megaporphyrytic, granophyric, and gneissic, two-mica granites. Gneissic fragments are medium- to coarse-grained and consist of subequal amount of plagioclase, K-feldspar, and quartz with accessory biotite and muscovite. Plagioclase grains are altered to albite and sericite, K-feldspar grains to sericite, and biotite grains (some with metamict zircons) to chlorite. Quartz grains have a consertal texture, and K-feldspar grains commonly show perthitic lamellae of albite. Granophyric pebbles are medium- to coarse-grained and contain subequal amounts of plagioclase, K-feldspar, and quartz plus minor amounts of biotite and magnetite. Quartz and K-feldspar occur as graphic intergrowths radiating out from relict feldspar cores. Plagioclase is altered to albite and sericite, K-feldspar to sericite, and biotite to chlorite. Megaporphyrytic granites consist of subequal amounts of plagioclase, megacrysts of K-feldspar up to 10.5 mm long, and quartz plus accessory biotite, muscovite, and magnetite. Plagioclase is altered to albite and sericite and is replaced by calcite; K-feldspar to sericite; biotite to chlorite and hematite,; and magnetite to hematite. Wodzicki et al. (1982a) report alaskite, biotite-quartz monzonite, biotite granodiorite, hornblende granodiorite, and pyroxene-quartz diorite clasts in the Carryer Conglomerate. Babcock et al. (in press) describe lithologies similar to the two-mica, megaporphyrytic, granitoid clasts in the Carryer Conglomerate in the Granite Harbour Intrusives to the west of the Bowers Supergroup. It is within the Carryer Conglomerate that these two-mica, epizonal, S-type granitoids make their first appearance in the stratigraphic succession. This is significant because it implies the presence of rocks similar to the Granite Harbour Intrusives in the nearby highlands at this time.

Camp Ridge Quartzite and Reilly Conglomerate

These formations crop out along the eastern margin of the study area and at Reilly Ridge respectively and comprise the upper formations of the Leap Year Group. They were not investigated during the 1981-1982 USARP expedition, but Laird et al. (1982) and Laird and Bradshaw (1983) discuss them in detail. The Camp Ridge Quartzite is at least 2.5 km thick in the northern Molar Massif area and rests with apparent unconformity on the Spurs and Molar Formations. It consists of texturally immature, reddish-brown to yellow, cross-bedded, quartzose sandstone and conglomerate interbedded with minor amounts of mudstone. The Camp Ridge Quartzite is composed of fluvial sediment which, in the northern Molar Massif area, was transported toward the northeast. According to Wodzicki et al. (1982a), the formation consists mainly of quartz but contains variable amounts of plagioclase, perthitic orthoclase, microcline, muscovite, and traces of biotite, epidote, clinozoisite, tourmaline, zircon, apatite, and garnet. The provenance is mainly granitic with a smaller component originating from a metamorphic terrane. The Reilly Conglomerate is a quartz-rich conglomerate with clasts of quartz, quartzite, minor amounts of schists, and traces of plagioclase, perthitic orthoclase, and microcline (Wodzicki et al., 1982a). It rests with an erosional contact on the Carryer Conglomerate at Reilly Ridge (Bradshaw et al., 1982). It is at least 300 m thick and is considered to be the stratigraphic equivalent of the Camp Ridge Quartzite (Laird et al., 1982).

The age of the Leap Year Group is not exactly known. Cooper et al (1983) consider it to be Late Cambrian to Ordovician. However, the presence of probable Granite Harbour Intrusives clasts in the Carryer Conglomerate and the lack of xenolithic/xenocrystic or layered granitoids associated with the Wilson Gneiss Complex suggest that sedimentation was younger than 480 $\pm$ 10 Ma, the age of the Granite Harbour Intrusives (Vetter et al., 1983). Furthermore, the entire Leap Year Group underwent folding, metamorphism, and uplift prior to 467 Ma (Adams et al., 1982). The deposition of the Leap Year Group thus probably took place between 480 and 467 Ma, i.e. somewhat later and over a shorter period than suggested by previous workers.

Sills and dikes intruding the Carryer Conglomerate are located along the south side of the lower Carryer Glacier in the western Solidarity Range. The intrusions are 1 to 10 m thick and intermediate in composition. They consist of coarse-grained plagioclase , fine- to medium-grained, aligned laths of plagioclase, minor amounts of clinopyroxene and sphene in an altered, glassy groundmass. Plagioclase and clinopyroxene grains are anhedral to subhedral. Plagioclase is altered to albite and replaced by calcite and chlorite. Clinopyroxene is altered to albite, calcite, chlorite, pumpellyite, epidote, and quartz (Figure 10). The metamorphic mineral assemblage is consistent with that found in the Solidarity and Glasgow Formations and indicates emplacement of the Carryer intrusive rocks prior to regional metamorphism. This is the first known occurence of post-Leap Year Group pre-Admiralty Intrusives igneous rocks in northern Victoria Land.

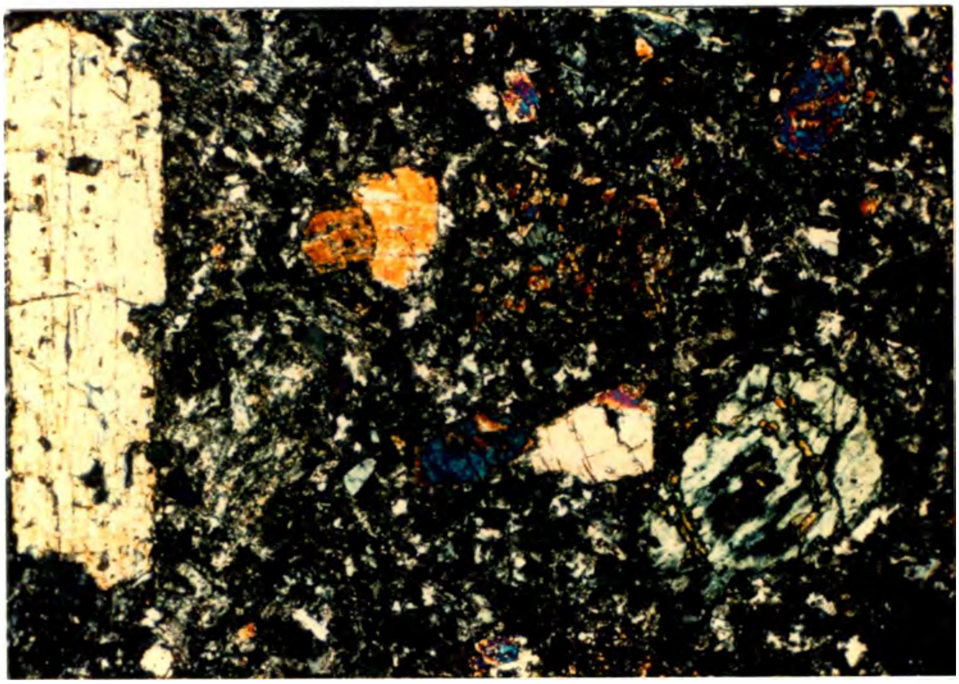


Figure 1Ø. Photomicrograph of a dike intrusive into the Carryer Conglomerate. Magnification is 4ØX.

Modal Analysis of Sandstones

Modal analyses of detrital framework grains of sandstones collected from the Sledgers Group (Molar Formation), Carryer Conglomerate, and Camp Ridge Quartzite were performed to determine their provenance. A modified version of the Dickinson and Suczek (1979) method was employed. Samples were etched with hydrofluoric acid and stained for plagioclase and K-feldspar. A total of fifty samples was counted. Point count data were recalculated as volumetric proportions using the method of Graham et al. (1976). The data are displayed on ternary diagrams (Figure 11).

The ternary diagrams indicate that the Sledgers Group sediments were derived from both a magmatic arc and a continental block. The scatter of points for the Sledgers Group analyses may represent contamination of magmatic arc sediments by continental block sediments. Carryer sandstone analyses plot in the recycled orogen and continental block provenance fields on the Q-F-L and Qm-F-Lt ternary diagrams and cluster near the apex of increased maturity or stability from continental block provenances on the Qm-P-K ternary diagram (Figure 11). the sandstone compositions agree with field data indicating that the Carryer Conglomerate was derived both from the

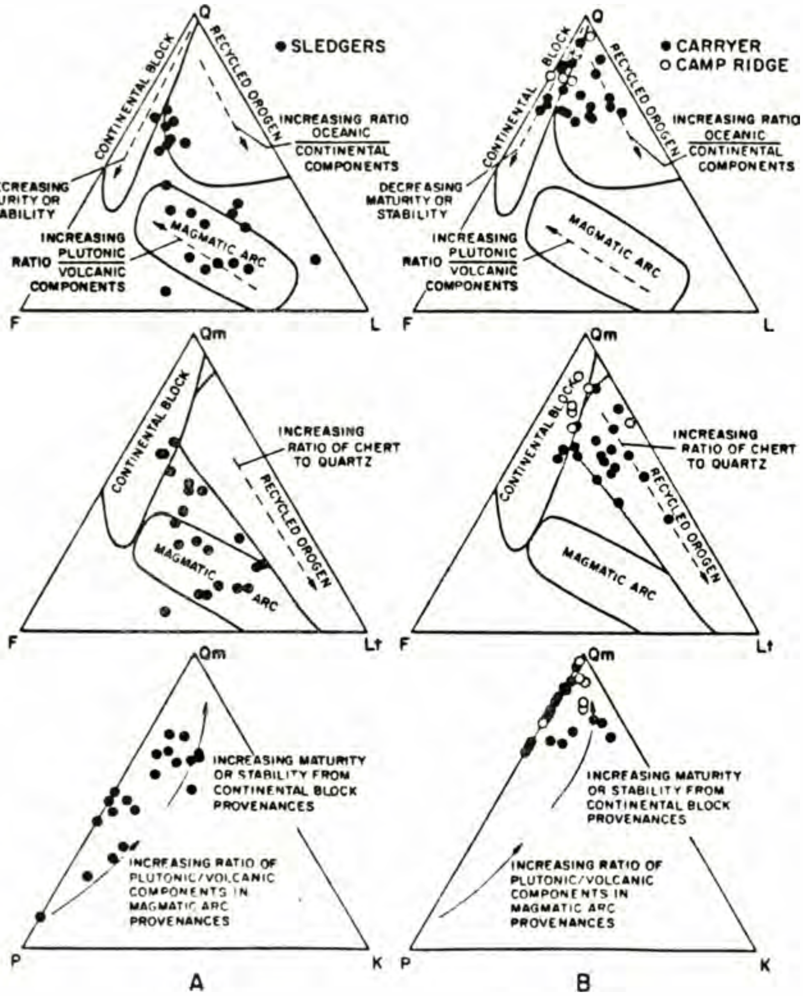


Figure 11. Dickinson and Suczek (1979)-type sandstone composition ternary diagrams showing compositional trends in (A) Sledgers Group sediments (Molar Formation and (B) Carryer Conglomerate and Camp Ridge Quartzite. Q = quartz, F = feldspar, L = lithics, Qm = monocrystalline quartz, Lt = total lithics, P = plagioclase, and K = potassium feldspar.

underlying Sledgers Group (recycled orogen) and from a terrane containing epizonal, S-type granitoids (continental block). The Camp Ridge quartzite analyses plot mainly in the field of continental block provenance on the Q-F-L and Qm-F-Lt ternary diagrams. On the Qm-P-K ternary diagram, the analyses plot with those of the Carryer Conglomerate. This is consistent with field data indicating that the Camp Ridge Quartzite was derived mainly from a granitic source.

Geochemistry of Igneous Rocks

Twenty-four samples of flows and intrusives were selected for chemical analyses. The sample locations are shown on the Plate and on a schematic stratigraphic column (Figure 12). Only samples with a minimum of veining and metasomatic replacement by minerals such as calcite and prehnite were analyzed. Eight of these samples are from dikes and flows of the Solidarity Formation; 13 are from dikes, sills, and flows of the Glasgow Formation; and three are from dikes and sills intruding the Carryer Conglomerate. A brief petrographic description of each analyzed sample is given in the Appendix. The samples were analyzed for major elements and for P, Sc, Ti, V, Cr, Sr, Y, Zr, Nb, and Ba. The analyses were performed by A. Irving at the University of Washington using inductively

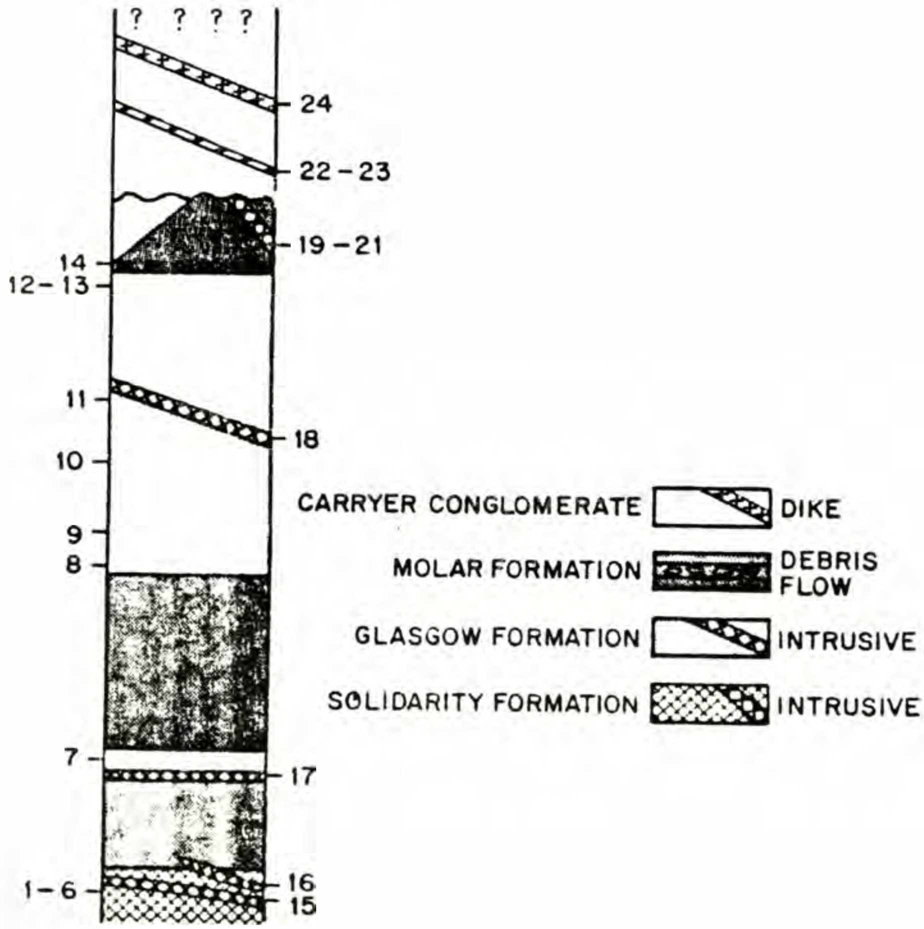


Figure 12. Schematic stratigraphic column showing relative stratigraphic locations of analyzed samples.

coupled plasma spectroscopy techniques described by Thompson and Walsh (1983). The results of the analyses (Appendix, Table 2) are plotted (Figures 13-18) together with the analyses of Glasgow Formation volcanics reported by Weaver et al. (1984). These analyses were used to classify the igneous rocks and to interpret their geochemistry in terms of the plate tectonic environment of their emplacement.

In most samples the concentration of elements with low field strength (ionic potential) such as K, Sr, and Ba are highly variable and probably reflect their mobility during metamorphism. Elements of higher field strength, especially Mg, Al, Sc, Ti, V, Cr, Fe, Y, and Zr do not show so much scatter, and on Harker variation diagrams, show a more systematic distribution (Figure 13). Concentrations of Nb are highly variable and may have resulted from contamination by grinding in a tungsten-carbide mill (Joron et al., 1980).

The analyses of the Solidarity Formation plot in the High Mg Tholeiite field on the Jensen (1976) discrimination diagram (Figure 14a). They have a positive slope on the Miyashiro and Shido (1975) diagram (Figure 14b). Both are characteristic of tholeiitic rocks. The analyses of the Glasgow Formation form a scattered calc-alkaline trend with the most mafic members plotting in the tholeiitic fields of

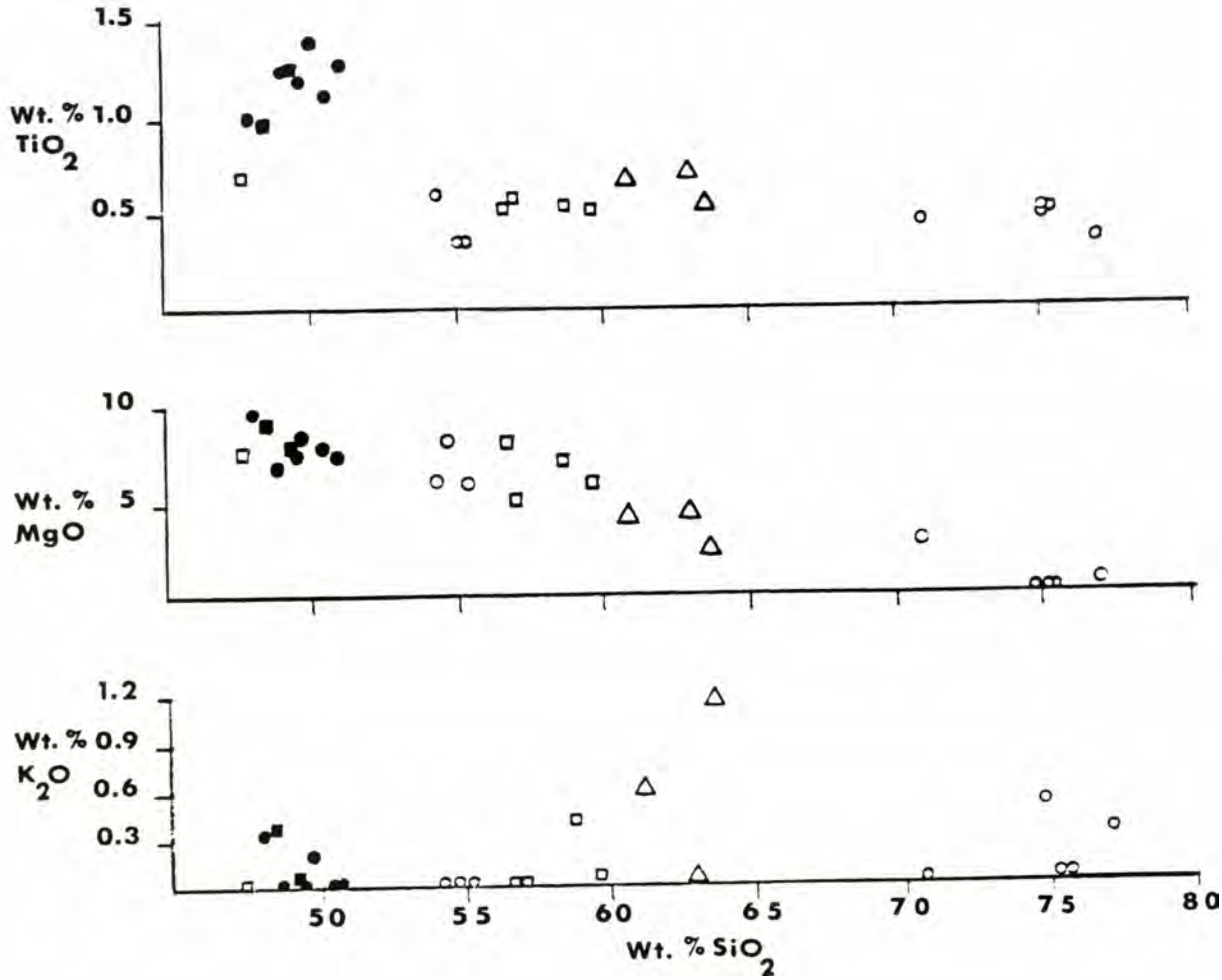


Figure 13. Harker diagrams of TiO_2, MgO, and K_2O vs. SiO_2. Solid circles and squares represent Solidarity volcanics and intrusives respectively. Open circles and squares represent Glasgow volcanics and intrusives respectively. Open triangles represent Carryer intrusives.

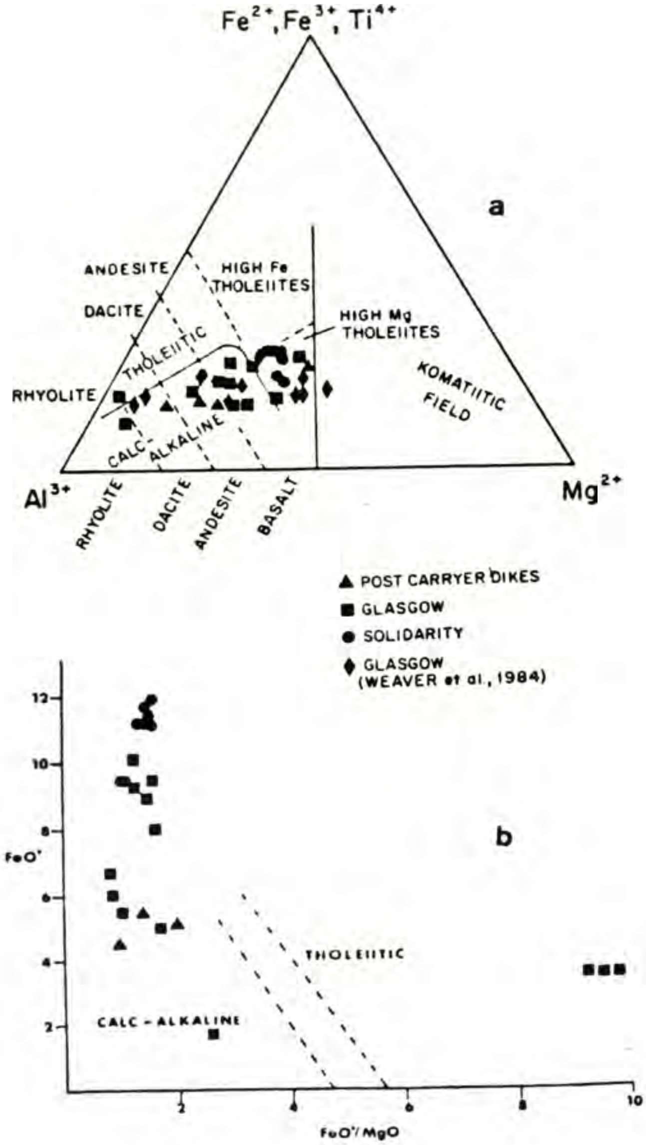


Figure 14. Discrimination diagrams for Bowers Supergroup igneous rocks. (a) Jensen (1976)-type cation discrimination plot. (b) Miyashiro and Shido (1975)-type discrimination plot. Tholeiitic Glasgow rhyolite data point on (a) represents three overlapping analyses.

both diagrams of figure 14. Three Glasgow rhyolites collected from north of the Alt Glacier are anomalously low in Mg and plot in the tholeiitic fields of both diagrams (these analyses overlap in figure 14a). These rocks may represent partial melts of a ferro-basalt (Babcock, oral communication). Post-Carryer intrusives are chemically indistinguishable from the Glasgow volcanics because they plot on the same calc-alkaline trend. On the Jensen cation plot (Figure 14a) data from Weaver et al. (1984) for the Glasgow Formation are in agreement with the results of this study. The analysis of their sample collected from the Husky Conglomerate plots in the komatiitic field of the diagram. Due to the re-interpretation of the nature of the Husky Conglomerate, it is suggested that this high Mg basalt may not be from the Glasgow volcanics.

On the Ti vs. Zr and Cr vs. Y plots of Pearce (1982) (Figures 15a-15b) the analyses of the Solidarity Formation plot in the overlap of the mid oceanic ridge basalt-arc lava fields of both diagrams. The Glasgow Formation analyses however, plot mainly in the arc lava field. A clear geochemical distinction between the two formations is evident, but both may have formed in an arc environment.

Shervais (1982) utilized a plot of V vs. Ti to further distinguish environments of emplacements for basaltic rocks (Figure 16). From this diagram it can be seen that

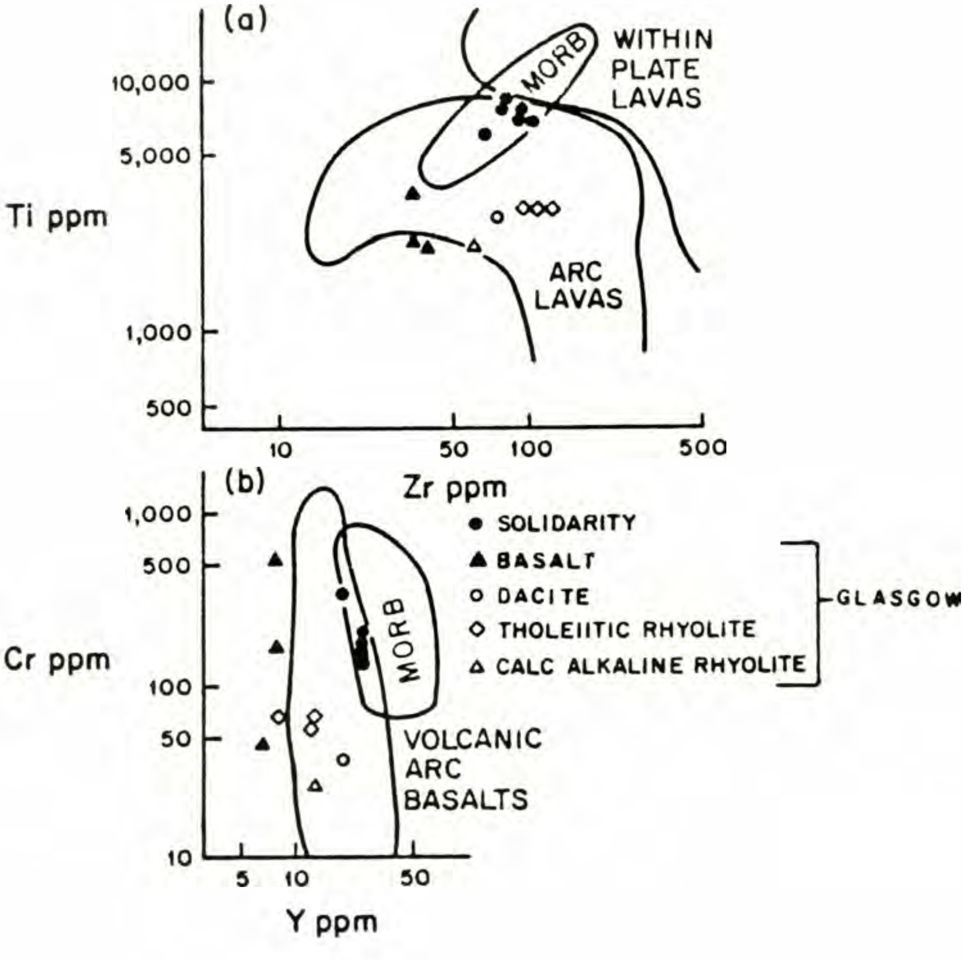


Figure 15. Pearce (1982)-type Ti/Zr and Cr/Y discrimination diagrams showing composition of Solidarity and Glasgow Formation volcanics.

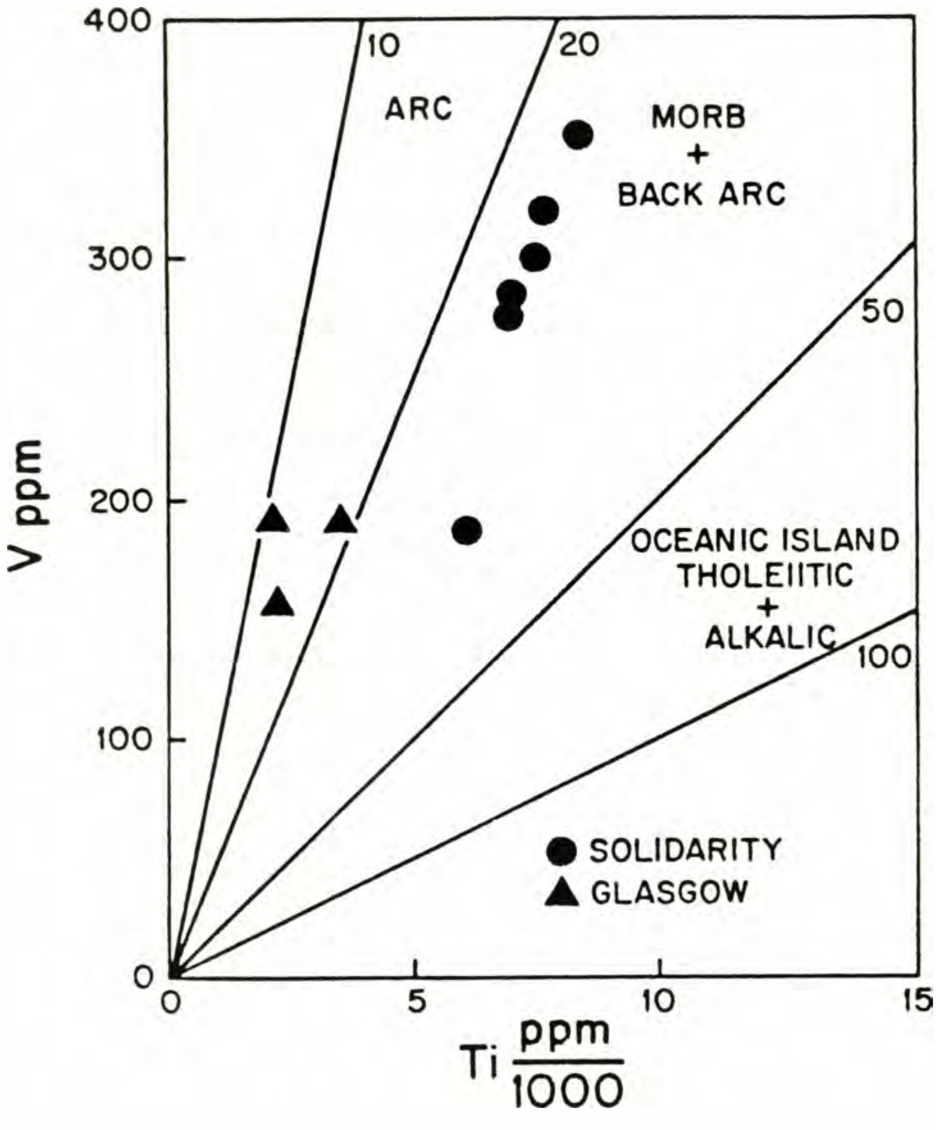


Figure 16. Shervais (1982)-type V/Ti discrimination diagram showing composition of basalts from the Solidarity and Glasgow Formations.

analyses of the Solidarity Formation plot in the MORB + back arc field, but most of the analyses lie close to the arc field. In contrast, the Glasgow basalt analyses plot within the arc field.

To further characterize the basaltic rocks, analyses are plotted on the MORB-normalized diagram of Pearce (1982) (Figure 17). On such plots, alkalic MORB and within plate basalts are enriched in elements Sr through Zr and, in some cases, Ti. They also have near MORB values for elements of higher field strength. On the other hand, volcanic arc basalts are characterized by enrichments in elements of low field strength up to Ba and depletions in elements P through Cr. The results of Solidarity and Glasgow analyses from this study and Glasgow analyses from Weaver et al. (1984) are plotted on figure 17.

The Solidarity Formation is enriched in low field strength elements but has near MORB values for high field strength elements as does the high Ti basalt of Weaver et al. (1984). The interpretation of these results is equivocal because of the possible mobility of the low field strength elements during metamorphism. The lack of Ti and Zr enrichment suggests the rocks are not alkalic MORB or within plate basalts. If one attributes enrichments of Sr through P to metasomatic addition during metamorphism, then these rocks could be mid-oceanic ridge basalts, or

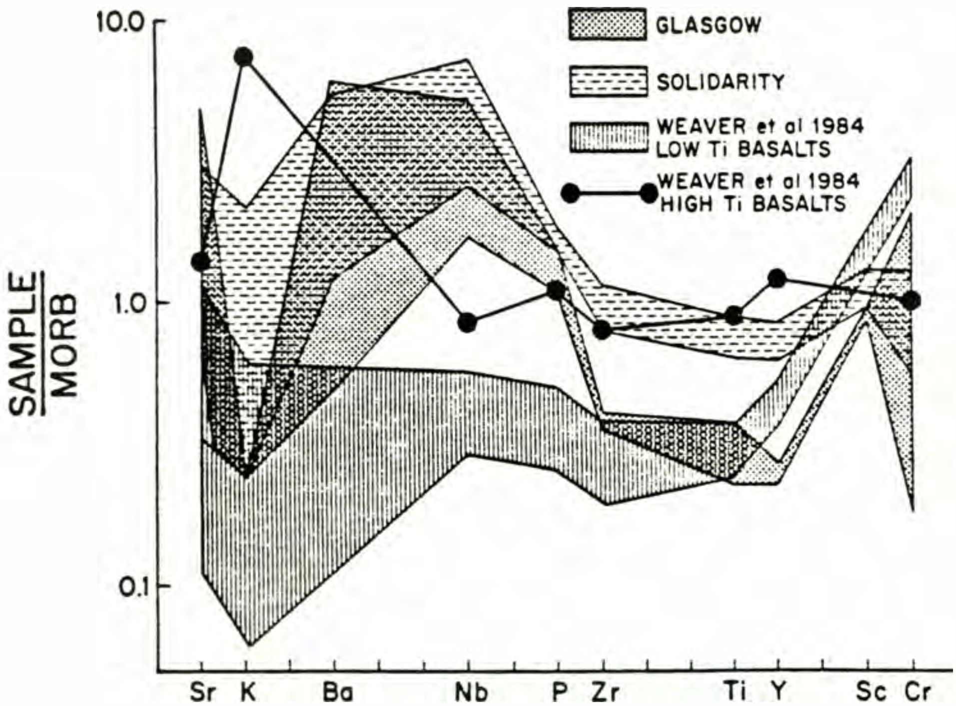


Figure 17. MORB-normalized elemental patterns of basalts from the Solidarity and Glasgow Formations.

according to Saunders et al. (Weaver et al., 1984), marginal basin/back arc basalts. If one accepts the enrichments of low field strength elements as being of primary origin, then the Solidarity Formation may represent a primitive magmatic arc basalt.

The Glasgow basalts are enriched in low field strength elements (except K) and they are depleted in high field strength elements (except for one sample that is unusually rich in Cr). In terms of high field strength elements, they correspond to the low Ti basalts of Weaver et al. (1984). The Glasgow basalts seem to be geochemically similar to volcanic arc tholeiites.

The petrogenesis of the volcanic rocks has been investigated by plotting their analyses on Cr-Y (Figure 18) and V-Ti (Figure 16) diagrams. According to Pearce (1982), the curved line on figure 18 shows the composition of magmas generated by various degrees of mantle partial melting. Subsequent fractional crystallization results in a vertical trend on this diagram. The data points suggest that the Solidarity Formation was formed by 15-20% partial melting of mantle followed by fractional crystallization of early formed Cr bearing phases such as olivine. On figure 16, analyses of the Solidarity Formation plot on a linear trend with a positive slope. Both V and Ti are incompatible elements under reducing conditions and would

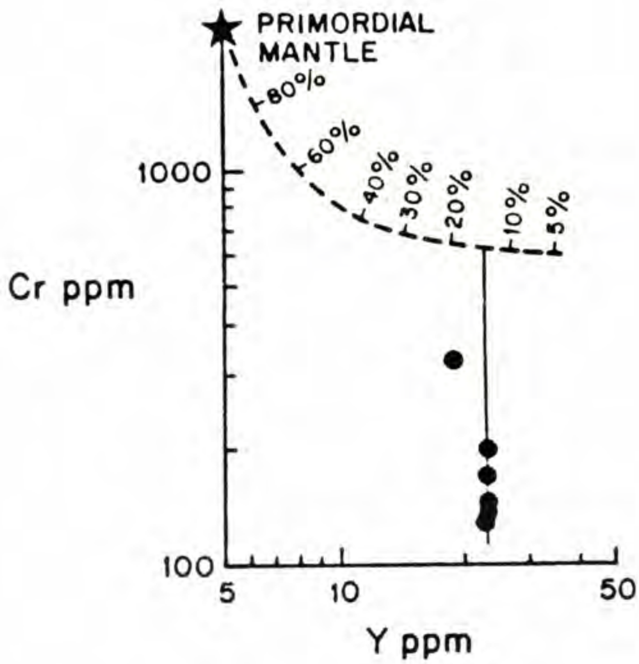


Figure 18. Pearce (1982)-type Cr/Y variation diagram showing compositional variations of the Solidarity Formation.

tend to be concentrated in progressively fractionated magmas. According to Shervais (1982), trends similar to that exhibited by the Solidarity Formation analyses on figure 16 are indicative of partial melting of mantle under reducing conditions followed by olivine and plagioclase fractionation. There is an insufficient munber of Glasgow basalt analyses to allow a similar investigation of their petrogenesis. However, according to Shervais (1982), a similar low V-Ti ratio is indicative of rocks generated by melts formed under more oxidizing conditions such as might be found in the mantle wedge overlying a devolatalizing, subducting, oceanic slab. Interpretations of this sort must assume single-stage fractionation of the magma with no replenishment. In the case of the Solidarity and Glasgow volcanics, the validity of this is diffcult to assess.

The geochemical evidence suggests that the Solidarity Formation volcanics are tholeiitic. Their tectonic environment of emplacement cannot be ascertained unequivocally on the basis of geochemistry alone. They may have been emplaced along a primitive magmatic arc, along a mid-oceanic ridge, or in a back-arc spreading environment. The former hypothesis is supported by the paucity of pelagic sediments and the presence of the overlying Molar Formation which is in part of continental block provenance. The Glasgow Formation volcanics are calc-alkaline and locally tholeiitic and were emplaced along a magmatic arc. The dominance of clac-alkaline rocks in the Glasgow Formation suggests the presence of continental crust, and this, in turn, supports the hypothesis that the Solidarity Formation volcanics are primitive magmatic arc tholeiites.

Metamorphism

Low-grade regional metamorphism has affected the rocks of the Bowers Supergroup resulting in the formation of spillites, keratophyryes, and metasediments.

Rocks from the Solidarity and Glasgow Formations fit the requirements for spillites and keratophyryes (Cann, 1969: Hughes, 1975) in that the metamorphic mineral assemblages reflect conditions lower than that of the greenschist facies and the igneous textures of the rocks have been preserved. Within the spillites, plagioclase is altered to albite and locally to white mica and is replaced by calcite and chlorite; clinopyroxene is replaced by chlorite and locally by epidote, calcite, prehnite, pumpellyite, sphene, and quartz; and orthopyroxene is replaced by chlorite. Veinlets of chlorite, muscovite, and calcite; quartz, calcite, and muscovite; prehnite; and quartz are common. Amygdaloidal spillitic rocks commonly have fillings of chlorite and locally muscovite, prehnite, and calcite. Within the keratophyryes, plagioclase is altered to albite and locally to white mica and is replaced by chlorite and calcite; amphiboles are replaced by chlorite and locally albite, white mica, calcite, epidote, pumpellyite, prehnite, quartz, and sphene; and the clinopyroxene is replaced by chlorite. Veins of quartz, epidote, and calcite; prehnite; and epidote are common. Amygdaloidal keratophyryes commonly have fillings of albite, pumpellyite, prehnite, and quartz; pumpellyite and quartz; pumpellyite; and chlorite. Solidarity and Glasgow Formation mafic and felsic intrusive rocks have developed secondary mineral assemblages similar to those found in the spillites and keratophyres.

Sandstones from the Molar Formation and the Carryer Conglomerate contain the metamorphic mineral assemblage quartz, albite, white mica, chlorite, epidote, prehnite, and pumpellyite. Plagioclase is altered to albite and white mica, and K-feldspar is altered to white mica. The matrix of the sandstones is recrystallized to quartz, chlorite, and muscovite. Prehnite is present in mafic volcanic clasts in the Molar Formation. Interstitial patches of prehnite, and pumpellyite after albite are present in the Carryer sandstones. Veins of calcite and quartz, calcite, and quartz are common in the metasediments. Dikes cutting the Carryer Conglomerate have developed metamorphic mineral assemblages similar to those found in the mafic intrusive rocks of the Sledgers Group.

Field measurements show that the stratigraphic thickness of the Bowers Supergroup is at least 6.5 km. All the rocks now exposed over approximately 2.0 km of relief are within the prehnite-pumpellyite metamorphic facies. Bradshaw et al. (1982), Laird et al. (1982), and Wodzicki et al. (1982a) have reported the occurrence of a prehnite-pumpellyite to pumpellyite-actinolite facies transition within the Bowers Supergroup. This study cannot confirm their findings.

Structure

Wodzicki and Robert (in press) have most recently described the structure of the Bowers Supergroup (Plate 1). They interpret the dominant structures present within the Bowers terrane as northwest-striking F_1 folds. These folds were recognized by Bradshaw et al. (1982) and interpreted by them as a major anticline bordered on both sides by major synclines. Wodzicki and Robert (in press) also recognize younger F_2 folds, and the structure of the Bowers Supergroup as described by them is summarized below.

F_1 folds define the structural grain of the study area. The dominant structure is a major anticline along which the Solidarity Formation is exposed. To the west of this anticline the Bowers Supergroup is overturned. Along the eastern end of the Solidarity Range, these rocks are in fault contact with the Carryer Conglomerate which is folded into a broad anticline. To the east of the Solidarity Formation, the rocks are folded into another anticline bordered by two synclines with the Camp Ridge Quartzite occupying the easternmost syncline. The style of folding depends on the dominant lithology present. Near Mt. Soza and along the Carryer Glacier where the Glasgow Formation is dominant, attitudes remain constant over large areas. Here the rocks show only major structural features. Where the Molar Formation is dominant, the wavelength of folds decreases. In areas where mudstone is dominant, as for instance along the ridge to the northwest of Mt. Jamroga, numerous short wavelength folds are present.

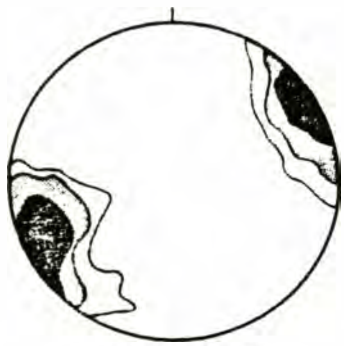
F_1 folding was accompanied by the development of S_1 axial plane cleavage in mudstones and other incompetent rocks and widely spaced S_{1s} conjugate shears in massive volcanics and other competent rocks. Metamorphic minerals are aligned parallel to S_1 and occupy shears and veins along S_{1s} planes suggesting that F_1 folding was synmetamorphic.

The orientation of all F_1 fold axes, poles to S_1 foliation, and poles to S_{1s} are plotted on equal area projections (Figure 19). The main structural features of the study area and orientations of F_1 fold axes within five sub-areas are shown in figure 20. F_1 fold axes consistently trend approximately N30°W but plunge variably. This horizontal to vertical variation in plunge defines a great circle (Figure 19). The variation in F_1 axes is interpreted as being caused by a younger period of folding, F_2, about axes trending N60°E and normal to F_1.

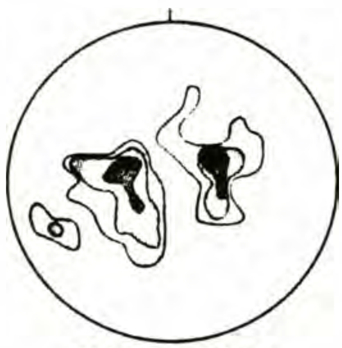
The S_1 axial plane cleavage strikes about N30°W and dips steeply. To the west of the main anticlinal axis, the dips are predominantly (95%) to the east. to the east of this axis, the dips are predominantly (75%) To the west. This gives the overall picture of a fan-shaped fold. The S_{1s} conjugate shears show reverse movement, strike approximately N30°W, and dip to the northeast and southwest at about 30°. Poles to S_1 and S_{1s} show considerable scatter and possibly lie along small circles consistent with a later period of F_2 folding (Figure 19).

At one locality in the central Solidarity Range, an F_2 fold hinge was observed folding S_0 bedding and S_1 foliation. The hinge is sharp and has a distinct chevron style. It is horizontal with a trend of N70°E. F_2 folding did not affect all parts of the study area equally. With

ALL F_1 AXES
171 pts., 1, 2, 6%



ALL S_1 POLES
180 pts., 1, 2, 6%



ALL S_{1s} POLES
33 pts., 2, 4, 9%

Figure 19. Equal area projections of all measured F_1 fold axes, poles to axial plane cleavage (S_1), and poles to conjugate shears (S_{1s}) (after Wodzicki and Robert, in press).

reference to figure 20, the attitude of F_1 in the Solidarity Range and Reilly Ridge sub-areas defines an almost continous girdle suggesting F_2 folding. In the Mt. Soza and especially in the Carryer Glacier sub-areas, F_1 axes plunge mainly to the southeast. In the Molar Massif sub-area, which includes the southern part of the Solidarity Range, F_1 axes plot in a group near horizontal suggesting the rocks are unaffected by F_2 folding.

The Bowers Supergroup is separated from the Wilson and Robertson Bay Groups by major faults. The eastern contact of the Bowers Supergroup is marked by the Leap Year Fault, first mapped by Sturm and Carryer (1970), named by Dow and Neall (1974), but first observed in outcrop by Stump et al. (1983). Weaver et al. (1984) favor right lateral motion along this fault.

The western contact of the Bowers Supergroup is marked by the steeply dipping Lanterman Fault which moved in two periods. The earlier movement resulted in the formation of up to 200 m of blastomylonite under greenschist facies conditions. The later movement resulted in the formation of a narrow clay-rich fault pug (see section on Husky Conglomerate). In all localities examined, fault pug separates the greenschist facies blastomylonite from the Sledgers Group.

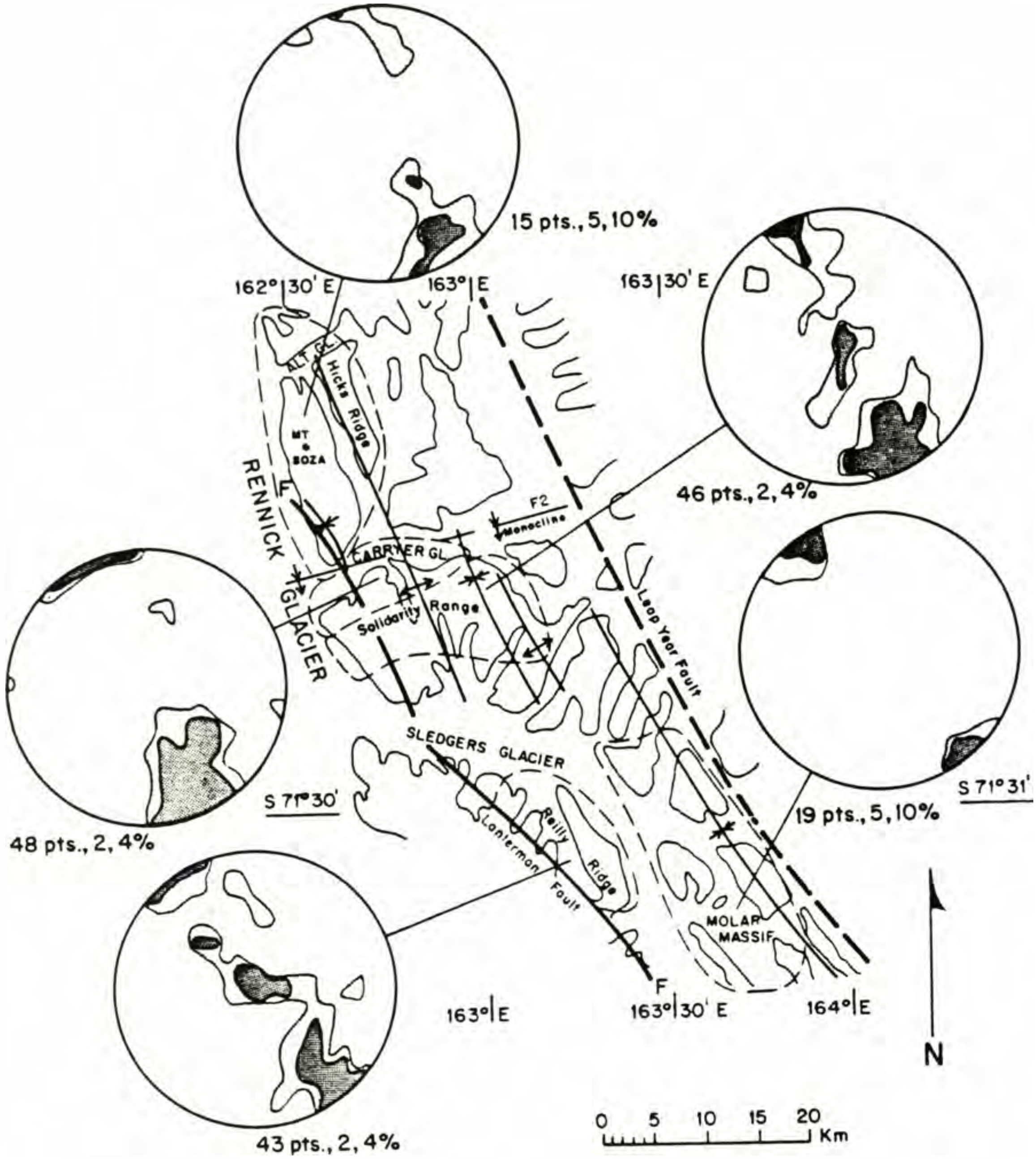


Figure 20. Equal area projections of F_1 fold axes within the Mt. Soza, Carryer Glacier, Solidarity Range, Reilly Ridge, and Molar Massif areas (after Wodzicki and Robert, in press).

To the northeast of the Lanterman Fault, several smaller displacement faults are present along Reilly Ridge, along the spurs leading to the Sledgers Glacier, and along the western edge of the Solidarity Range facing the Rennick Glacier. These faults are steep normal faults which, at least along Reilly Ridge, form a series of horsts and grabens.

Deformational and Metamorphic History

Whole rock K-Ar ages of slates in the Bowers Supergroup fall into two groups: 467-441 Ma in the Sledgers Group to the east of Longitude $163^{\circ}30'$; and 421-384 Ma in the Sledgers, Mariner, and Leap Year Groups to the west of Longitude $163^{\circ}30'$ (Adams et al., 1982). There is much disagreement in the interpretation of these ages. Adams et al. (1982) consider that the older ages record the Ross Orogeny which took place before the deposition of the Mariner Group, and the younger ages record the Borchgrevink Orogeny which post-dates deposition of the Leap Year Group. They conclude that the younger event is not recorded in the lower part of the Sledgers Group due to the isotopic and mineralogic resistance of these rocks.

Bradshaw et al. (1982) and Bradshaw and Laird (1983) regard the Ross Orogeny as having been post-Mariner and pre-Leap Year because this is in better agreement with paleontological data. The Mariner and the upper Sledgers rocks do not show evidence of the Ross Orogeny because they were poorly lithified during this time, and cleavage developed during the Borchgrevink Event post-dates Leap Year deposition (Bradshaw et al., 1982; Bradshaw and Laird, 1983).

In northern victoria Land, Tessensohn et al. (1981) recognize only the Ordovician Ross Orogeny. They recommend the term Borchgrevink Orogeny be abandoned because of the absence of evidence for a compressive mountain building event of mid-Paleozoic age.

Wodzicki and Robert (in press) have shown that two distinct episodes of folding, F_1 and F_2, have affected the Bowers Supergroup. Furthermore, whereas F_2 folding is intense over most of the study area, the northern Molar Massif and Southern Solidarity Range have remained virtually unaffected. It is only these latter areas east of Longitude 163°30' that record the older K-Ar ages. Therefore, they conclude that the 441-467 Ma ages record F_1 folding and the 384-421 Ma ages record F_2 folding. No radiometric data are available concerning the age of faulting. However, field evidence clearly shows greenschist facies mylonites along the Lanterman Fault predating normal faulting associated with clay-rich pug zones (Wodzicki and Robert, in press). In addition, that the mylonites have been metamorphosed suggests that the movement took place during the metamorphic event. Because the normal faulting is oriented approximately at right angles to F_2 fold axes, they both may have originated in the same stress field. Thus the order of deformational episodes may have been F_1 folding, strike-slip faulting, F_2 folding, and normal faulting. This succession can be explained by a counter-clockwise rotation of the axis of compression from N60°E during F_1 folding to about N-S during right lateral strike-slip faulting and finally to about N30°W during F_2 folding and normal faulting.

TECTONICS OF NORTHERN VICTORIA LAND

Much disagreement prevails regarding the tectonic evolution of northern Victoria Land. Tessensohn et al. (1981) feel the entire region has been a coherent block since the Cambrian. Their conclusion is based on the interpretation that all the basement units (the Wilson Group, the Bowers Group (Supergroup), and the Robertson Bay Group) are essentially correlative and that they are now exposed at different levels due to block faulting. Grindley and Oliver (1983) maintain the upper Precambrian and Cambrian terranes were accreted onto East Antarctica during the Ross Orogeny. Wilson et al. (1984) consider the Wilson, Bowers, and Robertson Bay terranes were juxtaposed by right lateral strike-slip faulting. On the basis of geochemical evidence, they interpret the Glasgow Formation rocks as intra-oceanic island arc tholeiites and Andean-type calc-alkaline volcanics and conclude the associated subduction zone dipped westward.

Any model for the tectonic evolution of northern Victoria Land must take into account the timing of geologic events in the Wilson Group, Bowers Supergroup, and Robertson Bay Group in addition to geologic data regarding the Bowers Supergroup that are relevant to determining subduction polarity.

Timing of Events

The timing of geological events in northern Victoria Land is summarized in figure 21. It is suggested that three terranes have been juxtaposed. There are three reasons for this conclusion.

Metamorphism of the Rennick Schist between 545-515 Ma (Adams, in press) was in part coeval with deposition of the Sledgers and Mariner Groups and possibly the Robertson Bay Group. Also, the Sledgers Group contains extensive volcanics and has a sediment source from the northeast where the Robertson Bay Group now lies, but volcanics appear to be absent from much of the Robertson Bay Group whose dominant sediment transport direction is from the south-southeast where the Sledgers Group now lies.

The Wilson Gneiss Complex at 520-472 Ma (Adams, in press) was emplaced at the same time as there was deposition and early metamorpohism of the Robertson Bay Group and coincided with a period during which there was no deposition in the Bowers Supergroup.

The emplacement of the Granite Harbour Intrusives between 490-470 Ma (Vetter et al., 1983) and their slightly later incorporation into the Carryer Conglomerate occurred at the same time as folding and metamorphism in the Robertson Bay Group.

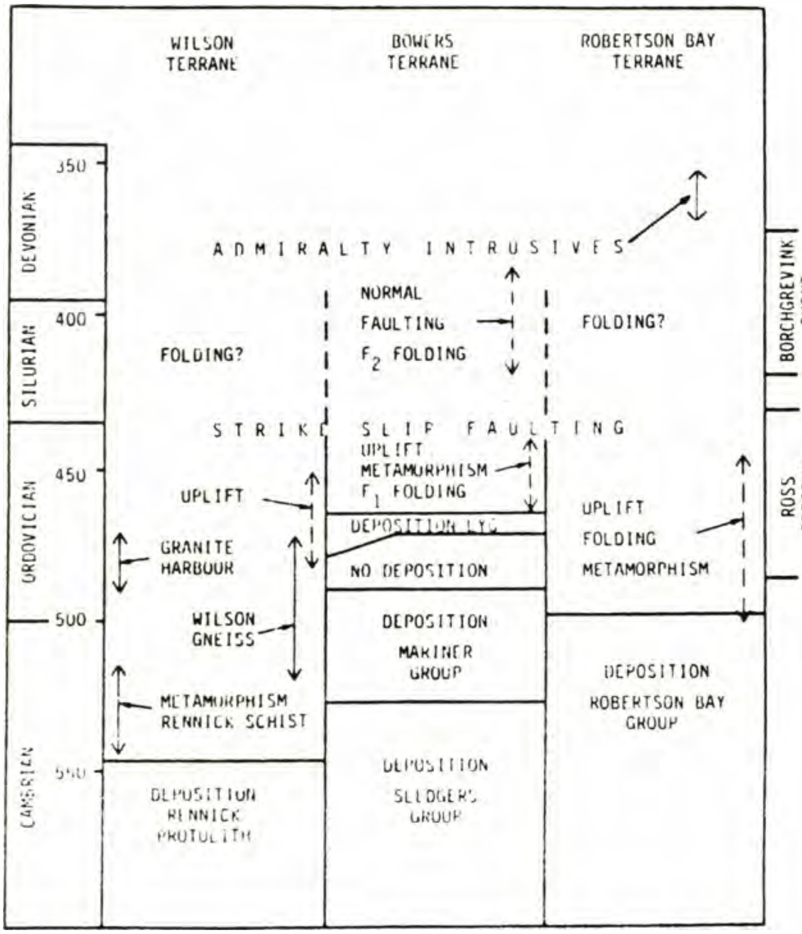


Figure 21. Timing of deposition, metamorphism, deformation, intrusion, and uplift in the Wilson, Bowers, and Robertson Bay terranes based largely on paleontological data of Cooper et al. (1983) and radiometric data of Adams et al. (1982) and Adams (in press). Solid arrows show Rb-Sr ages. Dashed arrows show K-Ar ages. LYG = Leap Year Group. From Wodzicki and Robert (in press).

The above, taken in conjunction with evidence for major strike-slip faults separating the Wilson Group, the Bowers Supergroup, and the Robertson Bay Group, support the concept of the existence of three separate terranes in northern Victoria Land as suggested by Grindley and Oliver (1983), Bradshaw et al. (1983), and Weaver et al. (1984). In addition, the Bowers Supergroup may be considered a tectono-stratigraphic terrane as defined by Coney et al. (1980).

F_2 folding is well documented in the Bowers terrane (Wodzicki and Robert, in press) and there are suggestions that late folds of similar orientation are present in nearby Wilson and Robertson Bay terranes (see introduction). If this is indeed so, the three terranes may have become stitched by about 421-384 Ma; the age of resetting of K-Ar dates in the Carryer Glacier region (Adams et al., 1982) and of F_2 folding. Certainly northern Victoria Land had become a coherent block by 354 Ma, the youngest recorded age for the emplacement of the Admiralty Intrusives (Vetter et al., 1983) in all three terranes.

The timing of the emplacement of the Granite Harbour Intrusives, F_1 folding, metamorphism of the Bowers Supergroup, and possibly strike-slip faulting suggests the events are related and result from a collision between the Wilson and Bowers terranes. This collision may therefore have been the ultimate cause of the Ross Orogeny in northern Victoria land spanning approximately 490-430 Ma (Wodzicki and Robert, in press).

F_2 folding and associated normal faulting were in part coeval with the emplacement of the Admiralty Intrusives and may have been the result of what has been referred to as the Borchgrevink Orogeny in northern Victoria Land (Craddock, 1972). However, the relatively mild nature of this deformation and the absence of a clear metamorphic overprint (except the resetting of K-Ar dates) suggests that the Borchgrevink should be regarded as an event rather than an orogeny.

Polarity of Subduction

The polarity of the subduction associated with the Glasgow arc volcanism is more difficult to assess as the data are somewhat equivocal. Weaver et al. (1984) favor westward-directed subduction for the following reasons. They consider the sediment source for the Sledgers Group lay to the southwest, no fragments of a subduction complex are present along the contact between the Bowers Supergroup and the Wilson Group, and the S-type Granite Harbour Intrusives lie to the west of the Bowers Supergroup. Furthermore, the proposed tectonic configuration for

Cambrian northern Victoria Land (see figure 7 Weaver et al., 1984) would explain the occurrence of reported Robertson Bay Group metasediments in the Morozumi Range west of the Lanterman Fault. The evidence presented in this paper favor an eastward-directed subduction for the following reasons.

The most important continental sediment source for the Molar Formation lay to the northeast or east of the Sledgers depositional basin, and the basin sloped toward the west or southwest. Evidence for this is not extensive but consistent. Furthermore, a westward dipping subduction zone would have interrupted transport of continental sediments unless they were from a continental fragment rafted away from Antarctica during back-arc spreading that may have formed the Solidarity Formation.

The absence of a subduction complex between the Wilson Group and Bowers Supergroup is readily explained by post-subduction strike-slip motion along the Lanterman Fault.

The turbidites in the Morozumi Range have been correlated with the Robertson Bay Group by Wright (1981). However, evidence for this correlation is equivocal and alternatively the rocks could represent remnants of Molar fore-arc sediments.

The Granite Harbour Intrusives are probably related to a collision (Babcock et al., in press) rather than westward-directed subduction. Collision of the Bowers and Wilson terranes is also supported by the sudden appearance of the Carryer Conglomerate, a thick molasse sequence containing clasts of the S-type Granite Harbour Intrusives. Furthermore, a collision between the Bowers and Wilson terranes would require the closure of an intervening basin (possibly the Bowers itself) and subduction between the two terranes would facilitate this closure.

Geologic History and Tectonic Evolution

Based on field, petrographic, and radiometric data, the geologic history of the Bowers Supergroup and, in general, the tectonic evolution of northern Victoria Land are summarized below (see schematic outline in Figure 21). The sequence of events is tentative, especially regarding the tectonic evolution of the region, but is compatible with available data from the central Bowers Mountains and is presented as an alternative for discussion.

1. In the Bowers terrane, eruption of at least 0.4 km of tholeiitic submarine basalts of the Solidarity Formation probably along a primitive magmatic arc.

2. Deposition of up to 2.7 km of Molar Formation during the Middle Cambrian in a northwest-striking basin that sloped to the southwest. The provenance of sediments was a coeval magmatic arc (Glasgow Formation) and a granitic and metamorphic basement that lay to the east or northeast.

3. Eruption of up to 2.7 km of tholeiitic and calc-alkaline Glasgow Formation volcanics along a magmatic arc which lay sub-parallel to the Molar sedimentary basin and west to southwest of a continental landmass. The arc was probably related to an eastward-dipping subduction zone that lay to the west.

4. Deposition of up to 0.9 km of shallow-marine sediments (Mariner Group) during a Middle to Late Cambrian regression. This time reflects a period of tectonic inactivity.

5. Collision of Wilson and Bowers terranes. This resulted in the emplacement of the Granite Harbour Intrusives (490-470 Ma) in the Wilson terrane, uplift and erosion of the Wilson terrane and the Sledgers and Mariner Groups in the Bowers terrane, and finally, deposition of the Leap Year Group in the Bowers terrane.

6. Convergence in a N60^{o}E direction resulting in F_1 folding and metamorphism of the Bowers Supergroup between 467-441 Ma. This folding was followed by right lateral

strike-slip movement along the Lanterman Fault and possible emplacement of the Robertson Bay Group along the Leap Year Fault. Events 5 and 6 represent the Ross Orogeny in northern Victoria Land.

7. F_2 folding about N70°E axes took place bewteen 421-384 Ma. This may have been accompanied by normal movement along a renewed Lanterman Fault, horst and graben development in the western part of the study area, and emplacement of the Admiralty Intrusives between 367-352 Ma. This probably represents the Borchgrevink Event within the Bowers terrane. The Wilson, Bowers, and Robertson Bay terranes were probably knit together by this time.

BOWERS TROUGH-DUNDAS TROUGH CORRELATION

Laird et al. (1977) have suggested a correlation between the Cambro-Ordovician stratigraphic sequences of the Bowers Trough in northern Victoria Land and the Dundas Trough in Tasmania. The basis for this correlation has been discussed earlier (see section on Impetus for the Present Study).

Data of this study have shown that the volcanics of the Sledgers Group are products of a magmatic arc related to probable eastward-directed subduction. The tholeiitic and calc-alkaline volcanics of the Dundas Trough however, are considered to be products of rifting developed along a Precambrian boundary (Williams, 1978). The contact between the Sledgers and Mariner Groups is conformable (Laird and Bradshaw, 1983), whereas the contact between the Dundas Group and the Crimson Creek Formation is obscure and may be unconformable (Brown et al., 1982). Deposition of the non-volcaniclastic Mariner Group in Antarctica coincides with outpourings of the felsic Mt. Read volcanics in Tasmania. The age of deposition of the Leap Year Group is now placed at the Middle Ordovician, significantly younger than previously thought and no longer coincident with deposition of the Owen Conglomerate. Cambro-Ordovician deformation in the Bowers Trough produced northwest-trending F_1 folds. No folding is associated with an event of similar age in the Dundas Trough. Silurian to Devonian deformation produced northeast-trending F_2 folds in the Bowers Trough (Wodzicki and Robert, in press), whereas an event of similar age produced northwest-trending folds in the Dundas Trough (Williams, 1978). Finally, several authors (Grindley and Oliver, 1983; Weaver et al., 1984; and Wodzicki and Robert, in press) have suggested that the rocks of the Bowers Trough are allochthonous, having been accreted onto East Antarctica. In light of the presently available data, it seems unlikely that the Bowers and Dundas Troughs were once continuous. This correlation should be abandoned and previous reconstructions of Antarctica and Australia based upon this hypothesis should be re-evaluated.

CONCLUSIONS

The Bowers Supergroup consists of the Sledgers, Mariner, and Leap Year Groups. The Bowers Supergroup is in fault contact with the Wilson Group along the Lanterman Fault. This contact is expressed by up to 200 m of metamorphically healed blastomylonite. This zone has previously been referred to as the Husky Conglomerate, a term which should now be abandoned.

The lowest member of the Sledgers Group, the Solidarity Formation, consists of submarine tholeiites probably erupted along a primitive magmatic arc. The sedimentary phase of the Sledgers Group, the Molar Formation, consists of quartzo-feldspathic and tuffaceous sediments. The quartzo-feldspathic sediments are of continental block provenance originating from east or northeast of their present location. The tuffaceous sediments are of magmatic arc provenance originating from the Glasgow Formation. The Glasgow Formation consists of tholeiitic to calc-alkaline basalts to rhyolites erupted along a magmatic arc related to probable eastward-directed subduction.

The Mariner Group consists of fossiliferous, non-volcaniclastic, marine sediments that were deposited during a period of tectonic quiessence.

The Leap Year Group is a molasse deposit that resulted from uplift and erosion during the Cambro-Ordovician Ross Orogeny. It is derived from a recycled-orogen (the Sledgers Group) and a continental block containing granitoid gneiss and S-type granitoids similar to those now located to the west in the Wilson terrane. The age of deposition of the Leap Year Group is probably no older than Early Ordovician, which is significantly younger than previously suggested.

Metamorphic conditions in the Bowers Supergroup did not exceed those of the prehnite-pumpellyite facies and was accompanied by F_1 folding resulting from a collision between the Bowers and Wilson terranes. F_2 folding and the resetting of K-Ar dates in the Bowers Supergroup is interpreted as the result of the Borchgrevink Event.

The Bowers Supergroup represents a tectono-stratigraphic terrane that was juxtaposed by strike-slip faults against the Wilson and Robertson Bay terranes. The allochthonous nature of the Bowers Supergroup may preclude any correlation between the Bowers and Dundas Troughs.

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APPENDIX

Table 1

Point count data of framework grains in the Sledgers Group, Carryer Conglomerate, and Camp Ridge Quartzite. Qm (monocrystalline quartz), Qp (polycrystalline quartz), K (potassium feldspar), P (plagioclase), Lv (volcanic lithic), Ls (sedimentary lithic), Lp (plutonic lithic), Ph (sand-sized mica), Mt (matrix), Hv (heavy mineral other than mica), Cc (calcite).

Sledgers Group

#	Qm	Qp	K	P	Lv	Ls	Lp	Ph	Mt	Hv	Cc
S63B	85	5	5	93	109	13	0	5	69	1	20
S63A	180	8	17	28	5	13	0	18	86	9	5
SL2B	100	8	16	54	72	76	0	2	59	13	0
SL1A	143	14	18	51	12	3	0	9	145	4	1
SL2A	51	5	8	12	21	238	0	15	35	3	10
SL1B	127	37	37	32	24	1	0	15	112	13	2
C7B	81	13	0	82	46	2	0	4	136	11	28
C38	86	7	16	80	69	26	0	23	61	5	27
CS3	134	10	36	40	30	5	0	33	100	2	10
C6	88	14	0	119	61	19	0	31	61	2	5

#	Qm	Qp	K	P	Lv	Ls	Lp	Ph	Mt	Hv	Cc
CS15	105	23	10	45	30	13	0	25	121	15	13
CS14	62	38	0	54	72	42	13	6	98	2	13
CS9	139	30	30	53	22	19	0	12	68	8	19
CS1	109	15	29	26	19	2	0	11	179	6	4
CS2	40	5	12	118	134	13	5	1	53	19	0
C37	42	5	16	72	126	35	0	18	77	3	7
CS11	127	45	52	55	38	3	0	17	46	12	5
S4	67	20	7	60	78	62	21	6	50	2	27
S18	38	1	13	62	99	51	17	8	22	8	81
S13	49	5	18	98	109	35	22	0	43	4	17
S16	40	18	18	120	102	14	15	7	45	0	21
S29A	19	0	0	164	118	0	0	0	99	0	0
C8	145	13	13	42	16	2	0	11	140	16	2

Carryer Conglomerate

Sandstones

#	Qm	Qp	K	P	Lv	Ls	Lp	Ph	Mt	Hv	Cc
C18	140	23	0	18	36	20	0	27	105	18	13
C43	146	34	32	12	36	14	0	16	89	18	4
C48A	172	26	0	40	8	24	0	30	68	10	22
C49	179	26	33	18	38	21	0	15	56	1	13
C20	104	27	0	27	28	3	0	3	82	3	0
C19	154	25	2	14	22	8	0	6	102	5	3

#	Qm	Qp	K	P	Lv	Ls	Lp	Ph	Mt	Hv	Cc
C48C	132	101	0	60	14	3	0	3	52	14	21
C47	144	37	11	48	13	28	0	12	74	24	9
C46A	136	51	2	16	36	20	0	17	57	59	6
SO2	176	23	0	8	22	5	0	6	146	5	9

Sandstone Clasts

#	Qm	Qp	K	P	Lv	Ls	Lp	Ph	Mt	Hv	Cc
C36	95	58	0	16	36	43	0	16	131	4	1
C44H	110	15	33	9	11	7	0	19	170	22	4
C44E	155	23	20	46	8	4	0	5	133	6	0
C34I	123	21	0	31	2	0	0	3	212	8	0
C34G	112	43	0	30	5	0	0	2	198	10	0
C34E	156	58	0	30	1	10	0	10	116	16	3
C34D	170	33	0	72	2	6	0	7	90	19	1
C34B	170	18	0	13	5	1	0	5	170	16	2
C34J	184	57	0	42	1	3	2	9	57	5	40
C44G	171	12	23	37	22	9	0	25	71	28	2
C34K	129	22	0	65	4	2	0	13	150	16	0

Camp Ridge Quartzite

#	Qm	Qp	K	P	Lv	Ls	Lp	Ph	Mt	Hv	Cc
CRQ1	225	16	7	13	12	Ø	Ø	3	43	4	Ø
CRQ3	263	4	16	11	8	5	Ø	8	66	8	Ø
CRQ4	249	45	74	Ø	Ø	Ø	Ø	3	26	Ø	Ø
CRQ6	229	77	Ø	5	11	6	Ø	3	32	37	1
CRQ7	214	2	21	19	19	1	Ø	21	5Ø	8	21
CRQ8	217	15	25	24	11	Ø	Ø	3	43	6	8

Table 2

Major and trace element analyses of volcanic and intrusive rocks from the Solidarity and Glasgow Formations and post Carryer Conglomerate dikes.

Field #	GF5Ø	GF47	GF34	C5Ø	C39	CS5
Sample #	1	2	3	4	5	6
Wt. %						
SiO_2	47.33	49.57	48.87	47.61	48.23	48.62
TiO_2	Ø.98	1.13	1.22	1.21	1.35	1.15
Al_2O_3	16.15	14.Ø2	13.82	14.39	14.62	14.62
Fe_2O_3	1Ø.31	12.31	12.18	12.Ø3	12.67	12.28
MnO	Ø.12	Ø.13	Ø.13	Ø.13	Ø.14	Ø.14
MgO	9.44	7.79	7.3Ø	6.76	7.24	8.21
CaO	11.22	1Ø.47	9.32	12.44	9.7Ø	1Ø.66
Na_2O	2.14	2.62	3.21	2.61	2.53	1.97
K_2O	Ø.32	<Ø.Ø4	<Ø.Ø4	<Ø.Ø4	Ø.2Ø	<Ø.Ø4
P_2O_5	Ø.19	Ø.19	Ø.21	Ø.2Ø	Ø.22	Ø.2Ø
LOI	2.44	2.56	2.28	2.99	1.93	1.76
SUM	1ØØ.64	1ØØ.79	98.54	1ØØ.37	98.83	99.61
PPM						
Sr	198	365	2Ø3	81	188	131
Ba	47	25	28	25	1Ø1	35
Y	19	24	25	24	25	25

Field #	GF5Ø	GF47	GF34	C5Ø	C39	CS5
Sample #	1	2	3	4	5	6
Nb	<1	1Ø	9	15	16	26
Zr	71	9Ø	94	79	81	1Ø4
Co	36	4Ø	39	45	47	42
Ni	16Ø	11Ø	11Ø	15Ø	1ØØ	12Ø
Cr	331	181	164	14Ø	151	2Ø3
Sc	42	49	44	39	52	49
V	185	272	3Ø8	293	34Ø	279
Zn	65	88	92	86	94	89

Field #	GF52	SO21	SO15	C22	SO6	SO4
Sample #	7	8	9	1Ø	11	12
Wt. %						
SiO_2	51.86	53.5Ø	54.28	69.64	74.2Ø	74.93
TiO_2	Ø.54	Ø.34	Ø.33	Ø.45	Ø.49	Ø.49
Al_2O_3	17.92	11.77	14.Ø4	13.16	12.48	12.27
Fe_2O_3	9.43	1Ø.9Ø	1Ø.4Ø	5.35	3.61	3.69
MnO	Ø.13	Ø.13	Ø.13	Ø.Ø7	Ø.Ø6	Ø.Ø7
MgO	5.82	8.Ø7	5.86	2.76	Ø.33	Ø.36
CaO	3.96	8.65	11.39	1.37	1.59	Ø.86
Na_2O	5.57	3.89	1.53	5.23	5.62	6.63
K_2O	<Ø.Ø4	Ø.Ø4	<Ø.Ø4	Ø.Ø4	Ø.52	Ø.Ø5
P_2O_5	Ø.17	Ø.14	Ø.14	Ø.13	Ø.1Ø	Ø.1Ø

Field #	GF52	SO21	SO15	C22	SO6	SO4
Sample #	7	8	9	10	11	12
LOI	4.37	2.62	2.37	2.11	0.80	0.75
SUM	99.77	100.05	100.47	100.31	99.80	99.90
PPM						
Sr	581	41	104	93	140	70
Ba	119	14	20	45	152	39
Y	7	8	8	18	65	57
Nb	6	18	6	16	26	34
Zr	33	34	38	75	107	110
Co	24	41	33	14	37	47
Ni	20	210	120	15	5	5
Cr	44	513	165	37	8	12
Sc	34	36	37	18	10	9
V	183	153	188	37	20	15
Zn	70	80	72	68	47	72

Field #	#43	SO9	#21	CS4	CS12	SO7
Sample #	13	14	15	16	17	18
Wt. %						
SiO_2	74.21	74.14	48.12	47.53	54.37	45.31
TiO_2	0.50	0.35	1.22	0.95	0.55	0.66
Al_2O_3	12.18	10.31	14.56	16.23	17.49	15.19
Fe_2O_3	3.68	1.97	12.68	10.37	8.48	9.86

Field #	#43	SO9	#21	CS4	CS12	SO7
Sample #	13	14	15	16	17	18
Wt. %						
MnO	0.06	0.06	0.14	0.13	0.11	0.12
MgO	0.35	0.67	7.63	8.89	4.90	7.16
CaO	0.86	3.66	11.34	11.66	3.27	13.84
Na_2O	6.34	4.63	1.62	1.72	5.85	2.87
K_2O	<0.04	0.32	0.06	0.37	<0.04	<0.04
P_2O_5	0.09	0.07	0.20	0.19	0.18	0.16
LOI	0.70	3.43	2.32	2.35	3.46	5.15
SUM	98.97	99.61	99.89	100.39	98.66	100.32
PPM						
Sr	62	302	269	166	445	80
Ba	26	321	54	65	93	18
Y	63	26	22	20	10	22
Nb	21	16	6	2	18	2
Zr	102	60	88	63	39	51
Co	43	27	43	39	22	36
Ni	30	40	100	160	30	130
Cr	13	13	147	314	35	326
Sc	8	5	44	45	34	33
V	13	22	312	444	182	163
Zn	80	37	80	105	71	68

Field #	GI43	#38	SO1	C45	#2	CI40
Sample #	19	20	21	22	23	24
Wt. %						
SiO_2	53.46	56.70	58.01	61.06	61.30	58.59
TiO_2	0.49	0.51	0.49	0.68	0.50	0.63
Al_2O_3	14.39	16.64	16.16	15.19	17.21	16.85
Fe_2O_3	7.00	6.41	5.93	4.95	5.49	5.95
MnO	0.10	0.09	0.08	0.07	0.09	0.08
MgO	7.72	6.88	5.62	4.26	2.43	3.93
CaO	7.27	2.88	4.62	5.98	2.20	3.86
Na_2O	3.59	5.98	6.12	4.28	5.72	5.02
K_2O	<0.04	0.41	0.06	0.06	1.12	0.55
P_2O_5	0.19	0.20	0.18	0.23	0.23	0.18
LOI	4.16	3.14	2.85	3.43	3.31	3.56
SUM	98.37	99.84	100.12	100.19	99.60	99.20
PPM						
Sr	391	376	368	983	342	712
Ba	203	101	112	585	371	186
Y	12	11	11	13	12	16
Nb	2	7	2	5	10	10
Zr	62	57	85	105	75	133
Co	28	99	22	24	16	19
Ni	175	110	120	110	15	60
Cr	506	269	270	131	43	81

Field #	GI43	#38	SO1	C45	#2	CI40
Sample #	19	20	21	22	23	24
PPM						
Sc	27	25	18	9	16	12
V	78	40	55	43	82	23
Zn	67	66	63	61	68	62

Description of Analyzed Samples

(GF5Ø) Porphyrytic basalt composed of 45% anhedral to subhedral clinopyroxene, Ø.Ø6 to 2.1 mm long; 35% subhedral to euhedral plagioclase approximately Ø.45 mm long; 1Ø% groundmass consisting of plagioclase and clinopyroxene; 5% anhedral to subhedral orthopyroxene up to 1.5 mm long; and 5% anhedral to subhedral magnetite up to Ø.3 mm long.

(GF47) Porphyrytic basalt composed of 35% subhedral to euhedral plagioclase up to Ø.5 mm long; 3Ø% anhedral to subhedral clinopyroxene, Ø.Ø8 to 2.Ø mm long; 2Ø% groundmass consisting of plagioclase, clinopyroxene, and sphene; 1Ø% anhedral to subhedral orthopyroxene up to 1.Ø mm long; and 5% anhedral sphene less than Ø.Ø1 mm long.

(GF34) Porphyrytic basalt composed of 5Ø% subhedral to euhedral plagioclase up to Ø.7 mm long; 4Ø% anhedral to subhedral clinopyroxene, Ø.Ø6 to 1.7 mm long; 5% anhedral to subhedral orthopyroxene up to 1.5 mm long; and 5% groundmass consisting of plagioclase and clinopyroxene.

(C5Ø) Porphyrytic basalt composed of 4Ø% anhedral to subhedral clinopyroxene, Ø.1 to 1.7 mm long; 35% subhedral to euhedral plagioclase up to Ø.45 mm long; 15% groundmass consisting of plagioclase, clinopyroxene, and sphene; 5% anhedral to subhedral orthopyroxene up to 1 mm long; and 5% anhedral sphene less than Ø.1 mm long.

(C39) Porphyrytic, intergranular basalt composed of 5Ø% anhedral to subhedral clinopyroxene, Ø.Ø3 to Ø.3 mm long; 45% subhedral plagioclase approximately Ø.3 mm long; and 5% anhedral orthopyroxene, Ø.1 mm long.

(CS5) Porphyrytic, intergranular basalt composed of 5Ø% anhedral to subhedral clinopyroxene, Ø.Ø5 to Ø.1 mm long; 4Ø% subhedral plagioclase up to Ø.5 mm long; and 1Ø% anhedral to subhedral orthopyroxene up to Ø.1 mm long.

(GF52) Porphyrytic, vesicular basalt composed of 4Ø% subhedral to euhedral plagioclase, Ø.3 to 1.Ø mm long; 3Ø% anhedral to subhedral clinopyroxene up to Ø.8 mm log; 2Ø% groundmass consisting of plagioclase and clinopyroxene; and 1Ø% vesicles.

(SO21) Porphyrytic basalt composed of 55% subhedral to euhedral clinopyroxene up to Ø.9 mm long; 4Ø% plagioclase microlites less than Ø.1 mm long; and 5% subhedral hornblende up to Ø.45 mm long.

(SO15) Porphyrytic basalt composed of 55% subhedral to euhedral plagioclase up to Ø.15 mm long; 35% anhedral to subhedral clinopyroxene, Ø.Ø3 to Ø.75 mm long; 5% anhedral to subhedral hornblende up to Ø.2 mm long; and 5% groundmass consisting of plagioclase and clinopyroxene.

(C22) Porphyrytic dacite composed of 5Ø% groundmass consisting of plagioclase, quartz, and magnetite; 35%

subhedral plagioclase, Ø.Ø9 to 5.7 mm long; 1Ø% anhedral to subhedral quartz, Ø.Ø9 to 3.5 mm long; and 5% anhedral hornblende, Ø.15 to 1.5 mm long.

(SO4,SO6,#43) Hypidiomorphic granular rhyolites composed of 7Ø% subhedral to euhedral plagioclase, Ø.Ø3 to 1.2 mm long; 25% anhedral quartz, Ø.Ø3 to Ø.3 mm long; and 5% subhedral hornblende up to Ø.45 mm long.

(SO9) Porphyrytic rhyolite composed of 7Ø% groundmass consisting of quartz, plagioclase, and pyrite; 15% subhedral to euhedral plagioclase up to 3.Ø mm long; 1Ø% anhedral to subhedral quartz up to 2.Ø mm long; and 5% anhedral to subhedral pyrite up to Ø.3 mm long.

(#21) Diabase composed of 55% sub-ophitic to ophitic clinopyroxene approximately 1.Ø mm long; 35% subhedral to euhedral plagioclase up to 1.Ø mm long; 5% opaque minerals; and 5% anhedral sphene less than Ø.Ø6 mm long.

(CS4) Diabase composed of 55% subhedral to euhedral plagioclase up to 1.2 mm long; 4Ø% sub-ophitic to ophitic clinopyroxene up to 2.7 mm long; and 5% anhedral sphene less than Ø.Ø5 mm long.

(CS12) Porphyrytic, vesicular basalt composed of 5Ø% groundmass consisting of plagioclase, clinopyroxene, and sphene; 25% anhedral to subhedral plagioclase up to 2.5 mm long; 15% subhedral clinopyroxene up to 3.1 mm long; and 5%

subhedral sphene up to Ø.3 mm long.

(SO7) Gabbroic dike composed of 5Ø% sub-ophitic to ophitic clinopyroxene up to 2.Ø mm long; 35% subhedral plagioclase up to 1.5 mm long; 1Ø% subhedral orthopyroxene up to 2.Ø mm long; and 5% subhedral magnetite less than Ø.5 mm long.

(GI43,SO1,#38) Diorites composed of 6Ø% subhedral plagioclase up to 3.Ø mm long; 3Ø% subhedral to euhedral clinopyroxene up to 2.7 mm long; and 1Ø% subhedral magnetite up to Ø.6 mm long.

(C45,CI4Ø,#2) Porphyrytic andesites composed of 7Ø% subhedral to euhedral plagioclase up to 2.1 mm long; 15% groundmass consisting of plagioclase, sphene, and magnetite; 1Ø% subhedral clinopyroxene up to 1.5 mm long; and 5% subhedral sphene up to Ø.4 mm long.