Geochemistry and provenance of Archean metasedimentary rocks in the southwestern Beartooth Mountains
by Peter Bouck Thurston

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Earth Sciences
Montana State University

Abstract:
A thick sequence of Archean metasedimentary rocks is exposed along the southwestern margin of the Beartooth Mountains, Montana.Rock types include quartz-biotite schist, biotite schist, biotite-garnet-staurolite-andalusite schist, iron formation (hornblende-cummingtonite-garnet schist), and dacitic metavolcanic rocks (quartz-muscovite-plagioclase schist). Preliminary chronologic data indicate an age of at least 3200 Ma for these racks (Paul Mueller, pers. comm.). The entire belt is metamorphosed from greenschist to middle amphibolite facies. Peak metamorphic conditions occurred at 550 degrees C and less than 3.8 kilobars. The entire rock package has experienced at least two periods of structural deformation. Early isoclinal folds (F1) are coincident with peak metamorphism (M1). Later open folds (F2) are superimposed on earlier structures. Primary sedimentary structures such as horizontal lamination, graded bedding, cross bedding, wavy bedding, and cut and fill structures are preserved. Analysis of sedimentary structures suggests that the rocks were originally deposited by turbidity currents in an environment similar to the midfan portion of a submarine fan. These data suggest deposition along an active continental margin; geochemical data indicates a provenance with sediment input from at least two different sources, one mafic and one felsic. These rocks are chemically unique in the northern Wyoming Province and were not derived from the adjacent Beartooth Mountains. A chronologically and chemically compatible source terrane has not been identified. The rocks are petrographically and chemically similar to early Archean greenstone belt sediments such as the Fig Tree group of Eriksson (1980). Similar rocks are exposed in central Wyoming (Condie, 1967). The style of metamorphism and deformation is sufficiently different from the surrounding region to classify these rocks as a distinct terrane. Previous work in the region has suggested the possibility of an Archean continental margin along the western edge of the Beartooth mountains (Wooden et al., in press). If this is the case then the metasedimentary rocks of the South Snowy Block could have been tectonically emplaced along this margin.

GEOCHEMISTRY AND PROVENANCE OF ARCHEAN METASEDIMENTARY ROCKS IN THE SOUTHWESTERN BEARTOOTH MOUNTAINS

by

Peter Bouck Thurston

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Earth Sciences

MONTANA STATE UNIVERSITY
Bozeman, Montana

December 1986

APPROVAL

of a thesis submitted by

Peter Bouck Thurston

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

December 1, 1986 — Date

David W. Mogk — Chairperson, Graduate Committee

Approved for the Major Department

Dec 1, 1986 — Date

Stephan G. Custer — Head, Major Department

Approved for the College of Graduate Studies

December 12, 1986 — Date

Henry L. Parsons — Graduate Dean

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University, I agree that the Library shall make it available to borrowers under rules of the Library. Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgment of source is made.

Permission for extensive quotation from or reproduction of this thesis may be granted by my major professor, or in his absence, by the Director of Libraries when, in the opinion of either, the proposed use of the material is for scholarly purposes. Any copying or use of the material in this thesis for financial gain shall not be allowed without my written permission.

Signature Peter B. Thurston

Date December 1, 1986

ACKNOWLEDGEMENTS

I would like to thank the American Copper and Nickel Company, Inc. for their generous financial support of this research. I would also like to thank John Ray, John Cuthill, Paul Mueller, and Joe Wooden for many enlightening discussions and critical reviews of this manuscript. Randi Hovin provided invaluable assistance with preparation of the diagrams.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES - continued

ABSTRACT

A thick sequence of Archean metasedimentary rocks is exposed along the southwestern margin of the Beartooth Mountains, Montana. Rock types include quartz-biotite schist, biotite schist, biotite-garnet-staurolite-andalusite schist, iron formation (hornblende-cummingtonite-garnet schist), and dacitic metavolcanic rocks (quartz-muscovite-plagioclase schist). Preliminary chronologic data indicate an age of at least 3200 Ma for these rocks (Paul Mueller, pers. comm.). The entire belt is metamorphosed from greenschist to middle amphibolite facies. Peak metamorphic conditions occurred at 550 degrees C and less than 3.8 kilobars. The entire rock package has experienced at least two periods of structural deformation. Early isoclinal folds (F_1) are coincident with peak metamorphism (M_1). Later open folds (F_2) are superimposed on earlier structures. Primary sedimentary structures such as horizontal lamination, graded bedding, cross bedding, wavy bedding, and cut and fill structures are preserved. Analysis of sedimentary structures suggests that the rocks were originally deposited by turbidity currents in an environment similar to the midfan portion of a submarine fan. These data suggest deposition along an active continental margin; geochemical data indicates a provenance with sediment input from at least two different sources, one mafic and one felsic. These rocks are chemically unique in the northern Wyoming Province and were not derived from the adjacent Beartooth Mountains. A chronologically and chemically compatible source terrane has not been identified. The rocks are petrographically and chemically similar to early Archean greenstone belt sediments such as the Fig Tree group of Eriksson (1980). Similar rocks are exposed in central Wyoming (Condie, 1967). The style of metamorphism and deformation is sufficiently different from the surrounding region to classify these rocks as a distinct terrane. Previous work in the region has suggested the possibility of an Archean continental margin along the western edge of the Beartooth mountains (Wooden et al., in press). If this is the case then the metasedimentary rocks of the South Snowy Block could have been tectonically emplaced along this margin.

INTRODUCTION

Archean metasedimentary rocks are exposed in a narrow belt along the southern margin of the South Snowy Block of the Beartooth Mountains in southwestern Montana (Figure 1). These rocks are unique in the northern Wyoming Province (Condie, 1976) because of their low metamorphic grade, excellent preservation of primary sedimentary structures, and distinct chemical composition. Similar metasedimentary rocks are reported from the southern Wind River Range (Condie, 1967), the Owl Creek Mountains, and Rattlesnake Range in the southern Wyoming Province, but comparable rocks are not known to exist in the northern Wyoming Province.

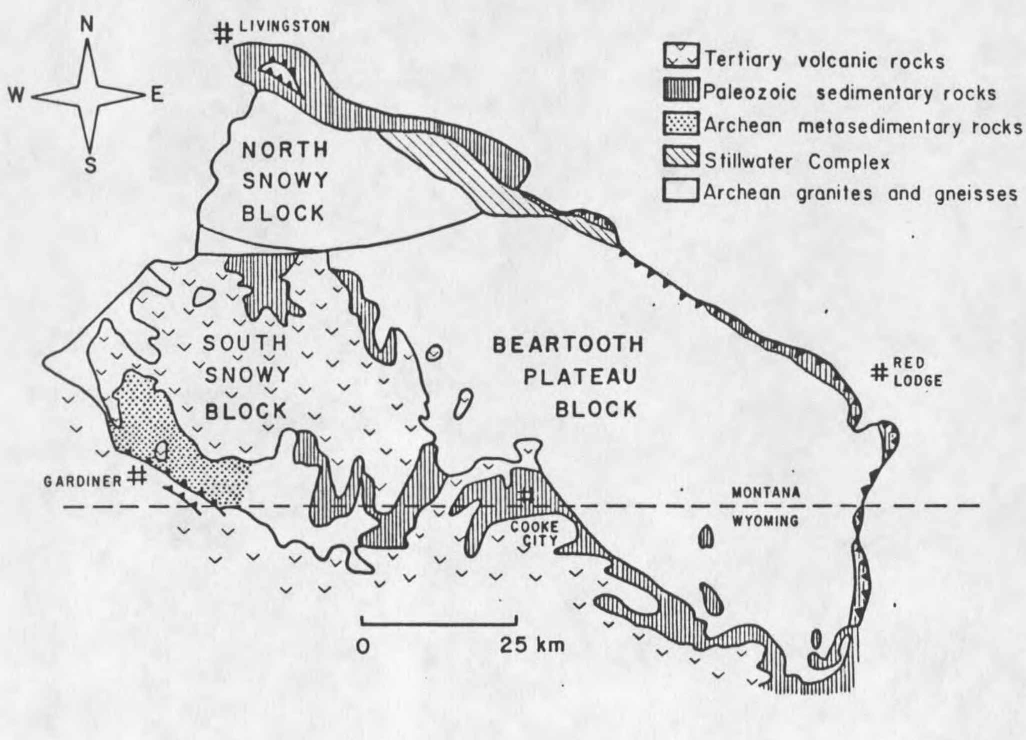

Figure 1. Geologic map of the Beartooth Mountains.

Previous research on Archean rocks in the South Snowy Block in general has been limited to a regional study along the southern margin of the block (Casella et al, 1982). In addition, specific projects concentrated on the gold mineralization in the Jardine area (Seager, 1944, Hallager, 1980) and surface geology of the Gardiner Quadrangle (Fraser et al, 1969).

This study examines metasedimentary rocks from the central part of the belt (Figure 2). The systematic evaluation of the sedimentology and geochemistry presented here suggests that the metasedimentary package was derived from a combination of mafic and felsic sources. The provenance, style of metamorphism, and style of deformation suggest that the entire metasedimentary package was tectonically emplaced in the late Archean.

GENERAL GEOLOGY

Archean metamorphic and igneous rocks of the South Snowy Block are for the most part covered by Eocene volcanic rocks and surficial deposits. Only along the southern margin of the block are Archean rocks well exposed. The metasedimentary sequence is bordered on the east by an Archean batholithic complex (Casella et al, 1982) consisitng of an early quartz-hornblende diorite and younger tonalites and granites (Wooden et al., in press). The minimum age of the metasedimentary rocks is constrained by ages from several of these plutons. The Crevice granite, which intrudes the central part of the belt, is dated at 2,620 Ma to 2,730 Ma by Rb/Sr and K/Ar methods (Brookins, 1968). These data are supported by a Rb/Sr model age on muscovite of 2,740 ± 30 Ma for the Hellroaring Mountain stock (Wooden et al., 1982). A U-Pb zircon age analysis suggests an age of 2,730 to 2,790 Ma for a biotite granodiorite that intrudes the eastern part of the metasedimentary belt (Montgomery, 1982). In the northern and southern portions of the area, these metasedimentary rocks are covered by Eocene volcanic rocks. To the west, the belt is terminated by a ductile shear zone in the Yankee Jim Canyon area (Burnham, 1980). The southwest corner is truncated by the Gardiner Fault, a high angle reverse fault of Laramide age (Fraser et al, 1969).

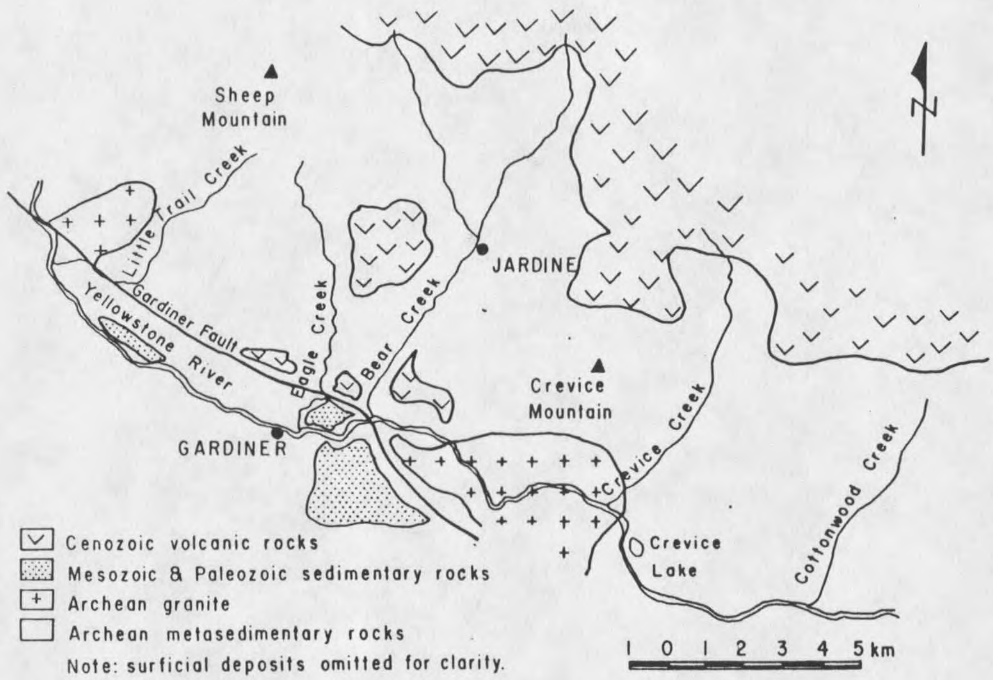

Figure 2. Distribution of metasedimentary rocks in the South Snowy Block.

METASEDIMENTARY ROCKS

Metasedimentary rocks are the oldest lithologic units in the study area. These rocks are metamorphosed from the upper greenschist to middle amphibolite facies with metamorphic grade increasing to the east. A metamorphic foliation defined by parallel alignment of biotite and chlorite is present throughout the region, and is locally very pronounced.

Rock types in the study area include quartz-biotite schist, biotite schist, biotite-staurolite-andalusite schist, garnet-biotite-chlorite schist, iron formation (both silicate and oxide facies), quartzite metaconglomerate, and felsic metavolcanic rocks (quartz-muscovite-plagioclase schist). Each of these lithologies is described in terms of its field appearance and petrography. Selected samples are analyzed for major and trace element geochemistry. For a complete description of analytical methods and listing of data refer to Appendices A and B.

Quartz-Biotite Schist

Quartz-biotite schist is the dominant lithology in the region. In outcrop the rocks are light grey to medium brown in color. Bedding is well exposed in many locations and is defined by abrupt changes in grain size and texture. Individual beds are 5.0 to 25.0 centimeters thick and sedimentary textures and structures such as grading, cross bedding, and cut and fill structures are often preserved. The rock is poorly sorted and is composed of detrital quartz and feldspar grains set in a matrix of quartz, biotite, and chlorite.

Two varieties of detrital quartz grains are present. Monocrystalline quartz grains are the most abundant, and commonly exhibit undulose extinction (Figure 3). Individual monocrystalline quartz grains range in size from 0.1 to 2.0 millimeters and are subrounded to subangular. Polycrystalline quartz grains tend to be slightly larger, have sutured grain boundaries, and are commonly fractured (Figure 4). Individual polycrystalline quartz grains are 1.0 to 2.0 millimeters in size and are subrounded to subangular A gradation between the two types exists. Both varieties of quartz grains are flattened and elongated in the plane of the foliation.

Plagioclase occurs as subrounded detrital grains from 0.5 to 2.0 millimeters in diameter and contain abundant quartz inclusions (Figure 5). Original grain boundaries and igneous textures such as oscillatory zoning and albite twinning are preserved despite metamorphic recrystallization. Compositions determined by optical (Michel-Levy) methods range from An_{24}-An_{31}. Plagioclase grains are also aligned and flattened in the plane of the foliation.

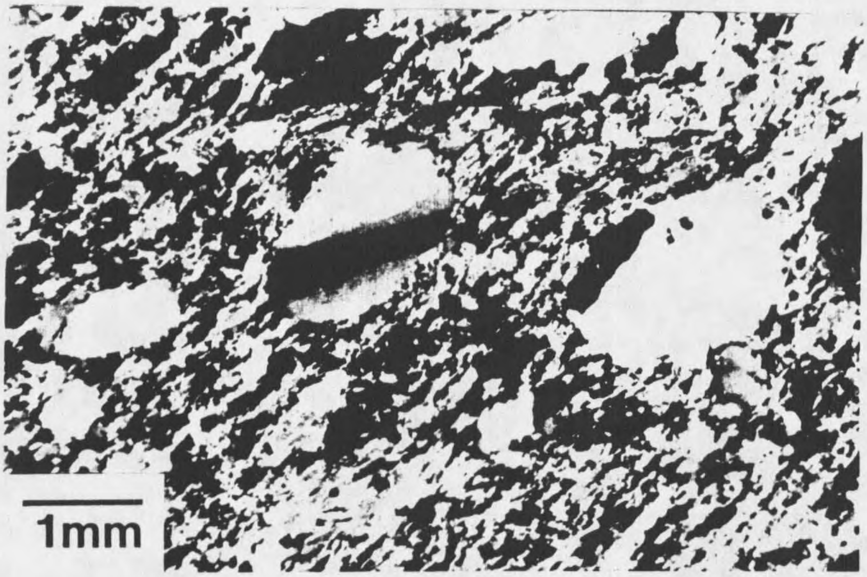

Figure 3. Photomicrograph of monocrystalline quartz grains.

Probable lithic fragments (Figure 6) also constitute a portion of the detrital grains. Angular to subrounded grains composed of aggregates of quartz and plagioclase are 0.5 to 2.0 millimeters in size. The plagioclase occurs as optically discontinuous aggregates of euhedral crystals suggesting an igneous origin. Positive identification of any specific rock type is difficult because of recrystallization, however most appear to be fragments of tonalite or trondhjemite.

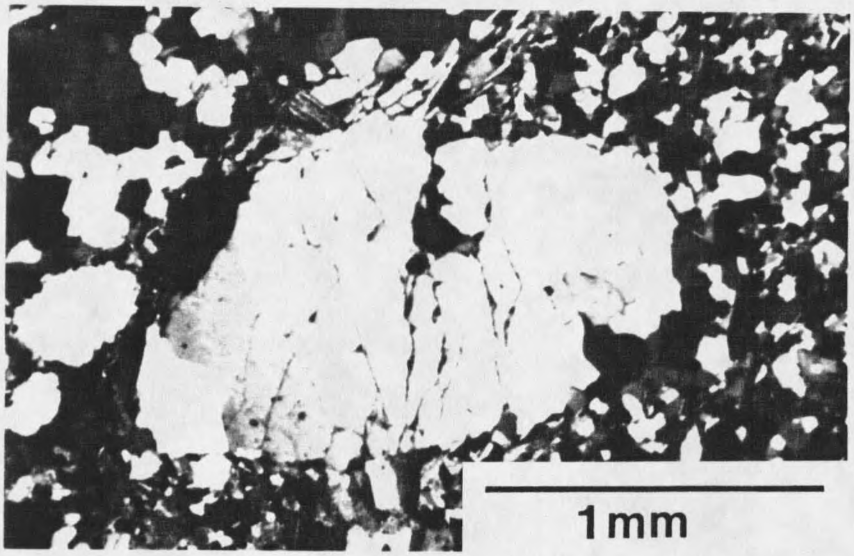

Figure 4. Photomicrograph of a polycrystalline quartz grain.

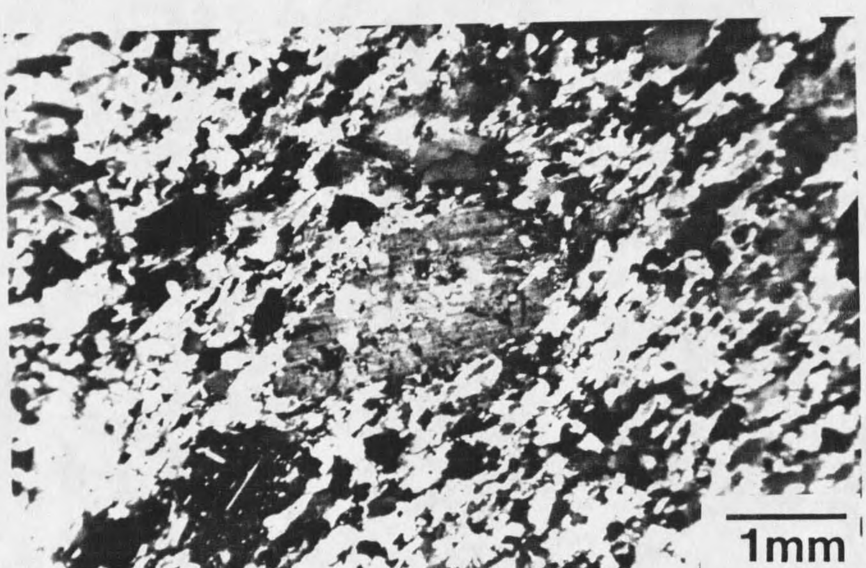

Figure 5. Photomicrograph of a detrital plagioclase grain.

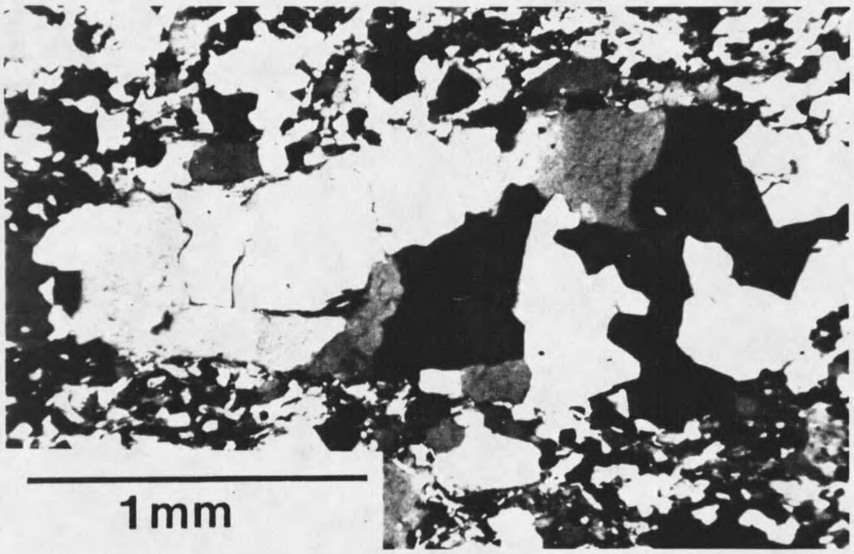

Figure 6. Photomicrograph of a large lithic fragment.

The matrix is composed of granoblastic quartz, laths of biotite and chlorite, and small euhedral plagioclase crystals. Plagioclase in the matrix has a similar composition to the detrital plagioclase grains suggesting that recrystallization of the feldspars was complete. Two generations of biotite are present. Primary biotite and chlorite occur as thin laths and define the primary (F_1) foliation which is parallel to observed lithologic contacts. Secondary biotite and chlorite occur as blocky crystals that cut across the primary (F_1) foliation and define an incipient secondary (F_2) foliation.

Porphyroblasts of garnet and staurolite are common in samples from the eastern portion of the area where metamorphic grade is above the staurolite isograd. Garnet porphyroblasts are euhedral and contain inclusions of quartz and biotite. Staurolite is subhedral and has inclusions of quartz.

Accessory minerals include tourmaline, apatite, zircon, and magnetite. Zircons are subhedral, show strong pleochroic halos in biotite, and lack visible metamorphic overgrowths. Under plane light the tourmalines typically have deep blue, rounded cores surrounded by euhedral yellow-green overgrowths. The blue cores may be part of the detrital population, suggesting that tourmaline was present in the source area.

The most common sedimentary feature is compositional layering. Individual layers are 0.5 to 50 centimeters thick. Graded bedding is typically well developed in the coarser-grained units. In individual graded beds biotite content increases towards the top with a corresponding decrease in detrital quartz and plagioclase. Single graded beds are 2.0 centimeters to 25.0 centimeters thick. Low angle cross stratification, ripple cross stratification, and wavy bedding are well developed in the finer grained units (Figures 7 and 8). Possible rip up clasts are also present (Figure 9). A channel scour filled with conglomerate is present in an outcrop in the central part of the study area

(Figure 10). This feature is 3.0 meters in width and is a maximum of 1 meter thick. The basal contact of the scour is sharp. The upper contact is gradational into coarse grained, quartz-biotite schist. Clasts are 0.5 to 2.0 millimeters in diameter and are mostly monocrystalline quartz with subordinate plagioclase and lithic fragments. The matrix is composed of quartz and biotite.

Figure 7. Horizontal laminations and ripple cross stratification in fine-grained quartz-biotite schist.

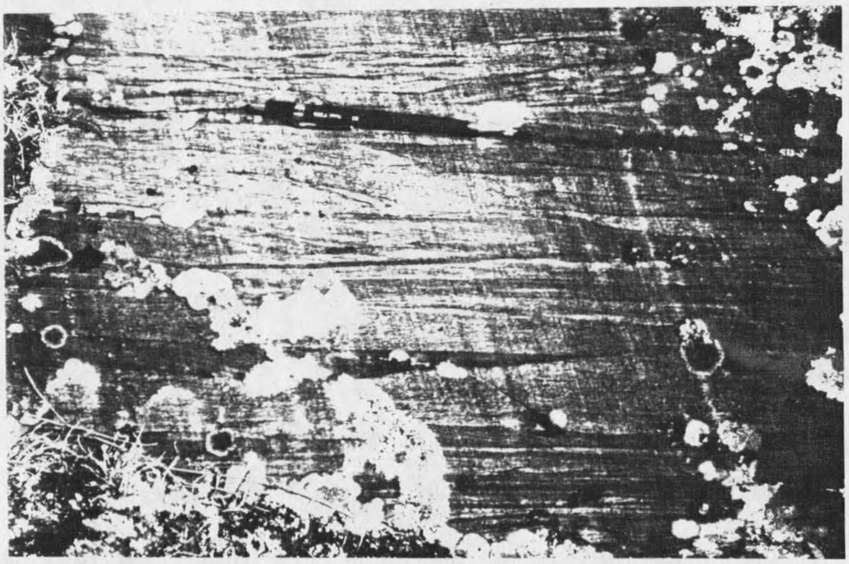

Figure 8. Sedimentary structures in quartz-biotite schist. Vertical lines are glacial striations. Bedding (S_0) and primary foliation (S_1) are parallel to pencil.

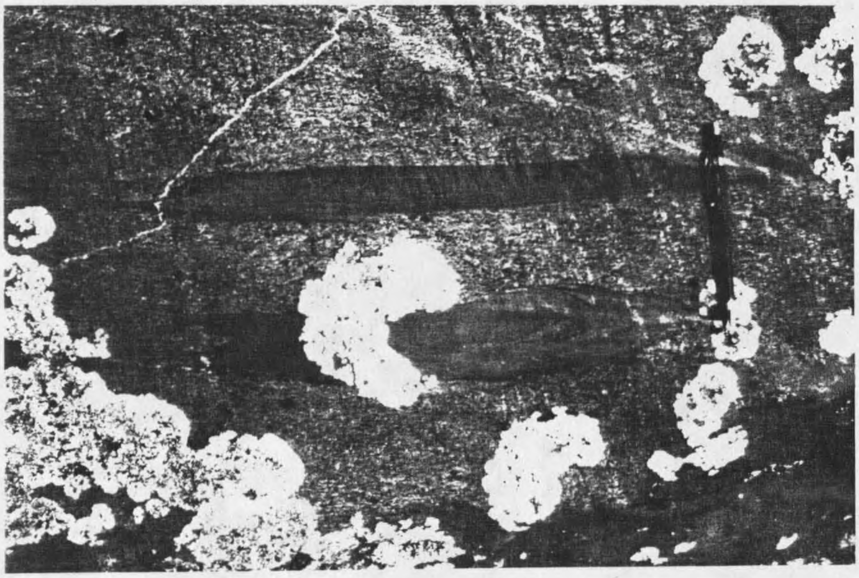

Figure 9. Rip-up clasts in quartz-biotite schist.

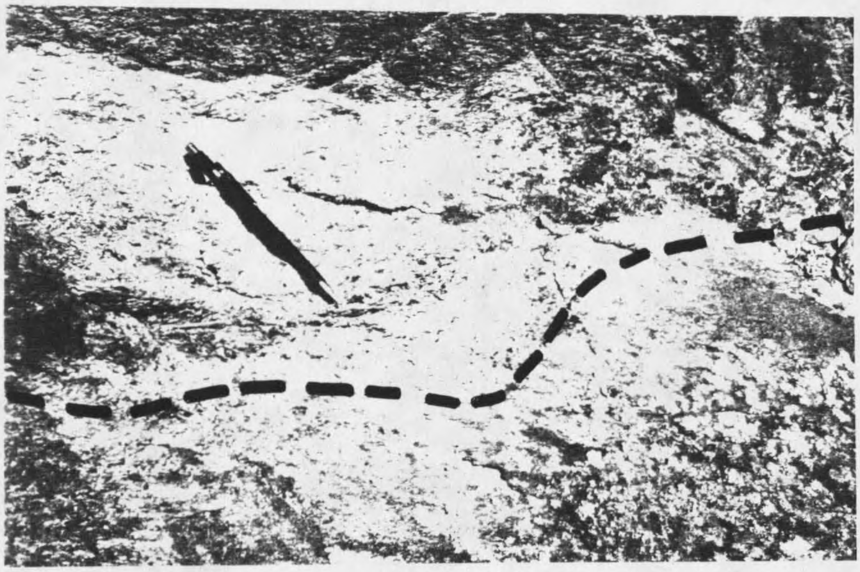

Figure 10. Basal contact of conglomerate-filled scour.

Modal analyses of 20 quartz-biotite schists (see Table 6, Appendix B) suggests a subarkosic sandstone as the protolith (after Folk, 1974). The proportion of matrix material is high (19 to 29 %); consequently these rocks are classified as greywackes.

Major and trace element analyses of 13 greywackes from the South Snowy Block are presented in Table 1. These rocks exhibit a wide range of silica values that roughly correlate with grain size. The highest SiO_2 contents are found in coarse grained rocks with the highest percentage of detrital quartz grains. The distribution of major elements with respect to SiO_2 content is presented in Figure 11. Al_2O_3, FeO, and MgO all decrease with increasing SiO_2. The CaO distribution is erratic and does not correlate with any observed petrologic features. The increase in Na_2O with increasing SiO_2 is related to abundant detrital plagioclase in the coarser-grained rocks and possibly to diagenetic albitization of feldspar (e.g. Boles, 1982). The increase in K_2O with decreasing SiO_2 is related to an increase in the relative porportion of matrix material (biotite) in the finer grained rocks. When compared to other Archean metagreywackes (Table 2) the South Snowy Block greywackes are unique in their low CaO (<2%) content and high $K_2O:Na_2O$ ratio (up to 2.7). Concentrations of FeO and MgO are slightly elevated and SiO_2, Al_2O_3, Na_2O and K_2O are all close to average. The South Snowy Block greywackes contain high concentrations of trace elements, particularly the transition metals. Concentrations of Zn, Ni, and V are between 50 and 100 ppm and Mn, Cr, and Ba are all between 300 and 400 ppm (Table 1).

Table 1. Major and trace element geochemistry.

Analysis	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Sample No.	8514	8530	8536	8560	8535	8562	8534	8585	8550	8531	8542	8553	8563	8573	8578	8556	AVG1	AVG2
SiO2	64.0	49.3	56.3	55.9	56.0	57.6	60.0	66.5	61.6	69.1	72.6	73.1	69.6	73.8	74.8	75.8	56.5	66.6
TiO2	0.64	0.67	0.77	0.67	0.73	0.68	0.64	0.59	0.60	0.48	0.43	0.46	0.53	0.44	0.39	0.40	0.69	0.54
Al2O3	15.0	18.0	19.6	18.6	18.2	16.4	16.5	14.5	15.0	13.1	11.6	11.6	11.9	10.8	11.4	10.5	17.5	13.9
FeO	7.30	11.0	9.53	9.85	10.53	9.23	7.68	7.95	10.54	5.53	4.60	5.36	6.49	4.77	3.48	4.36	9.28	6.95
MnO	0.09	0.09	0.12	0.09	0.12	0.10	0.11	0.07	0.07	0.09	0.06	0.06	0.06	0.08	0.07	0.08	0.10	0.08
MgO	3.82	5.06	4.57	4.19	4.36	5.23	4.05	3.41	3.96	2.54	2.26	2.40	3.18	2.42	1.67	1.80	4.48	3.19
CaO	0.44	1.71	0.66	0.72	1.14	1.06	2.13	0.70	0.70	1.90	1.29	0.87	1.13	1.24	1.50	1.56	0.94	1.23
Na2O	0.86	3.00	0.76	1.42	1.51	1.51	3.04	1.22	1.08	2.72	3.02	2.32	2.34	2.20	2.77	2.34	1.54	2.11
K2O	3.12	3.45	3.39	3.85	3.32	3.90	1.93	2.86	3.15	2.29	1.91	2.26	2.17	1.72	1.91	1.69	3.32	2.54
LOI	3.76	6.05	2.88	3.31	2.24	2.93	2.72	1.57	2.08	1.55	1.20	1.71	1.97	1.60	0.91	1.17	4.23	1.92
K2O/Na2O	3.63	1.15	4.46	2.71	2.20	2.58	0.63	2.34	2.92	0.84	0.63	0.97	0.93	0.78	0.69	0.72	2.16	1.20
FeO+MgO	11.12	16.06	14.10	14.04	14.89	14.46	11.73	11.36	14.50	8.07	6.86	7.76	9.67	7.19	5.15	6.16	13.76	10.14
Total	99.03	98.33	98.58	98.60	98.15	98.64	98.80	99.37	98.78	99.30	98.97	100.1	99.37	99.07	98.90	99.70	98.65	99.06
Mo	2	2	7	1	3	4	3	7	3	1	4	6	6	7	8	6	4	5
Cu	37	11	24	19	19	84	65	21	38	47	41	23	128	52	18	46	24	46
Pb	5	5	5	9	6	13	5	15	12	6	13	17	10	11	10	7	5	10
Zn	90	100	12	39	34	109	97	16	30	80	67	29	80	65	59	62	67	59
Ni	120	210	6	131	160	178	120	89	80	120	59	53	77	72	43	58	112	95
Co	23	33	2	22	27	29	25	16	14	25	12	12	21	16	9	14	19	19
Mn	540	550	440	510	250	670	760	328	176	450	514	418	410	305	558	378	510	441
As	3	2	2	19	13	27	2	2	122	2	93	37	18	10	14	18	2	29
Th	-	-	-	7	-	13	-	8	8	-	11	9	11	9	8	9	0	7
Sr	-	-	-	6	-	6	-	5	6	-	7	7	8	7	7	8	0	5
Bi	3	2	2	2	2	6	2	2	2	2	4	2	6	4	2	3	2	3
V	67	160	18	93	150	92	120	83	102	93	75	63	68	48	45	61	82	84
La	-	-	-	30	-	26	-	11	32	-	33	27	21	23	23	23	0	19
Cr	220	450	130	222	350	361	390	242	248	400	292	247	340	234	242	234	267	292
Ba	120	920	32	282	730	377	240	500	489	540	478	334	365	219	254	541	357	411
B	2	2	1	2	2	3	1	2	2	2	2	4	7	2	1	2	2	2
W	3	3	2	1	3	1	2	1	1	2	1	1	1	1	1	1	3	1

1-3 Biotite Schist
4-8 Fine Grained Quartz-Biotite Schist
9-12 Medium Grained Quartz-Biotite Schist
13-16 Coarse Grained Quartz-Biotite Schist
17 Average Biotite Schist
18 Average Quartz-Biotite Schist
Note: Major elements determined by XRF, Trace elements determined by ICP.

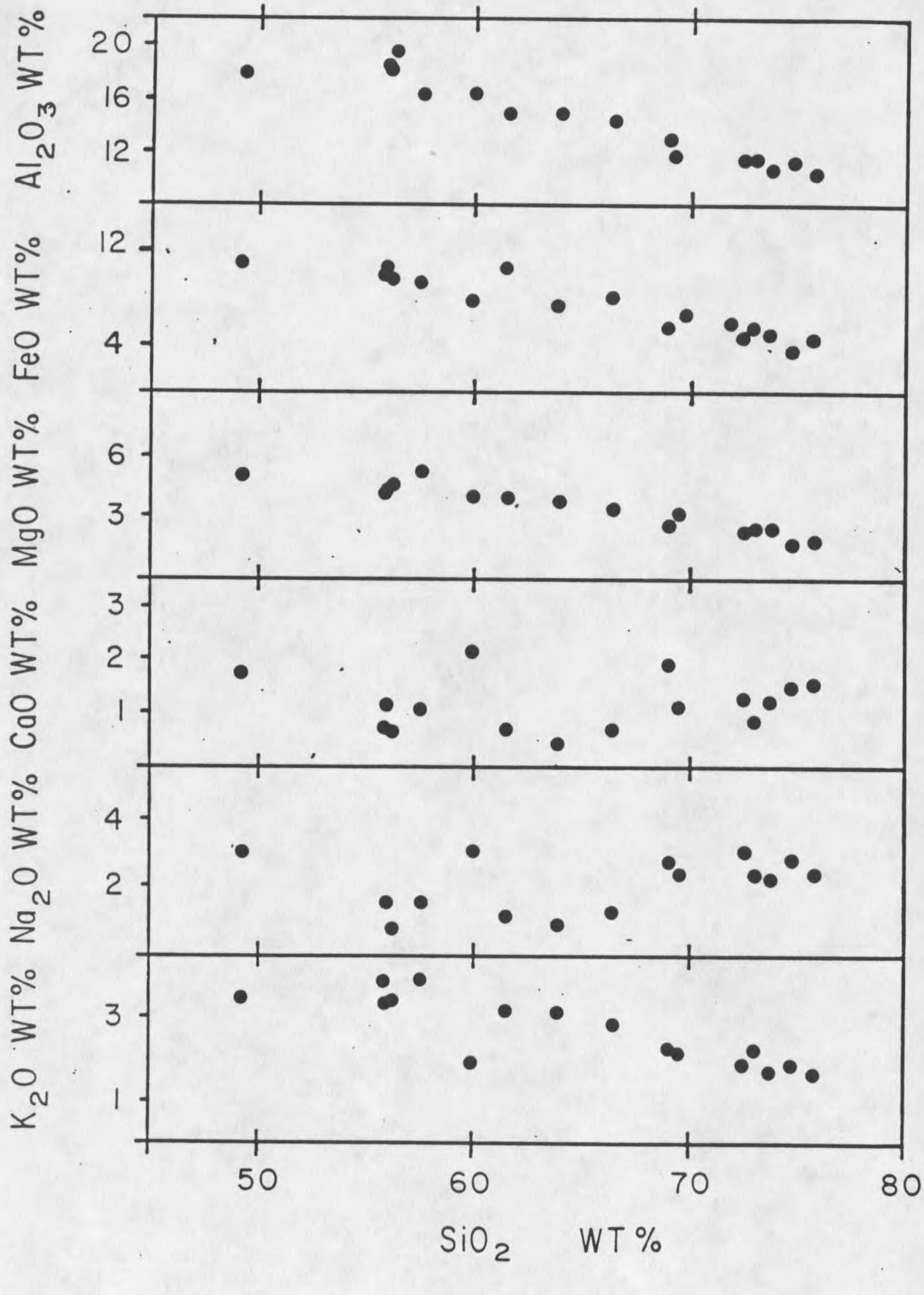

Figure 11. Major element variation diagram for metasedimentary rocks.

Table 2. Comparison of South Snowy Block greywackes with other Archean greywackes worldwide. Data presented are weight percent of oxides.

	1	2	3	4	5	6	7	8
SiO_2	66.65	64.3	68.1	70.7	64.7	63.4	65.6	82.8
TiO_2	0.54	0.5	0.7	0.6	0.6	0.4	0.6	0.3
Al_2O_3	13.85	15.6	15.7	10.9	14.0	15.0	15.8	8.1
FeO	6.95	5.3	5.3	6.7	6.4	4.7	6.0	2.9
MgO	3.19	3.6	2.8	4.8	4.8	3.7	3.2	1.2
CaO	1.23	4.2	1.8	2.1	3.4	5.9	2.3	1.8
Na_2O	2.11	2.9	3.2	1.9	3.1	4.2	3.8	0.5
K_2O	2.54	2.5	2.0	1.7	2.4	2.0	2.5	0.9
K_2O/Na_2O	1.46	0.86	0.63	0.89	0.77	0.48	0.66	1.80
FeO+MgO	10.1	8.9	8.1	11.5	11.2	8.4	9.2	4.1

1. Average of 13 greywackes, South Snowy Block, Montana, USA (this paper).
2. Average of 4 greywackes, Vermillion District, Minnesota, USA (Arth and Hanson, 1975).
3. Average of 3 greywackes, Burwash Fm., Slave Province, Canada (Henderson, 1975).
4. Average of 17 greywackes, Sheba Fm., Barberton Mountain Land, South Africa (Condie et al, 1970).
5. Average of 7 greywackes, Belvue Road Fm., Barberton Mountain Land, South Africa (Condie et al, 1970).
6. Average of 10 greywackes, Chitaldrug Schist Belt, India, (Naqvi and Hussain, 1972).
7. Average of 23 greywackes, Wind River Mountains, Wyoming, USA (Condie, 1967).
8. Average of 2 greywackes, North Spirit Lake, Superior Province, Canada (Donaldson and Jackson, 1965).

Rare earth element patterns for two greywackes are depicted in Figure 12. The greywackes exhibit a pronounced LREE enrichment and HREE depletion with La/Yb values of 7.2 and 12.4. A medium grained greywacke (sample 8544) and a quartzite metaconglomerate (sample 8563) both have slight negative Eu anomalies; the Eu/Eu* values are 0.76 and 0.89. These patterns are typical of quartz intermediate greywackes as described by Taylor and McLennan (1985).

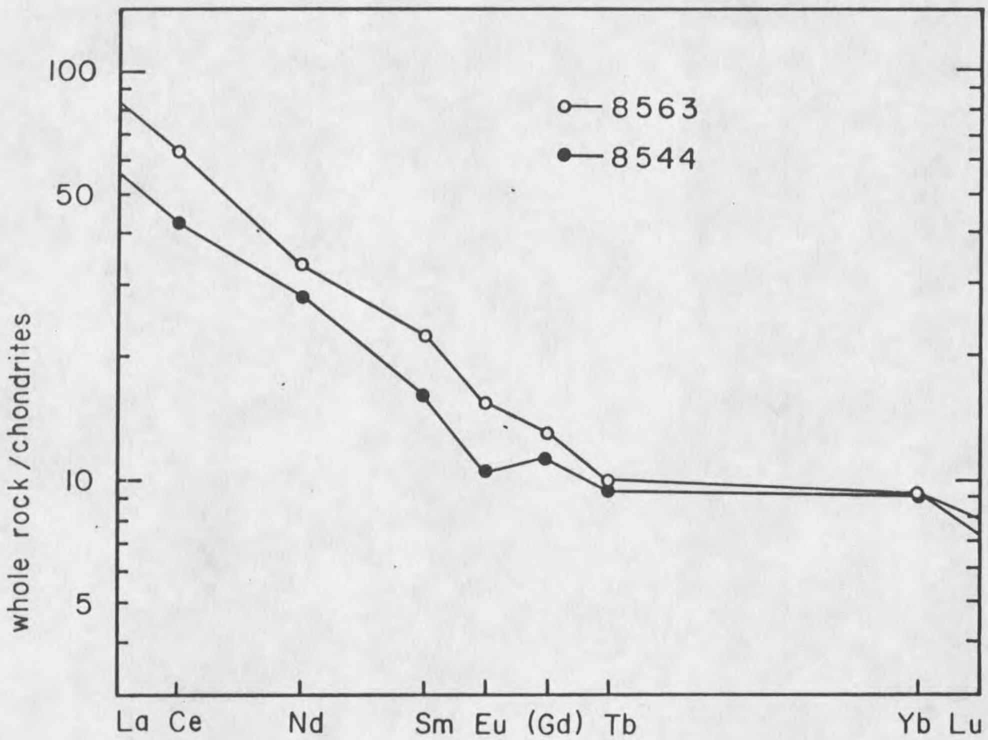

Figure 12. Rare earth element distribution in metagreywacke.

Biotite Schist

Biotite schist is a distinct rock unit consisting of 50% or more biotite and little or no detrital quartz. It is not as abundant as quartz-biotite schist but is still an important component of the metasedimentary sequence, especially in the Jardine area. The biotite schists are metapelites which are composed primarily of biotite and recrystallized quartz with a variety of metamorphic minerals. Porphyroblasts of garnet, staurolite, and andalusite are common. Accessory minerals include chlorite, muscovite, sericite, plagioclase, tourmaline, and zircon.

A metamorphic foliation (F_1) is pervasive and is defined by parallel alignment of biotite and chlorite laths. An incipient second foliation (F_2) is visible in thin section and is defined by alignment of secondary biotite in a crenulation space cleavage. Two distinct generations of biotite and chlorite growth are present. The primary biotite is elongate and the secondary biotite is blocky and crosscuts the F_1 foliation.

Porphyroblasts of garnet range from 0.5 to 2.0 millimeters in diameter. Syn-kinematic garnets contain S-shaped trains of inclusions. Post-kinematic garnets contain linear inclusions which are parallel to, and heliciticically overgrow, the F_1 foliation. Inclusions consist of quartz, biotite, and chlorite with minor tourmaline.

Staurolite porphyroblasts are 0.1 to 3.0 millimeters in size and contain abundant inclusions of quartz, chlorite, biotite, and garnet. Most of the staurolite grew prior to deformation, but some is syn-kinematic as evidenced by S-shaped inclusion trains.

Andalusite porphyroblasts are 5.0 to 10.0 millimeters in size. In most cases andalusite has undergone retrogade metamorphism to form muscovite with retention of the original porphyroblastic form. Most of the andalusite crystals are rotated in the plane of the foliation.

The fine grain size, abundance of micas, and metamorphic mineral assemblages in the biotite schist suggest that it was originally deposited as muds. Complete major and trace element chemistry for these rocks is given in Table 1. Compared to the greywacke, the mudstone is enriched in Al_2O_3, FeO, MgO, and K_2O and depleted in CaO and Na_2O. The K_2O:Na_2O ratio (up to 4.4) is higher as is the total FeO+MgO content (up to 16.06). Compared to other Archean mudstones (Table 3), the South Snowy Block mudstones have a depletion in CaO and a relatively high K_2O:Na_2O ratio. Overall distribution of major elements is quite similar to the greywacke, although quartz content is lower. Trace element data (Table 1) show concentrations of Cr, Ni, Zn, Co, V and Ba slightly higher than those in the greywackes.

Rare earth element geochemistry of two biotite schist samples is presented in Figure 13. Both samples are LREE enriched. La/Yb ratios are 2.4 and 8.8. Sample 8530 has a negative Eu anomaly with a Eu/Eu* value of 0.77. Sample 8536 has a slight positive Eu anomaly with a Eu/Eu* value of 1.08. These two samples define a wide range of REE values which probably reflects contributions from more than one source. Sample 8530 is very similar to the metagreywacke and may have been derived from the same area. Sample 8536 has a distinct mafic REE signature characterized by low La/Yb and low total REE abundance.

Table 3. Comparison of South Snowy Block mudstones with other Archean mudstones. Data presented are weight percent of oxides.

	1	2	3	4	5	6	7
SiO_2	56.5	56.8	56.2	63.9	61.8	65.4	60.8
TiO_2	0.7	0.9	1.0	0.8	0.6	0.4	0.7
Al_2O_3	17.5	21.3	21.6	20.1	14.3	22.1	24.1
FeO	9.3	8.3	8.6	6.6	11.8	4.0	5.5
MgO	4.5	4.9	5.0	2.4	6.7	0.5	3.5
CaO	0.9	2.0	1.3	0.4	1.0	2.0	0.01
Na_2O	1.5	2.9	2.3	2.8	1.1	2.4	0.6
K_2O	3.3	2.8	3.7	2.6	2.5	3.6	4.8
K_2O/Na_2O	3.1	1.0	1.6	0.9	2.3	1.5	8.0
FeO+MgO	13.8	13.2	13.6	9.0	18.5	4.5	9.0

1. Average of 3 mudstones, Beartooth Mountains, Montana, USA (this study).
2. Average of 3 mudstones, Burwash Fm., Slave Province, Canada (Henderson, 1975).
3. Vermillion District, Knife Lake (Grout, 1933).
4. Minnetaki Group, Superior Province, Canada (Walker and Pettijohn, 1971).
5. Average of 5 mudstones Fig Tree Group, Barberton Mountain Land, South Africa (Condie et al, 1970).
6. North Spirit Lake, Superior Province, Canada (Donaldson and Jackson, 1965).
7. Average of 10 mudstones, Gorge Creek Group, Pilbara Block, Western Australia (McLennan, 1983).

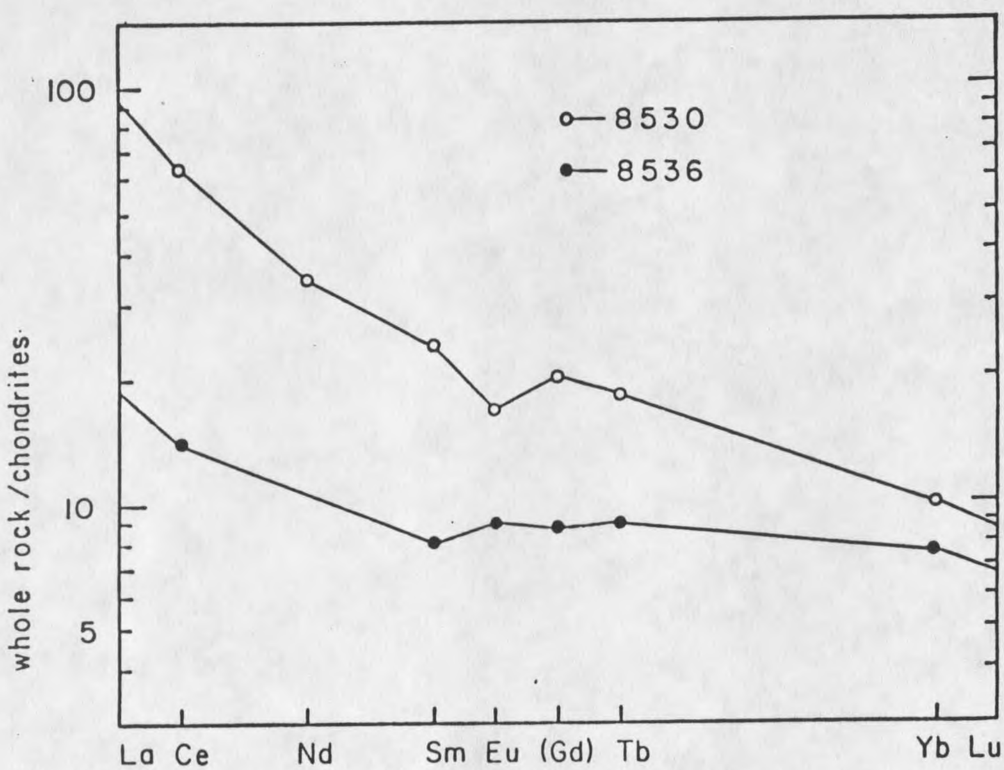

Figure 13. Rare earth element distribution in biotite schist.

Iron Formation

Iron formation occurs throughout the study area in discontinuous outcrops 1-10 meters thick. Several distinct horizons exist and tentative correlations can be made up to 1 kilometer along strike. Individual horizons are usually surrounded by a halo of garnet-chlorite schist or garnet-chlorite-biotite schist.

Both silicate and oxide facies of iron formation are present and are most abundant in the western part of the study area. The silicate facies iron formation is a massive hornblende-quartz-cummingtonite-garnet rock that is 1 to 2 meters thick in outcrop. Cummingtonite occurs as thin laths, bow tie shaped crystals, and as radiating aggregates of crystals. Cummingtonite crystals are often rimmed by grunerite. Hornblende occurs as elongate laths and is commonly replaced by biotite. Porphyroblasts of garnet up to 1 centimeter in diameter are common and contain inclusions of quartz, hornblende, and cummingtonite. The foliation is defined by parallel orientation of hornblende and cummingtonite.

Oxide facies iron formation is a thinly-laminated hornblende-cummingtonite-quartz rock with up to 20 percent magnetite and commonly 1 to 3 percent pyrrhotite. Alternating layers of hornblende-cummingtonite and quartz are 25-50 millimeters thick. Magnetite is disseminated throughout the rock.

In the surrounding garnet-chlorite schist there are three morphologies of garnet. Pre-tectonic garnets have linear inclusions and have been rotated with respect to each other. Syntectonic garnets have a snowball texture and S-shaped inclusions. Post-tectonic garnets helicitically overgrow the existing foliation.

Table 4. Major element geochemistry of Wyoming Province iron formations. Data presented are weight percent of oxides.

	1	2	3	4	5	6
SiO_2	56.9	50.9	48.1	47.6	44.2	45.5
TiO_2	0.36	0.28	0.2	0.3	nd	0.06
Al_2O_3	8.49	6.39	4.46	7.15	3.85	1.80
Fe_2O_3*	25.8	36.6	39.4	35.6	47.8	45.1
MnO	0.16	0.2	0.16	0.2	0.09	0.64
MgO	4.85	3.55	3.53	2.36	2.80	3.82
CaO	4.61	3.66	4.38	6.24	1.31	3.01
Na_2O	0.51	0.71	0.24	0.62	1.22	0.34
K_2O	0.22	0.26	0.08	0.14	0.36	0.07
Total	101.9	102.5	100.5	100.2	101.6	100.7

*Total iron as Fe2O3

1-4. South Snowy Block Iron Formation (Casella et al,1982).
5. Oxide Iron Formation, South Pass, Wyoming (Pride and Hagner, 1972).
6. Silicate Iron Formation, Montana (Immega and Klein, 1976).

Compared to other iron formations from the Wyoming Province (Table 4), the South Snowy Block iron formations are enriched in SiO_2, TiO_2, Al_2O_3, and CaO and depleted in total Fe. They also have high Cr, Ni, V, Ba, and Co contents which is consistent with the enrichment of these elements in the clastic metasedimentary rocks (Table 1). Rare earth element concentrations are illustrated in Figure 6. The silicate facies iron formation (sample 110236) has a low total REE abundance, a La/Yb ratio of 2.7, a negative Eu anomaly, and a Eu/Eu* value of 0.80. The oxide facies rock has a lower total REE abundance, a La/Yb ratio also of 2.7, and a Eu/Eu* value of 0.95. The reason for the different Eu

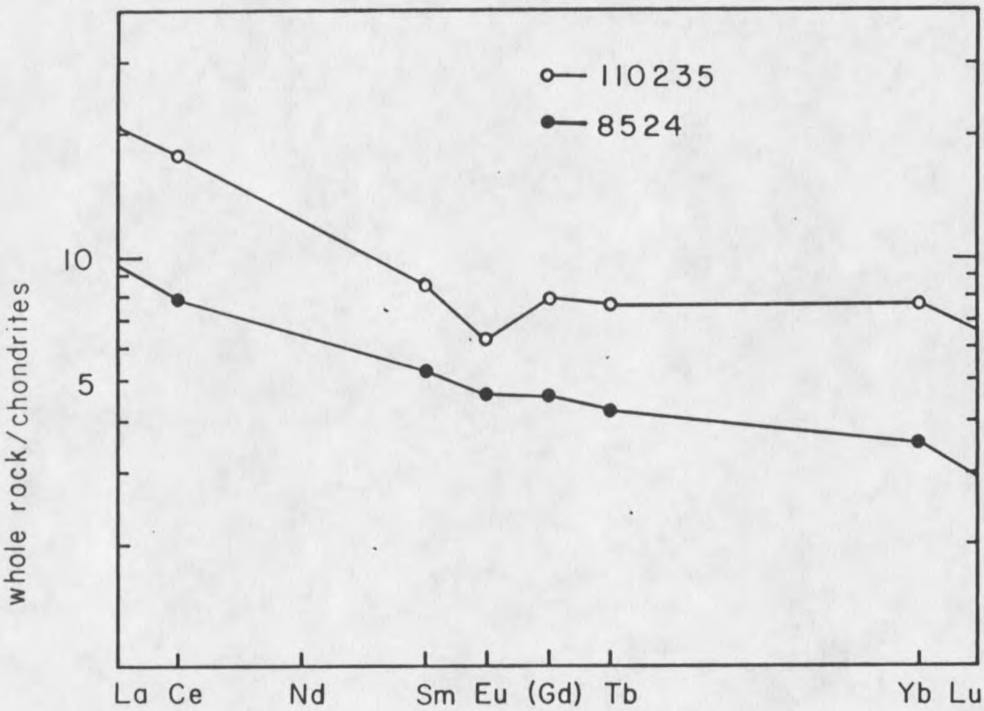

Figure 14. Rare earth element distribution of iron formation.

anomalies is not clear. It is possible that these iron formations have undergone complex diagenetic changes that could have altered the original REE abundances (e.g. Fryer, 1983). The lack of a negative Eu anomaly suggests that hydrothermal fluids may have been a contributing factor during deposition (Fryer, 1983). Both iron formations have mafic REE signatures similar to one of the mudstones (sample

8536) suggesting involvement of mafic rocks in their petrogenesis.

METAVOLCANIC ROCKS

Felsic metavolcanic rocks are interbedded with the metasedimentary rocks in the central part of the study area. They form distinctive white to orange-tan outcrops 1-3 meters thick. Although they seem to be concordant with bedding in the metasedimentary units, close examination reveals local discordances of 2-5 degrees along strike. Seven horizons are identified within the study area although some of these may represent structural repetition. These rocks have not been previously documented in the area and are interpreted to be either porphyritic sills or tuff deposits. These rocks have a pronounced foliation defined by crude alignment of micas and elongation of phenocrysts. The texture is porphyritic with plagioclase phenocrysts in a groundmass of quartz and white mica.

Plagioclase phenocrysts are 1.0 to 3.0 millimeters in size and are commonly twinned and zoned. Some of the phenocrysts are aggregates of several smaller crystals and quartz. Optical determinations on zoned crystals by the Michel-Levy method show a variation from An_{30} in the cores to An_{22} along the rims. The aggregates of crystals are not zoned and resemble the lithic fragments observed in the quartz-biotite schist. Alteration of plagioclase to sericite is common. The phenocrysts are often rotated in the foliation.

The groundmass consists of fine grained, granoblastic quartz, small laths of white mica (muscovite?), and minor biotite. Small euhedral plagioclase crystals are also present. Some of the laths of white mica are bent and kinked. The only retrograde mineral present is chlorite which does not grow in the plane of the foliation. Porphyroblasts of staurolite with inclusions of quartz are a minor phase.

The high SiO_2 content, low concentrations of FeO and MgO, and low $K_2O:Na_2O$ ratio (Table 5) indicate that the feldspar porphyry is dacitic in composition. Normative mineralogy suggests that it is compositionally similar to trondhjemite (after Barker, 1979; Figure 15).

Table 5. Major element geochemistry of metavolcanic rocks and common igneous rocks. Data presented are weight precent of oxides.

	1	2	3	4	5
SiO_2	72.9	73.3	70.99	71.9	62.6
TiO_2	0.14	0.14	0.49	0.29	0.74
Al_2O_3	15.5	15.4	14.28	15.5	16.8
FeO	1.45	0.94	2.36	2.1	5.57
MnO	0.02	<0.01	0.10	-	-
MgO	<0.5	<0.5	0.87	0.81	2.85
CaO	1.67	1.83	3.58	2.94	5.53
Na_2O	5.4	5.59	5.17	4.96	3.70
K_2O	0.84	0.97	0.80	1.52	2.10
Cr_2O_3	0.02	<0.01	-	-	-
LOI	0.93	0.99	1.20	-	-
$K_2O:Na_2O$	0.16	0.17	0.15	0.30	0.56
Total	98.87	99.16	99.84	100.02	99.89

1-2. Feldspar Porphyry (this study).
3. Dacite (Ewart, 1979).
4. Average Trondhjemite (McGregor, 1979).
5. Average Tonalite (LeMaitre, 1976).

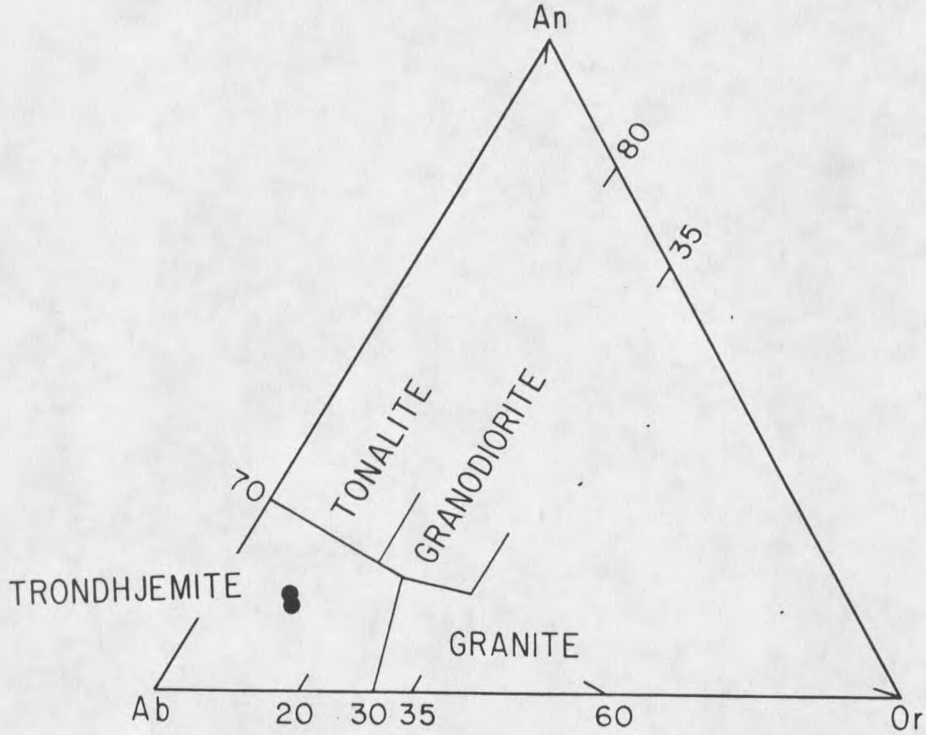

Figure 15. Normative Ab-Or-An plot of feldspar porphyry (after Barker, 1979).

PLUTONIC ROCKS

The central part of the belt contains the Crevice Mountain stock. The contact along the margin of the stock is sharp and there is little alteration of the surrounding metasedimentary units.

The rock is a weakly to non-foliated, biotite-muscovite quartz monzonite with an equigranular texture. Quartz, plagioclase, and microcline are present in equal amounts. Biotite and muscovite comprise 5-10% of the rock. Quartz occurs as large subhedral grains and commonly exhibits undulose extinction. Plagioclase (An_{20-25}) occurs as large anhedral grains and as small granular crystals. Microcline is present as large perthitic crystals. Myrmekite is common where microcline invades plagioclase grains. Both biotite and muscovite occur as small laths and aggregates of laths. Muscovite commonly cuts across biotite.

The metasedimentary sequence is also cut by several diabase dikes. Two varieties are present. The first is a fine-grained hornblende-plagioclase rock that is foliated. The second is a hornblende-plagioclase rock with very large (up to 3 centimeters) plagioclase phenocrysts. This rock is also foliated, but more weakly. Similar dike rocks occur throughout the Beartooth Mountains (Wooden, 1975).

METAMORPHIC GRADE

Biotite and chlorite are present throughout the metasedimentary package and place the minimum metamorphic grade in the middle greenschist facies. The lowest grade assemblages are found in the west-central part of the belt. Assuming the presence of primary muscovite, staurolite is produced by the following reactions:

(1) chlorite + muscovite =

staurolite + biotite + quartz + H_2O

(2) chlorite + muscovite + almandine =

staurolite + biotite + quartz + H_2O

The discontinuous reaction diagnostic of medium grade metamorphism in these rocks is:

chlorite + staurolite + muscovite + quartz =

Al_2SiO_5 + biotite + H_2O

This reaction breaks the staurolite-chlorite join of an AFM diagram and permits coexistence of Al_2SiO_5 + biotite (Thompson and Norton, 1968; Winkler, 1979) (Figure 16).

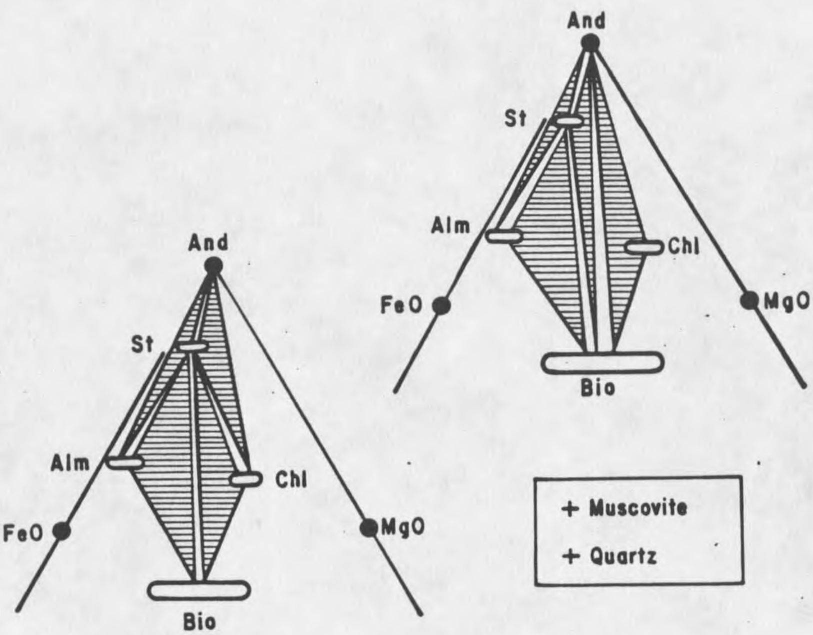

Figure 16. Discontinuous reaction in biotite schist (after Winkler, 1979).

The peak pressure and temperature of metamorphism are qualitatively constrained by two continuous model reactions:

(1) chlorite + muscovite =

staurolite + biotite + quartz + H_2O

(2) staurolite + muscovite + quartz =

biotite + andalusite + H_2O

These reactions have been determined experimentally by Hoschek (1967). Coexistence of staurolite, andalusite, garnet, and chlorite limits the peak metamorphic temperature and pressure to 550 degrees Celsius and 3.8 kilobars, respectively (Figure 17). This suggests a metamorphic thermal gradient of almost 50 degrees Celsius per kilometer.

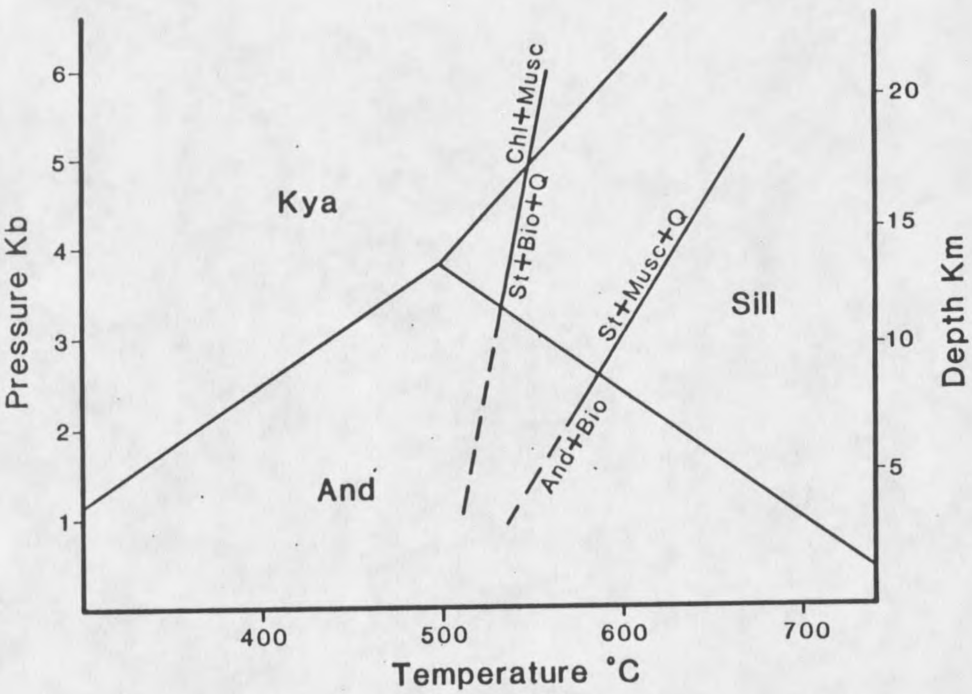

Figure 17. Pressure and temperature of peak metamorphism.

Prograde metamorphism in the biotite schist began with growth of a garnet + quartz + biotite + plagioclase assemblage and development of a primary foliation (S_1). This was followed by growth of porphyroblasts of staurolite and andalusite. Folding, growth of secondary biotite and chlorite, and development of an incipient S_2 surface were accompanied by rotation of staurolite, andalusite, and garnet porphyroblasts. Muscovite after andalusite and chlorite after biotite were produced by retrogression path during a later thermal event.

STRUCTURE

The metasedimentary rocks strike N to NE and dip between 39 and 80 degrees to the E and SE. A strong regional foliation (S_1) defined by alignment of micas is generally parallel to observed bedding (S_0). Axial planes of small scale isoclinal folds (F_1) are parallel to the regional foliation and plunge 70-80 degrees to the north. Microscopic F_1 isoclinal folds have strongly attenuated limbs. The F_1 isoclinal folds are deformed by F_2 open folds. These trend NE and plunge 10-50 degrees to the NE. F_2 folds are well developed in less competent micaceous units and are rarely observed in the massive quartz-rich units. Kink bands and chevron folds are also common in the more micaceous units and are probably related to F_2 since the trend and plunge of their hingelines is the same. Graded beds and bedding-cleavage relationships are evidence of overturned folds along Bear Creek (Casella, et al., 1982). Bedding-cleavage relationships are only visible in the more micaceous rocks and are not developed in the massive units.

Structural data collected in this study is presented in Figure 18. These data were collected in the central part of the belt between Crevice Creek and Cottonwood Creek (see Figure 2) and are consistent with previous work in the same general area (Casella et al., 1982). In the west-central part of the belt near Jardine (Figure 2), the proportion of fine grained micaceous units increases and deformation becomes more intense. Hallager (1980) recognized F_1 isoclinal folds and two later sets of open folds, one (F_2) striking NW and the other (F_3) striking NE. The F3 folds of Hallager (1980) are interpreted here as F2 folds (see Figure 18). NW trending open folds (F_3) are not observed in the eastern part of the belt but they are known to exist in the Jardine area (John Cuthill, pers. comm.). Prior work based on mapping in the Crevice Mountain area (Figure 2) (Brox and Cavalero, 1975) also indicates F_1 isoclinal folds deformed by NE trending F_2 open folds.

A working model of the structural evolution of the metasedimentary belt based on both previous (Brox and Cavalero, 1975; Hallager, 1980) and current work at Jardine (John Cuthill, pers. comm.) consists of an early period of N to NE trending isoclinal folding (F_1) followed by coaxial open folding (F_2). Finally, a gentle west-northwest trending flexure (F_3) warped the region. The F_3 open folds are not recognized in the eastern part of the belt perhaps related to the competent nature of the rocks.

The first deformational event D1 was characterized by isoclinal folding accompanied by growth of the peak metamorphic mineral assemblage. Syn-kinematic growth of porphyroblasts demonstrates that folding and prograde metamorphism were coeval. The D_2 event produced F_2 folds, an incipient S_2 foliation, and retrograde mineral assemblages.

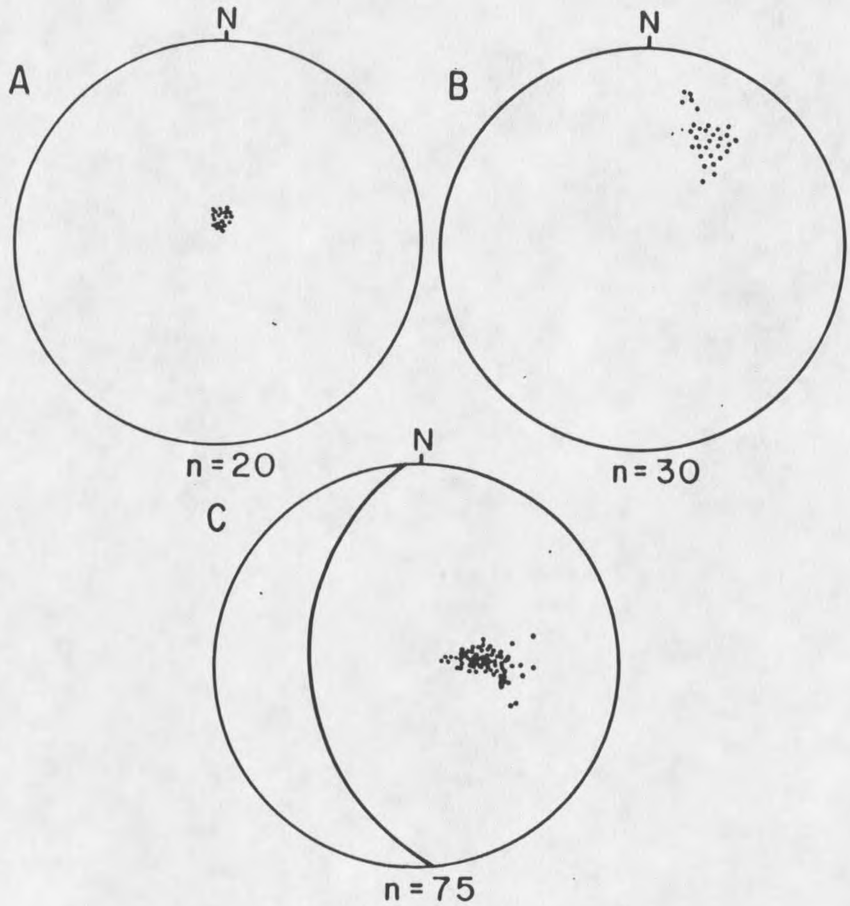

Figure 18. Stereonets. A: Trend and plunge of hingelines of F_1 isoclinal folds. B: Trend and plunge of hingelines of F_2 open folds. C: Strike and dip of regional foliation (S_0 = S_1).

ENVIRONMENT OF DEPOSITION

The structural history of the metasedimentary package suggests that the entire section may have been substantially thickened and in many places overturned by isoclinal folding during the D1 event. This makes stratigraphic correlation tenuous and requires that any models of depositional environment be interpreted on a regional scale, of gross lithologic packages.

Sedimentologic and stratigraphic evidence suggest that the South Snowy Block greywacke (quartz-biotite schist) and mudstone (biotite schist) were originally deposited by turbidity currents. As stated earlier, the subarkosic sandstone units contain up to 29 percent matrix. Much of the matrix may have been derived from the breakdown of mafic rock fragments during diagenesis (e.g. Kuenen, 1966). The sandstones are poorly sorted and commonly are normally-graded. The presence of graded beds implies rapid deposition of sediment from turbulent suspension. Formation of graded beds by turbidity currents has been demonstrated in flume experiments (Kuenen and Migliorini, 1950).

Stratigraphic evidence also supports deposition by turbidity currents. Partial Bouma sequences (Bouma, 1962) are preserved throughout the metasedimentary package and are most common in the coarser grained units. A typical vertical sequence observed in the field consists of a lower unit of massive normally graded sandstone 5 to 50 centimeters thick. The massive sandstone is locally overlain by a 1 to 3 centimeter thick layer of finer grained horizontally laminated sandstone. Above this a ripple laminated siltstone 1 to 2 centimeters thick is usually present. Completing the sequence is an upper unit of siltstone or mudstone which lacks any sedimentary structures. This lithologic sequence is repeated many times throughout the sedimentary package and although these repetitions may be structural, they closely resemble the ABCE and ACE sequences described by Bouma (Bouma, 1962). If so, the massive A units would have been deposited rapidly from suspension. As the turbidity current decelerated deposition under upper plane bed conditions resulted in horizontally laminated sand. With a further decrease in velocity ripples formed in finer grained sediment. Finally the suspended sediment settled out forming the E unit of Bouma. In many cases the B and/or C units are absent. This can be attributed to a very rapid decrease in velocity with only a massive graded bed (A unit) and suspended load (E unit) being deposited. The presence of Bouma sequences, both partial and complete, implies deposition by turbidity currents.

The eastern part of the metasedimentary belt is composed of massive sandstone units with a very small proportion of mudstone or iron formation. The sandstone is commonly graded and ABC Bouma sequences are locally preserved. The east-central part of the belt from Cottonwood Creek to Crevice Creek (Figure 2) contains finer-grained sandstone and a higher proportion of mudstone and iron formation. A measured section from this area is presented in Figure 19. Sedimentary structures are most abundant in this part of the outcrop belt. Bouma sequences, cut-and-fill structures, graded beds, wavy bedding, cross stratification, and rip up clasts are common (see Figures 6-10). Although the sandstone beds are volumetrically more important, they occur as thinner individual units and are much finer-grained. Individual horizons of both mudstone and iron formation are much thicker and laterally continuous. The western portion of the belt is poorly exposed but fine-grained sandstone and mudstone have been reported from Sheep Mountain (Hallager, 1980) (Figure 2). To the west of Sheep Mountain the metamorphic grade increases and the rocks become highly deformed.

In general, the sedimentary package coarsens to the east. This is accompanied by an increase in the abundance and thickness of sandstone units. A corresponding decrease in thickness and abundance of mudstone and iron formation accompanies this change. The lateral and vertical distribution of rock types, presence of partial Bouma sequences and distributary channels, and abundant graded bedding suggests that this sequence was deposited on a submarine fan. The general stratigraphy of the sedimentary

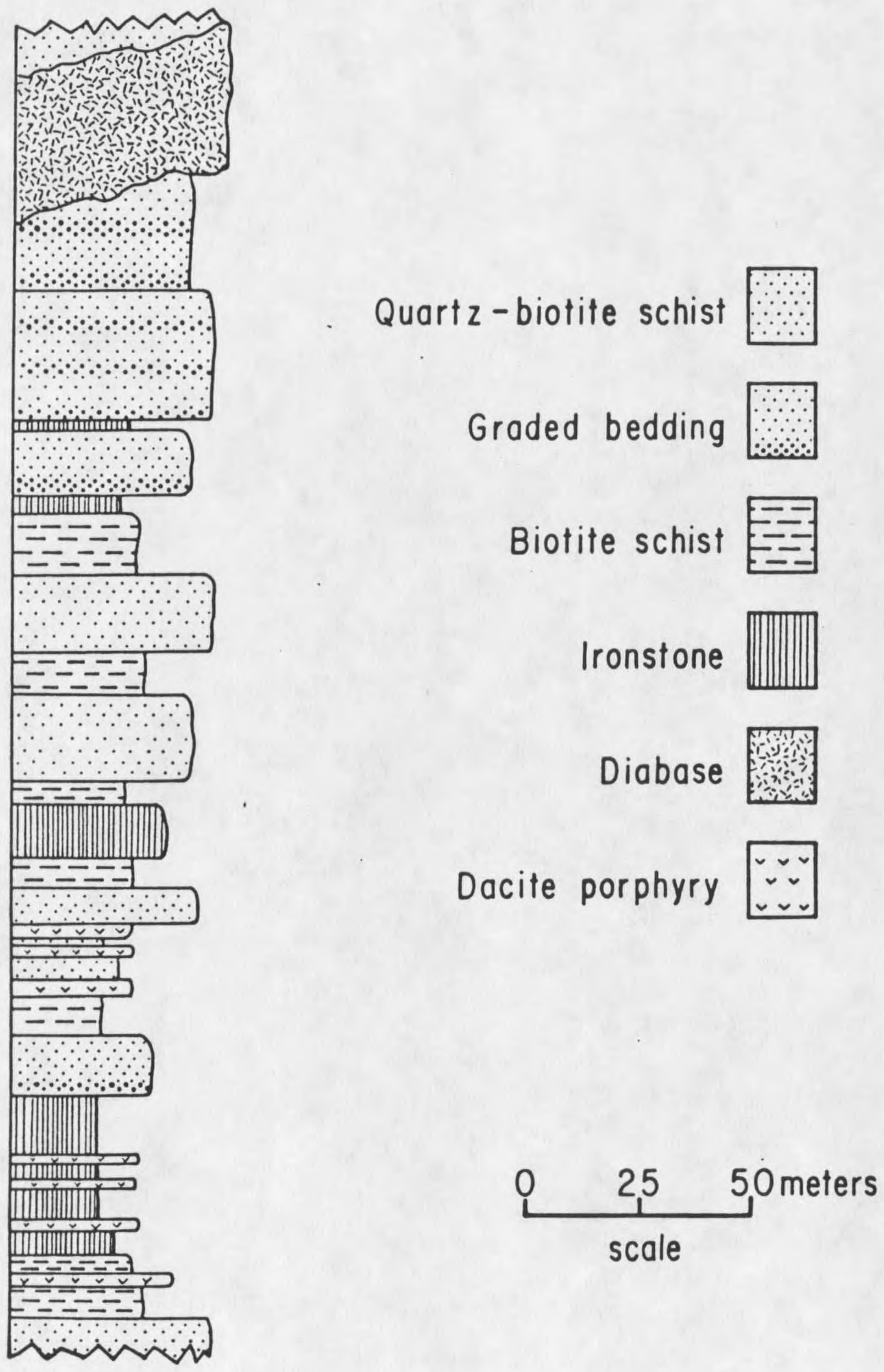

Figure 19. Measured section from the central part of the outcrop belt approximately 2.5 kilometers southeast of Crevice Lake.

package, as discussed below, is consistent with the midfan to distal fan environments of Walker (1979) (Figure 20). This model is useful for purposes of comparison, but application of it to this particular lithologic package is limited due to incomplete areal exposure. The sedimentary facies diagnostic of a submarine fan, in particular the fanhead facies, are not recognized in the area.

The observed distribution of lithologies is consistent with the following model. The sediments were originally deposited along the margin of an actively subsiding sedimentary basin. Deposition of clastic material was by turbidity currents along a submarine slope. Graded, poorly sorted, massive sand with distributary channels and minor amounts of mud and silt characterize deposition in the midfan area (Walker, 1979). A transition to finer grained sand and mud occurs between the midfan and distal fan. The central part of the belt contains this transitional zone. Towards the basin center, deep water pelagic mud and chemically precipitated iron formation are most abundant. Sands interbedded with muds and iron formation suggest that turbidites periodically invaded the deeper water environment.

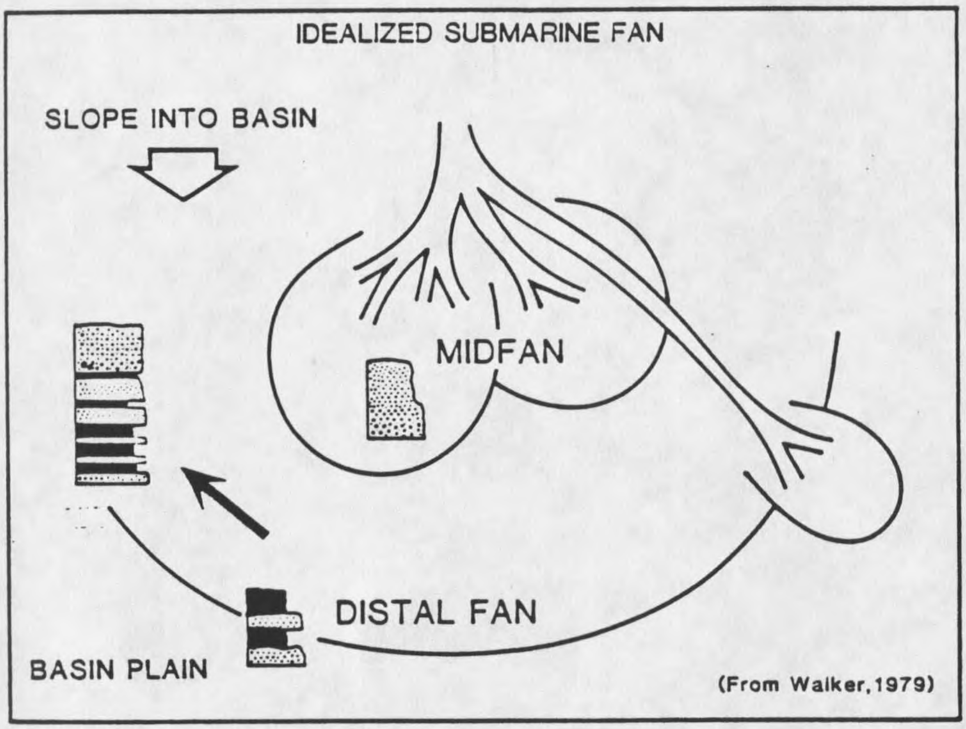

Figure 20. Model of depositional environment showing location of observed sedimentary sequence.

PROVENANCE

Conventional analysis of sandstone composition to determine provenance (Dickinson and Suzcek, 1979) is of limited use when applied to metamorphic rocks. The framework mineralogy of the greywacke has been altered during diagenesis and metamorphism to the point where the only major identifiable components preserved are quartz and plagioclase. Lithic fragments have been mostly destroyed and as a consequence the proportion of matrix has increased. Because of these factors a different approach is necessary for evaluating provenance.

A more suitable technique is the use of geochemical parameters to constrain the tectonic setting and composition of the source area. An approximate tectonic setting is determined by the use of discriminant functions based on major element geochemistry (Bhatia, 1983). Data shown in Figure 21 indicate an active continental margin setting with some contribution from a volcanic arc; however, not all data fit into one of the fields. The high $K_2O:Na_2O$ ratios and presence of plutonic rock fragments in the meta-greywacke also suggest a continental margin provenance (Taylor and McLennan, 1985; Crook, 1974).

The chemical composition of the source area can be approximated by interpreting the geochemistry. Most of the metagreywackes and pelites have elevated concentrations of

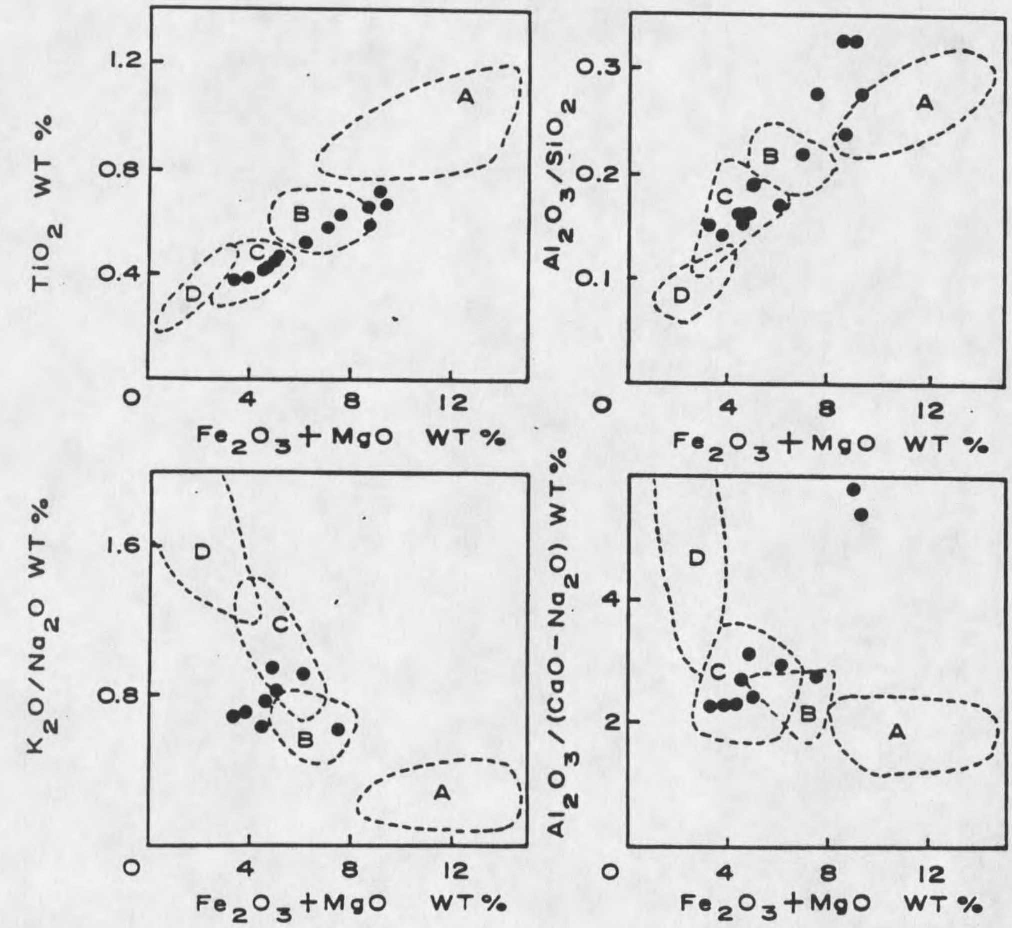

Figure 21. Major element composition plots of sandstones commonly used for discrimination of tectonic setting. Dotted lines mark the the major fields of sandstones representative of various tectonic settings although some points fall outside these fields. Fields are: A - Oceanic Island Arc; B - Continental Island Arc; C - Active Continental Margin; D - Passive Margin. Fe_2O_3 represents total iron as Fe_2O_3 (after Bhatia, 1983).

FeO, MgO, Cr, Ni, Co, Cu, and Zn. REE data is less clear but one mudstone (Figure 13, sample 8536) has a low total REE abundance and a low La/Yb ratio (La/Yb = 2.4). These data are interpreted to be the product of mafic or ultramafic rocks in the source area. However, not all of the samples have a strong mafic affinity. Some of the metagreywackes, especially the quartz-rich samples, have low concentrations of FeO and MgO and are clearly more felsic in composition (see Table 1). The abundance of detrital quartz and plagioclase grains, possible tonalitic rock fragments, high SiO_2 and Al_2O_3, and LREE enrichment in the metagreywackes indicates a felsic source area.

The bulk composition of the greywacke could have been attained by mixing of sediment from at least two different source areas, one mafic-ultramafic and one tonalitic-trondhjemitic. There are some problems with this hypothesis. The metagreywackes have very low concentrations of CaO, Na_2O, and K_2O. If a tonalitic-trondhjemitic rock was indeed the felsic source, much higher CaO and Na_2O contents would be expected. The low total abundance of alkalis and CaO may be the result of prolonged weathering, but this seems unlikely since some of the metagreywacke contains euhedral doubly-terminated zircons which are magmatic in origin (Paul Mueller, pers. comm).

DISCUSSION

The South Snowy Block metasedimentary rocks are compositionally unique in the northern Wyoming Province. Their CaO contents are very low (just over 1 %) when compared to pelites from the North Snowy Block (Mogk, 1984) and hornfels from the Stillwater Complex contact aureole (Beltrame, 1982). This low CaO content may be due to low CaO content in the source or perhaps weathering or hydrothermal alteration. In addition to low CaO content, the metasedimentary rocks have a low total abundance of alkalis and a high K_2O:Na_2O ratio. Again this is unique in the previously mentioned suites from the northern Wyoming Province. Trace element data also demonstrate the unique chemical character of these rocks. The transition metals, particularly Cr, Ni, Co, Cu, and Zn have a distinct enrichment pattern. When compared to other metasedimentary rocks from the northern Wyoming Province (Figure 22), the South Snowy Block rocks display an enrichment in transition metals even at high (>70%) SiO_2 concentrations. The other Archean suites from the northern Wyoming Province are not enriched in transition metals over such a wide range of SiO2 values. Rocks from the eastern Beartooth Block are also enriched in Cr, and Ni (Mueller and Wooden, 1982; Wooden, Mueller, and Mogk, in press); however these rocks are not comparable with respect to major element and REE geochemistry to the South Snowy Block metagreywackes.

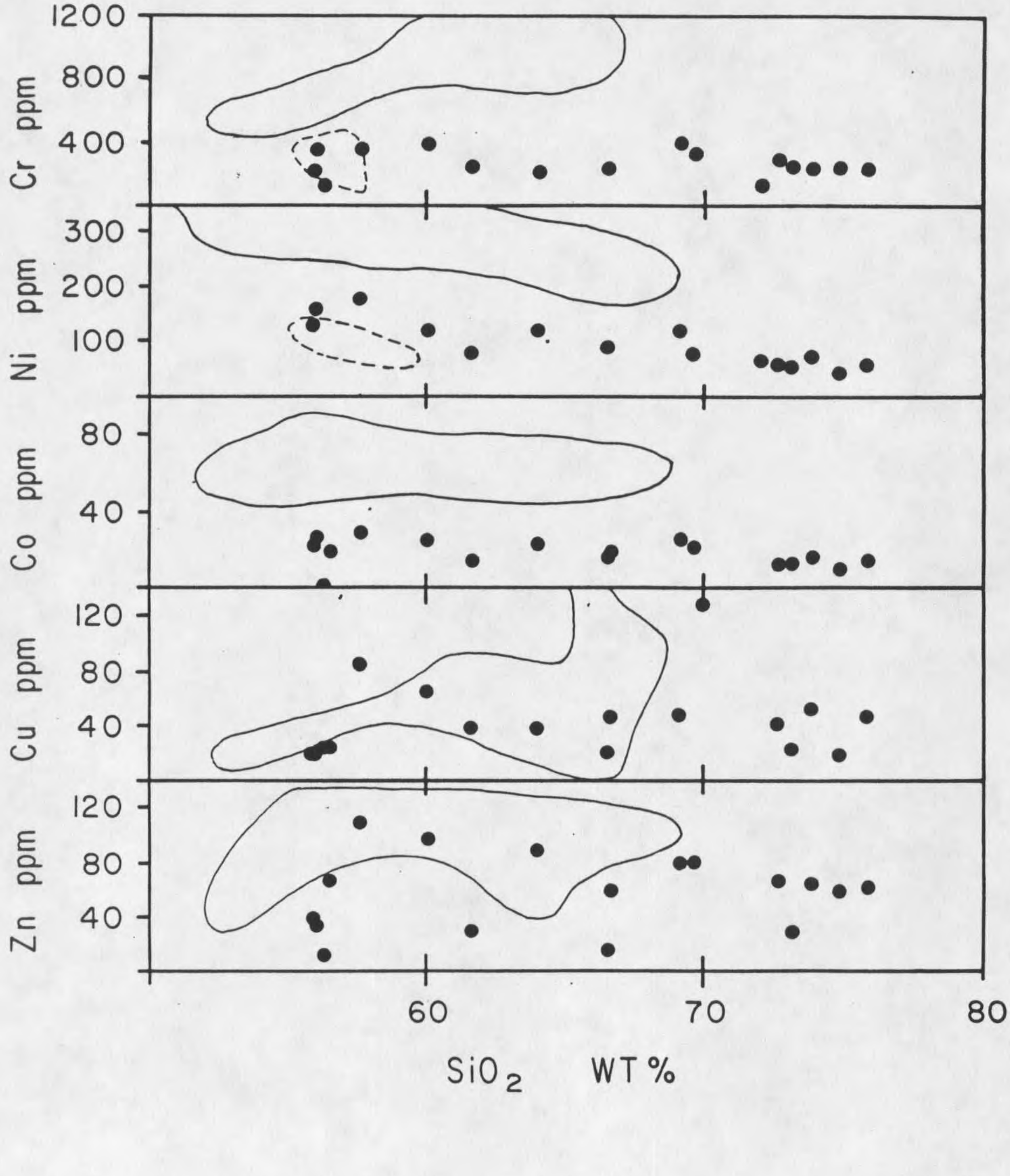

Figure 22. Trace element variation in northern Wyoming Province metasedimentary rocks. Solid line - Stillwater Hornfels. Dashed line - North Snowy Block. Solid circles - South Snowy Block.

REE patterns of South Snowy Block metagreywackes (La = 100x, $(La/Yb)_n$=7.2-12.4) are distinctly different than North Snowy Block metasedimentary rocks (La = 50x, $(La/Yb)_n$ = 4-7) (Mogk, 1984; Mueller et al., 1984), but similar to eastern Beartooth clastic rocks (La = 100x, $(La/Yb)_n$ = 7-15) (Mueller et al., 1984). The similarity with eastern Beartooth rocks is coincidental since these rocks do not have comparable major element abundances and have had a very different geologic history (Mueller et al, 1983). REE data from other metasedimentary suites in the northern Wyoming Province are nonexistent.

Accumulation and preservation of a thick sequence of sediments consisting of greywacke, mudstone, and iron formation requires an actively subsiding sedimentary basin. The configuration and original location of this basin is unknown but provenance data suggest that the metasedimentary package was deposited along a continental margin in a manner similar to the deposition of the 3,300 Ma Fig Tree Group of Eriksson (1980). The regional distribution of lithologies demonstrates that rock units coarsen both to the east and at structurally higher levels in the section, suggesting that clastic sedimentation was prograding westward towards the basin center (Figure 23). Provenance data indicate a significant contribution from a mafic or ultramafic source. The geochemical signature, especially the high Cr and Ni concentrations, is common in sedimentary rocks in the upper levels of early (3.4 - 3.0 Ga) Archean greenstone belts (Condie, 1981, Taylor and McLennan, 1985). In addition the metagreywacke is petrographically similar to greenstone belt sediments such as the Goldman Meadows Formation at South Pass, Wyoming (Condie, 1967). Although komatiites and Mg-rich basalts characteristic of the lower levels of early Archean greenstone belts (Condie, 1981) are not exposed in the South Snowy Block, their existence is inferred by the strong mafic geochemical signature.

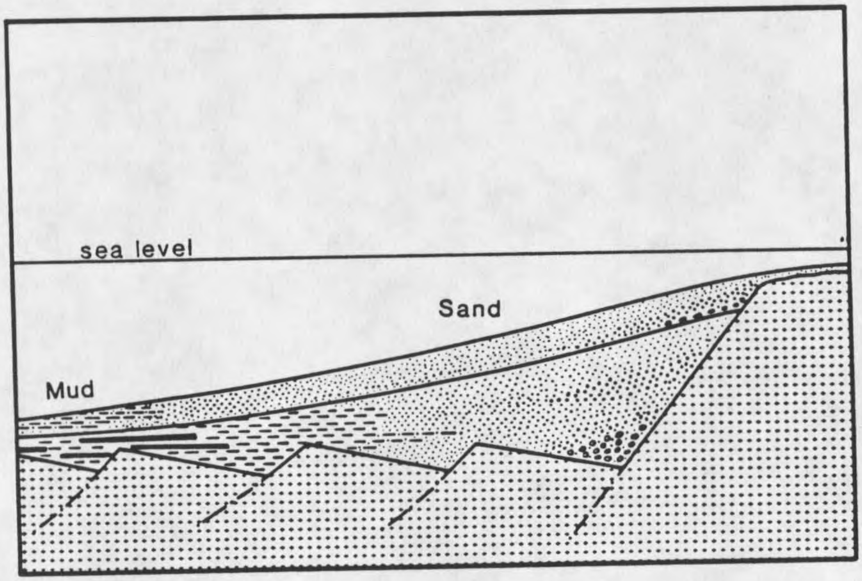

Figure 23. Inferred configuration of the depositional setting.

Geochemical and petrologic evidence suggest that this metasedimentary package is part of early Archean greenstone belt. This association is important since greenstone terranes are not exposed anywhere in the northern Wyoming

Province, however they do exist in the central and southern Wyoming Province (Granath, 1975; Condie, 1967; John Ray, pers. comm.) Preliminary U-Pb dates on zircons from the South Snowy Block metagreywackes suggests that they are at least as old as 3,200 Ma (Paul Mueller, per. comm.). This is considerably older than 2,800 Ma andesites in the central Beartooth Mountains and the 2,961 Ma greenstones in the Owl Creek Mountains of central Wyoming (Mueller et al, 1985). The ages of other greenstones in the Wyoming Province have not been determined.

The low metamorphic grade, style of deformation, similarity to greenstone belt sediments, and unique geochemical signature all suggest that the metasedimentary rocks in the South Snowy Block were not derived from the Beartooth Mountains. Examination of potential source terranes in the northern Wyoming Province fails to locate a chronologically and chemically compatible source area.

The fact that these rocks are not compatible with the surrounding region has important tectonic implications. The Beartooth Mountains have experienced a long evolution of continental crust which experienced a major period of growth through continental collision around 2,800 Ma (Mueller et al, 1982, 1984). Andesites were produced as a result of this collision (Mueller et al, 1982, 1983) and the North Snowy Block was tectonically thickened and accreted as a series of east verging nappes (Mogk, 1981, 1984). The batholithic complex along the eastern border of the metasedimentary belt was also emplaced during this event.

Since the metasedimentary rocks are older than, and chemically incompatible with, the surrounding region they may have been tectonically emplaced. These rocks represent a distinct terrane which has experienced a very different depositional, structural, and metamorphic evolution from the surrounding region. It is separated from adjacent terranes by major faults and therefore can be considered to be a suspect terrane similar in definition to Phanerozoic suspect terranes (Jones et al., 1983) but on a much smaller scale than the large amalgamated terranes of Alaska and British Columbia.

The geochemistry demonstrates that these rocks were not derived from the Beartooth Mountains. The style of deformation and metamorphism is incompatible with the kinematic history of the surrounding Beartooth Mountains (Mogk and Henry, in press) suggesting that the D_1 event occurred prior to juxtaposition along the southwestern margin of the Beartooth Mountains. This metasedimentary sequence may be a metamorphic terrane similar in style with Phanerozoic metamorphic terranes such as the Yukon-Tanana terrane in Alaska (Coney et al, 1980).

There is, however, another possibility. Perhaps the metasedimentary package represents a sample of an upper crustal level whose source region has long since been eroded. If this is the case, the metasedimentary rocks represent a tectonically preserved block of rock which was derived from a nearby source that no longer exists. This hypothesis is not likely since isostatic equilibrium must be maintained and it would be impossible to preferentially preserve a small piece of the Beartooth Mountains without preserving a comparable crustal level elsewhere.

The northern Wyoming Province can be divided into two general regions. Dominantly meta-igneous rocks are present in the central and eastern Beartooth Mountains, and dominantly metasupracrustal rocks are present in the Gallatin, Madison, Tobacco Root , and Ruby Ranges to the west (Wooden et al., in press). The North Snowy Block mobile belt (Mogk and Henry, in press) roughly defines the boundary between these two regions. It has been suggested that the western margin of the Beartooth Mountains marks the approximate location of an Archean continental margin (Wooden et al., in press). If so, the low grade metasedimentary rocks of the South Snowy Block may have been emplaced by transcurrent faulting during the 2,800 Ma orogenic event. Further research in the region is necessary to validate this hypothesis.

REFERENCES

REFERENCES

Arth, J.G., and Hanson, G.N., 1975, Geochemistry and origin of the early Precambrian crust of north-eastern Minnesota: Geochimica et Cosmochimica Acta, v.38, p.325-341.

Barker, F., 1979, Trondhjemite: definition, environment and hypotheses of origin: in: Barker, F. (ed.), Trondhjemites, Dacites and related Rocks. Elsevier, p. 1-12.

Beltrame, R.J., 1982, Systematic variations in hornfels at the base of the Stillwater Complex, Montana: in: Montana Bureau of Mines and Geology Special Publication 84, p. 107-130.

Bhatia, M.R., 1983, Plate tectonics and geochemical composition of sandstone: Journal of Geology, v.91, p.611-627.

Boles, J.R., 1982, Active albitization of plagioclase, Gulf coast Tertiary: American Journal of Science, v.282, p.165-180.

Bouma, A.H., 1962, Sedimentology of some flysch deposits: A graphic approach to facies interpretation. Elsevier, Amsterdam, 168 p.

Brookins, G.D., 1968, Rb-Sr and K-Ar age determinations from the precambrian rocks of the Jardine-Crevice Mountain area, southwest Montana: Earth Science Bulletin, v.1, p.5-9.

Brox , G.B., and Cavalero, R.A., 1978, Report on Jardine Mine Park County, Montana: Unpublished report to the Anaconda Company.

Burnham, B., 1980, Mylonite zones in Park County, Montana: Unpublished M.S. Thesis, University of Montana, Missoula, 84 p.

Casella, C.J., Levay, J., Eble, E., Hirst, B., Huffman, K., Lahti, V., and Metzger, R., 1982, Precambrian geology of the southwestern Beartooth Mountains, Yellowstone National Park, Montana and Wyoming: in: Montana Bureau of Mines and Geology Special Publication 84, p.1-24.

Condie, K.C., 1967, Geochemistry of early Precambrian greywackes from Wyoming: Geochimica et Cosmochimica Acta, v.31, p.2135-2149.

Condie, K.C., Macke, J.E., and Reimer, T.O., 1970, Petrology and geochemistry of early Precambrian greywackes from the Fig Tree Group, South Africa: Geological Society of America Bulletin, v.81, p.2759-2768.

Condie, K.C., 1976, The Wyoming Archean Province in the western United States: In: B.F. Windley (Ed.), The Early History of the Earth, Wiley-Interscience, London, p.419-424.

Condie, K.C., 1981, Archean Greenstone Belts, Elsevier, Amsterdam, 434p.

Coney, P.J., Jones, D.L., and Monger, J.W.H., 1980, Cordilleran suspect terranes: Nature, v.288, p.329-333.

Dickinson, W.R., and Suzcek, C.A., 1979, Plate tectonics and sandstone compositions: American Association of Petroleum Geologists Bulletin, v.63, p.2164-2182.

Donaldson, J.A., and Jackson, G.D., 1965, Archean sedimentary rocks of the North Spirit area, northwestern Ontario: Canadian Journal of Earth Science, v.2, p.622.

Eriksson, K.A., 1980, Transitional sedimentation styles in the Moodies and Fig Tree Groups, Barberton Mountain Land, South Africa: evidence favoring an Archean continental margin: Precambrian Research, v.12, p.141-160.

Ewart, A., 1979, A review of the mineralogy and chemistry of Tertiary-Recent dacitic, latitic, rhyolitic, and related salic volcanic rocks. In: Barker, F. (ed.), Trondhjemites, Dacites and related Rocks, Elsevier, p. 13-22.

Folk, R.L., 1974, Petrology of sedimentary rocks. Hemphill, Austin, Texas, 170 p.

Fraser, G.D., Waldrop, H.A. and Hyden, H.J., 1969, Geology of the Gardiner area, Park County Montana: U.S. Geological Survey Bulletin 1277, 117p.

Fryer, B.J., 1983, Rare earth elements in iron formation: in: Iron-Formation: Facts and Problems, Elsevier, p.345-358.

Granath, J.W., 1975, Wind River Canyon: An example of a greenstone belt in the Archean of Wyoming, U.S.A.: Precambrian Research, v.2, p.71-91.

Grout, F.F., 1933, Contact metamorphism of the slates of Minnesota by granite and gabbro magmas: Geological Society of America Bulletin, v.44, p.989-1004.

Hallager, W.S., 1980, Geology of Archean gold-bearing metasediments near Jardine, Montana: Unpublished PhD Dissertation, University of California, Berkeley, 136 p.

Henderson, J.B., 1975, Sedimentology of the Archean Yellowknife Supergroup at Yellowknife, District of Mackenzie: Geological Survey of Canada Bulletin 246, 94 p.

Hoschek, G., 1969, The stability of staurolite and chloritoid and their significance in metamorphism of pelites: Contributions to Mineralogy and Petrology, v.22, p.208-232.

Immega, I.P, and Klein, C., 1976, Mineralogy and petrology of some metamorphic Precambrian iron-formations in southwestern Montana: American Mineralogist, v.61, p.1117-1144.

Jones, D.L., Howell, D.G., Coney, P.J., and Monger, H.W.H., 1983, Recognition, character and analysis of tectonostratigraphic terranes in western North America: Journal of Geologic Education, v.31, p.295-303.

Kuenen, Ph.H. and Migliorini, C.I., 1950, Turbidity currents as a cause of graded bedding: Journal of Geology, v.58, p.91-127.

LeMaitre, R.W., 1976, The chemical variability of some common igneous rocks: Journal of Petrology, v.17, p.589-598.

McGregor, V.R., 1979, Archean gray gneisses and the origin of the continental crust: evidence from the Godthab region, West Greenland. In: Barker, F. (ed.), Trondhjemites, Dacites and related Rocks, Elsevier, p.169-204.

McLennan, S.M., Taylor, S.R., and Kroner, A., 1983, Geochemical evolution of Archean shales from South Africa. I. The Swaziland and Pongola Supergroups: Precambrian Research, v.22, p.93-114.

McLennan, S.M., Taylor, S.M., and Eriksson, K.A., 1983, Geochemistry of Archean shales from the Pilbara Supergroup, western Australia: Geocimica et Cosmochimica Acta, v.47, p.1211-1237.

Mogk, D.W., 1981, Tectonic thickening of Archean continental crust, North Snowy Block, Beartooth mountains, Montana: Geological Society of America Abstracts with Programs, v.13, no.7, p.513.

Mogk, D.W., 1984, The petrology, structure, and geochemistry of an Archean terrane in the North Snowy Block, Beartooth Mountains, Montana: Unpublished Ph.D dissertation, University of Washington, 440 p.

Mogk, D.W. and Henry, D.J., in press, Metamorphic petrology of the northern Wyoming Province: evidence for Archean collisional tectonics: Proceedings of the 7th Rubey Colloquium, 1986.

Montgomery, C.W., 1982, Preliminary zircon U-Pb dating of biotite-granodiorite from the South Snowy Block, Beartooth Mountains: in: Montana Bureau of Mines and Geology Special Publication 84, p.41-44.

Mueller, P.A., Mogk, D.M., Wooden, J.L., Henry, D.J., and Bowes, D.R., 1984, Archean metasedimentary rocks from the Beartooth Mountains: evidence for an accreted terrane?: Geological Society of America Abstracts with Programs, v. 16, no.6, p.602.

Mueller, P.A., Wooden, J.L., Henry, D.J., and Mogk, D.W., 1982, Granitoids, granulites and continental collision: The Archean of southwestern Montana: Geological Society of America Abstracts with Programs, v.14, no.7, p.572.

Mueller, P.A., Wooden, J.L., Schultz, K, and Bowes, D.R., 1983, Incompatible-element-rich andesitic amphibolites from the Archean of Montana and Wyoming: evidence for mantle metasomatism: Geology, v.11, p.203-206.

Naqvi, S.M., and Hussain, S.M., 1972, Petrochemistry of early Precambrian metasediments from the central part of the Chitaldrug schist belt, Mysore, India: Chemical Geology, v.10, p.109-118.

Pride, D.E., and Hagner, A.F., 1972, Geochemistry and origin of the Precambrian iron formation near Atlantic City, Fremont County, Wyoming: Econmic Geology, v.67, p.329-338.

Seager, G.F., 1944, Gold, arsenic, and tungsten deposits of the Jardine-Crevasse Mountain district, Park County, Montana: Montana Bureau of Mines Memoir 23, 111 p.

Taylor, S.R. and McLennan, S.M., 1985, The continental crust: its composition and evolution: Blackwell Scientific Publications, 312 p.

Thompson, J.B. and Norton, S.A., 1968, Paleozoic metamorphism in New England and adjacent areas: In (E-An Zen et al., eds.) Studies of Appalachian Geology, Wiley Interscience, New York, p.127-184.

Walker, R.G., 1979, Turbidites and associated coarse clastic deposits: in: Facies Models, Geoscience Canada, p. 171-188.

Walker, R.G., and Pettijohn, F.J., 1971, Archean sedimentation: analysis of the Minnitaki Basin, northwestern Ontario, Canada: Geological Society of America Bulletin, v.82, p.2099-2115.

Winkler, H.G.F., 1979, Petrogenesis of Metamorphic Rocks, Springer-Verlag Berlin, 348 p.

Wooden, J.L., 1975, Geochemistry and Rb-Sr geochronology of Precambrian mafic dikes from the Beartooth, Ruby Range, and Tobacco Root Mountains, Montana, unpublished PhD dissertation : University of North Carolina, Chapel Hill, North Carolina, 194p.

Wooden, J.L., Mueller, P.A., Hunt, D.K., and Bowes, D.R., 1982, Geochemistry and Rb-Sr geochronology of Archean rocks from the interior of the southeastern Beartooth Mountains, Montana and Wyoming: in: Montana Bureau of Mines and Geology Special Publication 84, p.45-56.

Wooden, J.L., Mueller, P.A., and Mogk, D.W., in press, A review of the geochemistry and geochronology of the Archean rocks of the northern part of the Wyoming Province: Proceedings of the 7th Rubey colloquium, 1986.

APPENDICES

APPENDIX A

ANALYTICAL METHODS

XRF-FUSION WHOLE ROCK ANALYSES

Fusion

The assay pulp is dried overnight at 105 degrees celsius then 0.75 grams of sample is weighed into a porcelain crucible and placed in a muffle furnace for 20 minutes at 950 degrees celsius (high sulfide samples are first roasted at 800 degrees celsius with air blast for 20 minutes prior to ignition). The sample is then placed in a dessicator to cool prior to weighing for loss on ignition. The ignited sample is then mixed with lithium tetraborate (JMC Spectroflux 100) to bring the total weight to 5.00 grams. The mixture is placed in a 20 cc Pt-5% Au crucible and inserted into a muffle furnace at 1200 degrees celsius for 25 minutes. The crucibles are swirled three different times during this period to mix the melt prior to pouring into 30 mm Pt-5% Au moulds. The resulting disks are removed from the moulds and are ready for presenting to the XRF.

XRF Measurements

A Philips model PW1220 XRF unit is used for all the measurements made under the following conditions:

ELEMENT	TUBE TARGET	Kv/Ma	COUNTER	COLLIMATOR	CRYSTAL	TIME (sec)
Na	Cr	60/32	Flow	Coarse	T1AP	60
Mg	"	"	"	"	"	"
Al	"	"	"	"	PET	"
Si	"	"	"	"	"	"
K	"	"	"	Fine	LIF100	20
Ca	"	"	"	"	"	"
Ti	"	"	F&S	"	"	"
Cr	W	"	"	"	"	"
Mn	"	"	"	"	"	"
Fe	Cr	"	Scint	Coarse	"	"
Co	W	"	F&S	Fine	"	"
Ni	Cr	"	"	Coarse	"	"

Background measurements are made for Na Mg, Al, Ti, Co, and Ni using the same conditions as the elements.

Standards

Calibration of the XRF system was done using a group of approximately 75 International Reference Samples from 13 organizations in 9 countries consisting of such groups as CCRMP, USGS, NBS, and NIM. Listed in the table below are the ranges covered by the standards and the relative accuracy of XRF values produced for the major elements.

ELEMENT	RANGE (%)	OVERALL RELATIVE DEVIATION* (%)
Na_2O	0.5 to 10	4.40
MgO	0.5 to 50	3.67
Al_2O_3	0.5 to 70	2.37
SiO_2	1 to 94	1.32
CaO	0.1 to 85	3.93
K_2O	0.1 to 15	2.16
Fe	0.1 to 67	1.72

$$\text{*OVERALL RELATIVE DEVIATION} = \sqrt{\frac{\Sigma(\text{REL. DEV.})^2}{(N-1)}}$$

Accuracy

To further demonstrate the relative accuracy of the XRF analysis, the following table compares the "recommended" or "usable" values for the standards to those produced by the XRF.

	AGV-1		BR		GSP-1		NIM-D	
ELEMENT	USABLE VALUE	XRF	USABLE VALUE	XRF	USABLE VALUE	XRF	USABLE VALUE	XRF
%Na_2O	4.32	4.55	3.07	3.13	2.81	2.98	0.37	<0.5
%MgO	1.52	1.53	13.4	13.0	0.97	0.93	25.3	25.2
%Al_2O_3	17.2	17.0	10.3	10.1	15.3	15.0	4.18	4.34
%SiO_2	59.6	59.5	38.4	38.5	67.3	67.5	51.1	50.8
%K_2O	2.92	2.97	1.41	1.34	5.51	5.55	0.09	<0.1
%CaO	4.94	4.88	13.9	13.4	2.03	2.00	2.66	2.61
%Fe	4.74	4.82	9.02	9.09	3.00	3.00	8.92	8.73

Precision

The precision of the XRF method is illustrated in the following table showing the means and standard deviations for the major elements measured on 36 different disks of the same sample run at different times.

ELEMENT	MEAN	S.D.
%Na_2O	2.72	0.11
%MgO	6.51	0.12
%Al_2O_3	17.6	0.15
%SiO_2	53.3	0.27
%K_2O	1.00	0.01
%CaO	7.77	0.03
%Fe	5.26	0.02

ICP ANALYSES

In addition to the XRF-Fusion analyses, 97 samples were analysed for 30 elements by ICP. The methodology is as follows:

First, 500 mg of sample is weighed and transferred to a test tube then 2 mls of aqua regia is added and the mixture is heated in a water bath for 60 minutes at 95 degrees celsius. After digestion the mixture is diluted to 10 mls with dilute HCL. The sample is then aspirated through a standard nebulizer into an argon plasma stream. The elements are determined by the emission spectrograph of the ARL 3500 ICP unit. This instrument is calibrated using standard solutions. Quality control is done by periodically inserting USGS standard samples in each batch.

APPENDIX B

DATA

Table 6. Modal analyses of metagreywacke.

Sample No.	8531	8542	8550	8553	8590	8591	8556	8563	8572	8573	8578	8559	8561	8567	8580	8575	8576	8545	8544	8554
# of points	440	520	480	480	460	580	440	440	440	440	520	480	440	440	430	440	400	440	440	460
Quartz(P)	38	56	34	42	19	11	22	34	38	18	65	44	24	35	27	43	54	21	34	17
Quartz(M)	250	302	292	287	264	350	271	264	266	240	292	294	261	245	253	261	212	234	246	262
Plagioclase	48	64	41	49	53	48	37	48	42	80	46	39	36	47	47	32	32	53	32	64
(An)	-	(29)	(26)	(31)	(28)	-	-	(28)	(31)	(30)	(24)	(22)	-	(27)	-	-	-	(25)	(22)	(24)
Biotite	90	81	104	87	109	139	103	89	83	97	117	98	115	104	94	102	97	123	125	117
Chlorite	2	5	4	1	11	27	3	2	5	2	-	3	2	6	6	-	5	3	2	-
Garnet	8	6	2	6	4	4	4	2	6	1	-	-	1	-	1	2	-	5	-	-
Staurolite	1	4	3	5	-	-	-	-	-	-	-	-	1	-	2	-	-	1	-	-
Tourmaline	-	-	-	2	-	1	-	-	-	-	-	-	-	2	-	-	-	-	1	-
Opaque	3	2	-	1	-	-	-	1	-	2	-	2	-	1	-	-	-	-	-	-
MODES																				
Qp	11	13	9	11	6	3	7	10	11	5	16	12	7	11	8	13	18	7	11	5
Qm	74	72	80	76	79	86	82	76	77	71	72	78	81	75	77	78	71	76	79	76
F	14	15	11	13	16	12	11	14	12	24	11	10	11	14	14	10	11	17	10	19
Matrix	24	19	24	21	27	29	25	21	21	23	23	21	27	26	24	24	26	30	29	25
Framework	76	81	76	79	73	71	75	79	79	77	78	79	73	74	76	76	75	70	71	75

Table 7. Rare Earth and trace element data for South Snowy Block metasedimentary rocks. All concentrations in ppm.

Element	8524	110235	8530	8536	8544	8563
Sm	0.97	1.53	4.47	1.45	2.95	4.15
Eu	0.32	0.44	1.17	0.62	0.73	1.07
Lu	0.10	0.22	0.29	0.22	0.27	0.26
Ba	177.00	122.00	1210.00	160.00	423.00	670.00
U	----	2.16	4.40	1.32	3.28	8.24
Th	2.13	4.00	8.92	3.95	8.62	11.59
Yb	0.71	1.54	1.97	1.53	1.84	1.85
Nd	----	----	20.60	----	16.99	20.12
Na	3461.00	3070.00	22930.00	269.00	17760.00	18080.00
La	3.17	7.00	28.86	6.18	18.92	31.38
Ce	6.97	15.81	55.17	12.56	37.91	57.98
Tb	0.20	0.36	0.85	0.42	0.44	0.47
Cr	131.00	170.00	366.00	204.00	217.00	309.00
Hf	0.73	1.66	3.20	1.44	3.66	5.02
Sr	----	----	----	----	213.00	122.00
Zr	----	----	150.00	----	130.00	198.00
Cs	0.21	0.23	8.33	----	3.49	8.12
Sc	5.79	15.75	24.99	10.86	12.01	12.26
Rb	18.98	11.29	124.00	7.46	72.46	80.83
Fe	24890.00	145950.00	83140.00	184240.00	40300.00	47900.00
Zn	33.80	80.78	108.00	113.00	74.62	81.04
Ta	0.17	0.35	0.62	0.33	0.63	0.78
Co	6.41	10.35	26.08	8.70	14.49	16.06

8524 - Magnetite Iron Formation
110235 - Silicate Iron Formation
8530 - Biotite Schist
8536 - Biotite Schist
8544 - Quartz-biotite Schist
8563 - Quartzite Metacomglomerate

Table 8. ICP geochemical data.

Rock Type	Sample No.	Mo ppm	Cu ppm	Pb ppm	Zn ppm	Ag ppm	Ni ppm	Co ppm	Mn ppm	As ppm	U ppm	Th ppm	Sr ppm	Cd ppm	Sb ppm	Bi ppm	V ppm
BS	8514	1.7	37	5	90	0.5	120	23	540	3	ND	ND	ND	0.3	10	3	67
BS	8526	5.7	96	16	66	0.5	98	26	120	48	ND	ND	ND	0.6	10	2	80
BS	8528	5.2	4.3	6	47	0.5	94	17	250	4	ND	ND	ND	0.3	10	2	81
BS	8530	1.8	11	5	100	0.5	210	33	550	2	ND	ND	ND	0.5	10	2	160
BS	8536	7.1	24	5	12	0.5	6	2	440	2	ND	ND	ND	0.3	10	2	18
CGL	8564	8	63	14	57	0.2	47	14	433	14	5	10	5	1	4	8	53
CGL	8565	8	89	7	53	0.1	33	13	291	10	5	7	8	1	2	4	36
CGL	8587	8	69	15	61	0.2	88	18	393	2	5	11	5	1	2	2	52
DB	8512	1.9	82	5	36	0.5	31	13	310	2	ND	ND	ND	0.3	10	2	75
DB	8516	2.2	34	5	50	0.5	24	16	390	2	ND	ND	ND	0.4	10	2	87
DB	8517	2.9	53	8	16	0.5	40	16	330	2	ND	ND	ND	0.5	10	2	66
DB	8568	2	84	3	24	0.1	30	13	193	12	5	1	41	1	2	3	66
FMV	8504	5.3	25	5	16	0.5	6	2	90	81	ND	ND	ND	0.3	10	2	6.3
FMV	8520	3.5	17	12	25	0.5	6	3	120	4	ND	ND	ND	0.3	10	2	7.9
FMV	8525	1.5	4.3	10	20	0.5	3	1	100	2	ND	ND	ND	0.3	10	2	6.7
FMV	8527	3.9	6.3	8	33	0.5	5	2	86	2	ND	ND	ND	0.4	10	2	14
FMV	8532	1.9	5.3	13	31	0.5	8	3	110	3	ND	ND	ND	0.3	10	3	6.3
FMV	8538	1.5	27	7	11	0.5	10	3	77	4	ND	ND	ND	0.3	10	2	5.9
FMV	8541	5.1	11	16	47	0.5	5	3	87	4	ND	ND	ND	0.4	10	2	7.7
FMV	8548	6	57	7	5	0.2	4	2	23	9237	5	9	9	1	3	3	3
FMV	8577	4	18	9	16	0.1	4	2	64	2	5	2	14	1	2	3	5
FMV	8584	5	5	17	3	0.1	1	1	65	3	5	6	3	1	2	14	1
GBCS	8549	6	11	24	93	0.2	126	21	532	1123	5	11	5	1	2	2	123
GBCS	8502	9.2	24	5	60	0.5	86	15	410	340	ND	ND	ND	0.3	10	2	64
GBCS	8570	6	16	11	152	0.1	112	15	404	86	5	10	2	1	2	2	82
GR	8508	7.4	3.1	13	26	0.5	9	3	200	33	ND	ND	ND	0.3	10	2	7
GR	8513	5.5	10	19	28	0.5	3	1	69	2	ND	ND	ND	0.3	10	2	10
GR	8533	5.1	2.8	14	42	0.6	13	5	280	4	ND	ND	ND	0.3	10	2	16
QBSFG	8507	1.9	2.9	5	85	0.5	150	27	370	83	ND	ND	ND	0.7	10	3	160
QBSFG	8518	2	5.7	7	19	0.6	150	28	580	4	ND	ND	ND	0.5	10	4	100
QBSFG	8535	3.2	19	6	34	0.5	160	27	250	13	ND	ND	ND	0.5	10	2	150
QBSFG	8562	4	84	13	109	0.1	178	29	670	27	5	13	6	1	5	6	92
QBSFG	8585	7	21	15	16	0.1	89	16	328	2	5	8	5	1	2	2	83
IF	8501	2.4	21	5	14	0.5	13	2	220	23	ND	ND	ND	0.5	10	2	34
IF	8506	7.7	14	6	29	0.5	36	6	760	45	ND	ND	ND	0.7	10	4	31
IF	8509	0.5	120	5	34	0.5	25	12	300	52	ND	ND	ND	0.4	10	2	65
IF	8511	4.3	9.1	5	24	0.5	25	4	330	3	ND	ND	ND	0.4	10	2	36