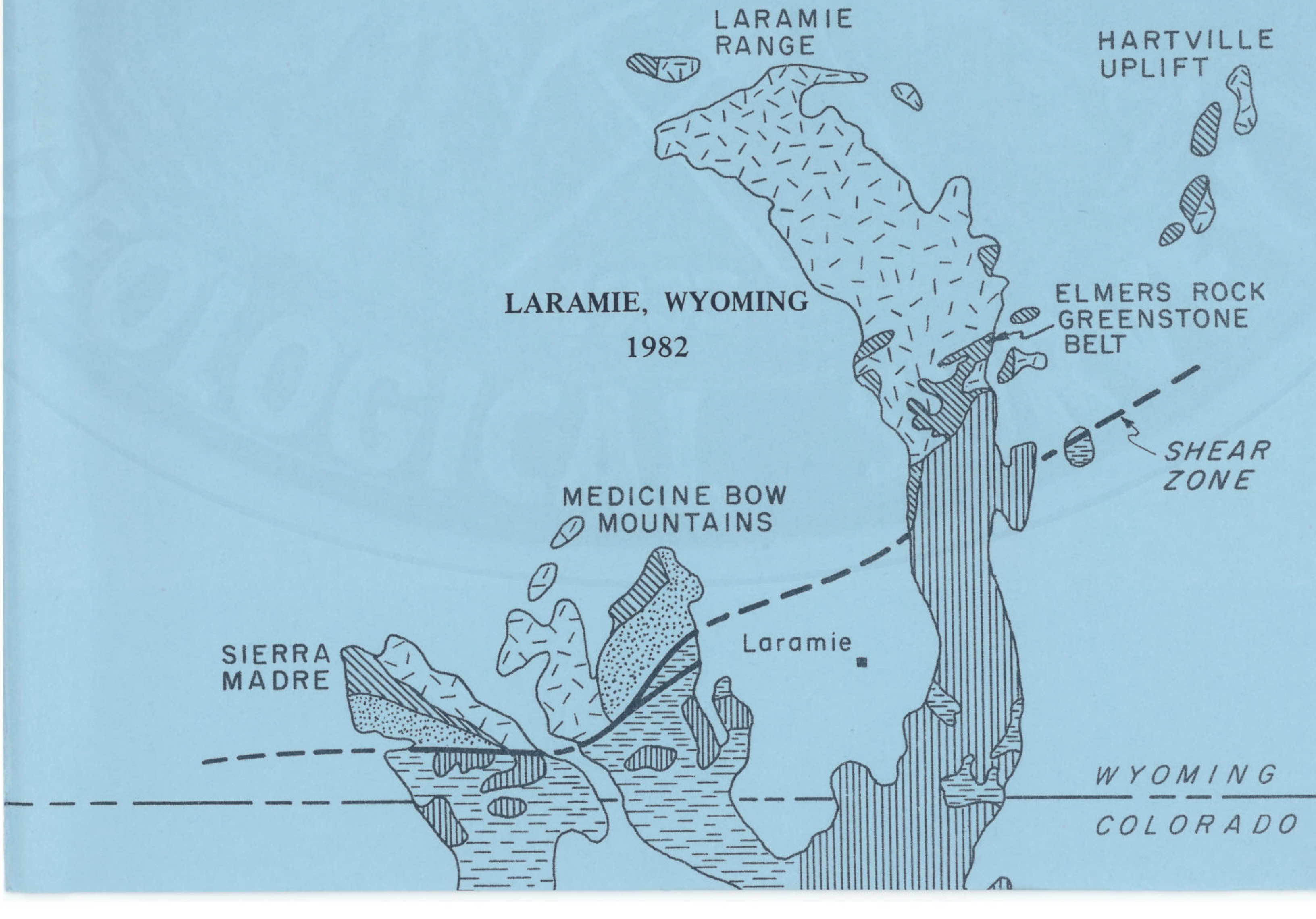
THE GEOLOGICAL SURVEY OF WYOMING
Gary B. Glass, State Geologist

REPORT OF INVESTIGATIONS No. 14

# GEOLOGY OF THE ELMERS ROCK GREENSTONE BELT LARAMIE RANGE, WYOMING

by

P.J. Graff, J.W. Sears, G.S. Holden, and W. D. Hausel




LARAMIE, WYOMING
1982

THE GEOLOGICAL SURVEY OF WYOMING

Gary B. Glass, State Geologist

REPORT OF INVESTIGATIONS No. 14

# GEOLOGY OF THE ELMERS ROCK GREENSTONE BELT, LARAMIE RANGE, WYOMING

by P.J. Graff, J.W. Sears, G.S. Holden,

*Research Associates of Wyoming, Casper*

and W.D. Hausel

*The Geological Survey of Wyoming, Laramie*


LARAMIE, WYOMING

1982

First printing of twelve hundred copies by
Prairie Publishing Company, Casper. Maps
printed by Pikes Peak Lithographing Company,
Colorado Springs, Colorado.

This report can be obtained from

The Geological Survey of Wyoming
Box 3008, University Station
Laramie, Wyoming 82071

CONTENTS

# ILLUSTRATIONS



# TABLES

# INTRODUCTION

Archean rocks of southern Wyoming and northern Utah (Graff and others, 1980) form the southern edge of an Archean block called the Wyoming Province (Engel, 1963; Karlstrom, 1979). This block is cored by Archean granites, high-grade granitic gneisses, and remnants of infolded Archean volcanogenic metasedimentary sequences, and contains nearly all the Precambrian rocks exposed in Wyoming. Precambrian exposures in southeastern Wyoming include a relatively complete section of these Archean and early Proterozoic rocks (Figure 1). Along this southern edge, the Archean rocks of the Wyoming Province are unconformably overlain by a thick sequence of late Archean - early Proterozoic miogeoclinal platform-type metasediments which are juxtaposed against an extensive Proterozoic eugeoclinal terrain to the south (Houston and others, 1968; Graff, 1978; Karlstrom, 1981). Deposition and preservation of the miogeoclinal clastic wedge demonstrate achievement of stability due to crustal thickening within the Wyoming Province and mark the end of Archean thin-crust tectonic styles.

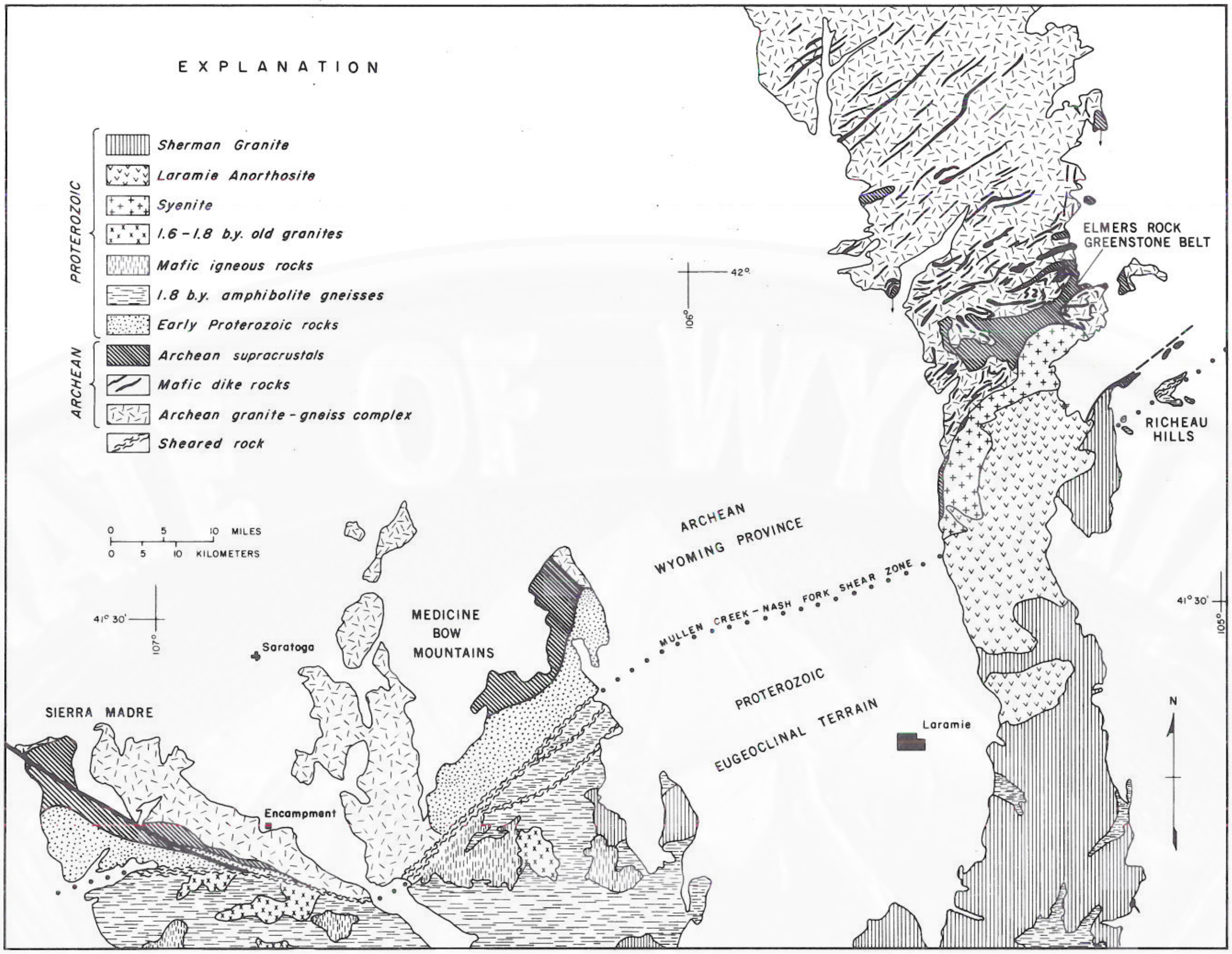
It is the study of the infolded Archean volcanogenic metasedimentary supracrustal sequences that can best provide some insight into the sedimentary and tectonic history of the Wyoming Province.

These sequences of supracrustal rocks are dominated by volcano-sedimentary piles which are best described as greenstone belts. Unfortunately, most of the supracrustal terrains of the Wyoming Province have been disrupted by post-depositional tectonics, and, as a result, only fragments of belts are exposed within the Archean block. Because characteristic structural styles and sedimentary sequences have been destroyed or are not exposed in most of the fragmented belts, the morphological features needed to definitely identify the terrain as a greenstone belt are not recognized. The ranking of such terrains as greenstone belts is tenuous.

Consequently, interpretation of Archean geologic history from these poorly-exposed terrains is difficult and must be supplemented by analogies to other Archean shield areas. But the Laramie Range (Figure 2) contains a greenstone sequence, the Elmers Rock greenstone belt, first recognized in 1981 (Graff and others, 1981), which has been preserved relatively intact. Study of this area may help in interpreting the geologic history of the Wyoming Province.

Greenstone belts are defined by their structural morphology and stratigraphic sequences; features common to greenstone belts are listed in Table 1. In plan view (Figure 3) they form cuspate, elongate basins which are commonly infolded into or intruded by extensive granitic bodies. Margins of these basins may also be in fault contact with older granitic gneisses. Cross-section views show a series of plunging synclinal keels, tightly folded and faulted parallel to axial planes.

The stratigraphic sequences of these belts are divisible into three parts: a lower series of mafic and ultramafic rocks, a middle series of mafic to calc-alkaline volcanic rocks, and an upper unit of metasedimentary rocks.



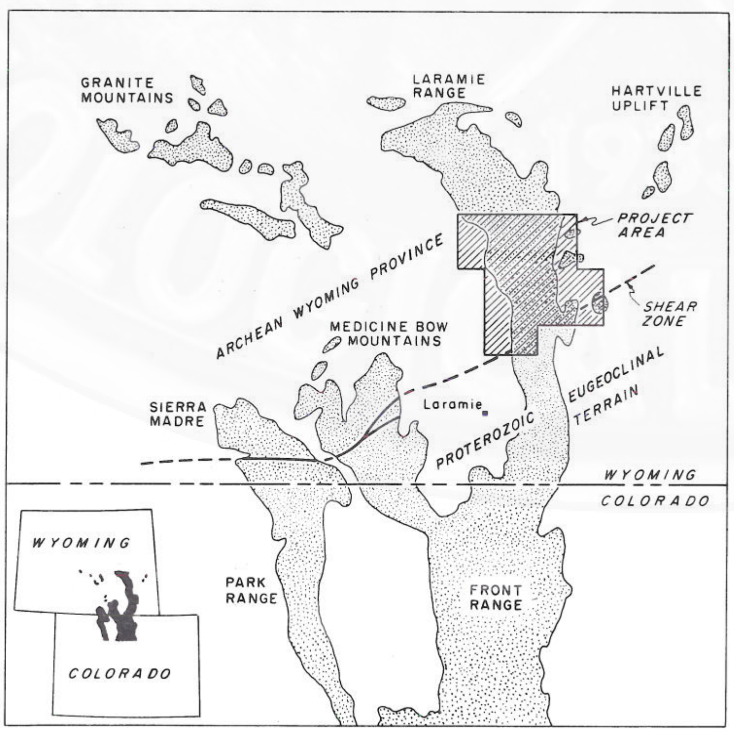




*Figure 1 [above]. Location of Precambrian rocks along the southern edge of the Wyoming Province.*

*Figure 2 [left]. Location of the project area and Precambrian rocks in southeast Wyoming and northern Colorado.*

The lower mafic and ultramafic rocks are peridotites with sheets of basaltic composition and sheets and pods of komatiitic composition. The middle volcanic series is dominated by flows of amphibolitic character. These flows contain pillow basalts and form a series of basalt-rhyolite cycles (Goodwin, 1968). Boulder conglomerates occur at the base of the upper metasedimentary sequence which consists of a thick series of pelites, graywackes, minor quartzites, marbles, and banded iron formation.

Reviews of greenstone belt characteristics are presented in Anhaeusser and others (1969), Goodwin (1968), Windley (1977), and Windley and Bridgwater (1977). The review by Windley and Bridgwater (1977, page 38-39) is of particular interest because it divides greenstone-type supracrustal rocks into several different types of belts. Of these types, the "high-grade supracrustal belt" best models the features of the Elmers Rock greenstone belt. The model and occurrence are compatible in structural and stratigraphic constraints, in metamorphic mineral assemblages, and in the overall chemistry of rock units.

*Table 1. Features common to greenstone belts and present in the Elmers Rock belt.*

| STRUCTURAL | STRATIGRAPHIC | MISCELLANEOUS |
|---|---|---|
| Bordering granite-gneiss domes | Rapid facies changes | Low- to intermediate-pressure metamorphic conditions |
| Post-metamorphic granites | Dominant basal mafic volcanics with low-K tholeiites | Sulfidic metavolcanics |
| Keel-shaped synclinal folds | Ultramafic pods in volcanics | Contorted mafic and ultramafic dikes in bordering gneisses |
| Curvilinear axial traces | Pillow lavas | Mafic schlieren in bordering gneisses |
| Highly strained boundaries with granite-gneiss | Granitic boulders in conglomerate with mafic graywacke matrix | Metamorphic grade higher at edges than in center of belt |
| Steep regional dip | Minor quartzite, marble, and calc-silicates | |
| Schistosity parallel to bedding | Pelites | |
| Branching synclines | Banded iron formation | |
| Strike faults along synclines | | |

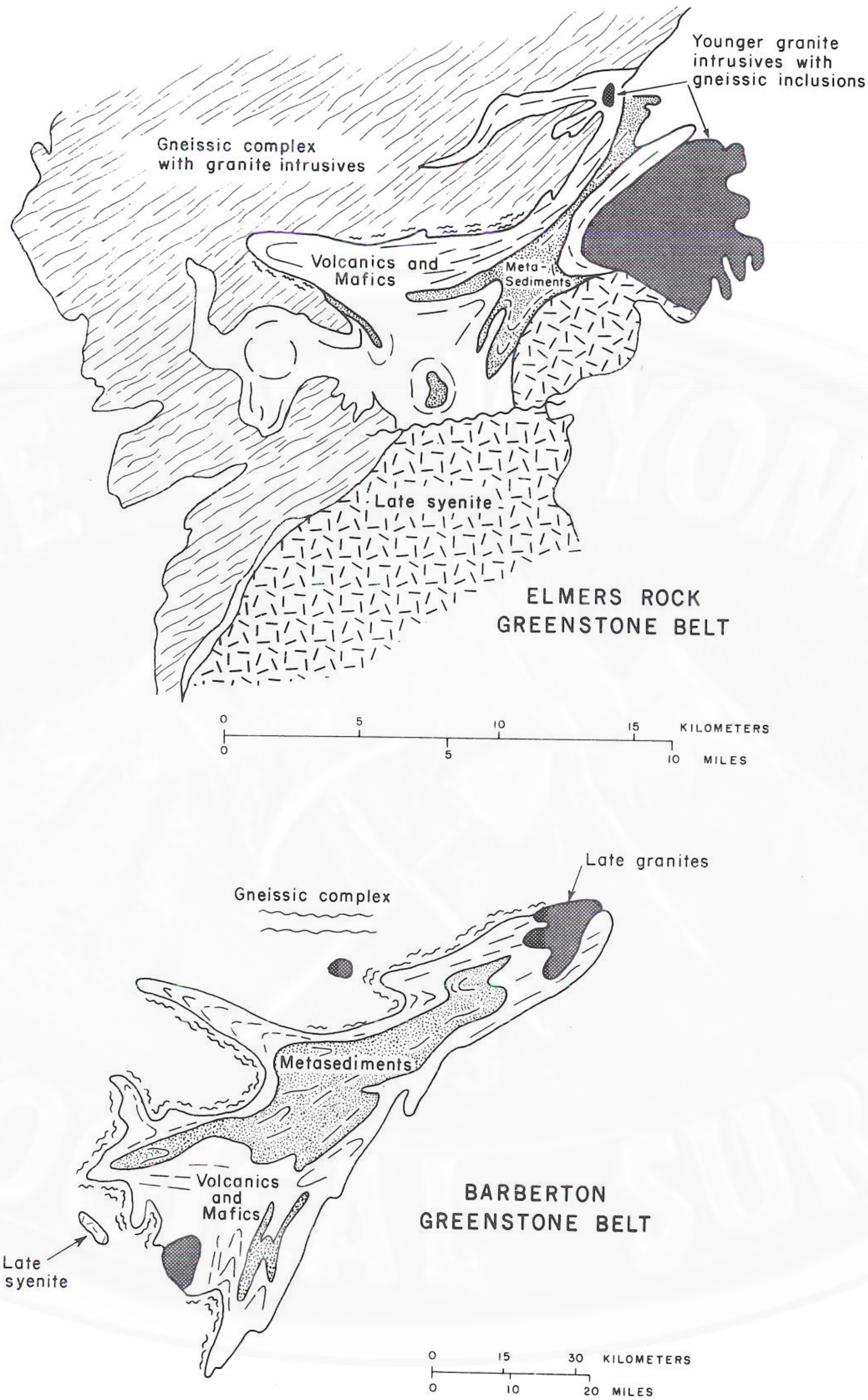



*Figure 3. Comparative sketches of the Elmers Rock greenstone belt (roughly the same area as is shown in detail on Plate 1), and the Barberton greenstone belt, a typical greenstone belt from South Africa, after Anhaeusser (1977).*

# REGIONAL GEOLOGIC SETTING

Precambrian rocks of southeastern Wyoming are divisible into the following groups: Archean granite-gneiss complex, Archean supracrustal rocks, early Proterozoic-type sequences (Houston and Karlstrom, 1980), Proterozoic amphibolite terrains, and Proterozoic intrusive rocks. These groups are separated into two distinct geologic provinces (Figures 4,5, and 6) by a major structural feature, the Mullen Creek - Nash Fork shear zone (Houston and McCallum, 1961; Houston and others, 1968). The Wyoming Province consists of the Archean granite-gneiss complex, the Archean supracrustal rocks, and the early Proterozoic-type sequences which unconformably overlie them. These groups lie north of the Mullen Creek - Nash Fork shear zone. South of the shear zone, Precambrian rocks consist of Proterozoic amphibolite gneisses and intrusive rocks.

The Mullen Creek - Nash Fork shear zone is a crustal suture that represents the collision of an early Proterozoic island arc system with the cratonic rocks of the Wyoming Province. Formats for the tectonic systems involved in this collision are presented by Graff (1978), Karlstrom (1981), and Hills and Houston (1979). The suture juxtaposes different crustal levels and has a displacement of more than six miles in a vertical sense (Hills and Houston, 1979) and perhaps hundreds of miles in a horizontal sense. The shear zone marks the southernmost exposures of Archean and early Proterozoic-type rocks in Wyoming.

Age of movement along this suture is determined by the radiometric ages of granites that bracket movement along the shear zone. Hills and Houston (1979) summarize movement on the shear zone as having occurred between 1.73 and 1.64 billion years before present.

This boundary between the Archean and Proterozoic provinces has been recognized for some time in the Medicine Bow Mountains (Houston and others, 1968) and extends westward through the Sierra Madre (Graff, 1978). Eastward extension of the zone has been projected to the Laramie Range (Houston and others, 1968; Hills and Houston, 1979; Karlstrom, 1979). In the Laramie Range, the younger 1.435 billion-year-old Laramie anorthosite-syenite complex and 1.42 billion-year-old Sherman Granite (ages from Subbarayudu, 1975) have intruded the area where the shear zone should be exposed. During field studies for this report, cataclastic migmatites were recognized in the Richeau Hills area east of the anorthosite body. The sheared rocks of the Richeau Hills are correlated in this report with those of the Mullen Creek - Nash Fork shear zone. This correlation reinforces the earlier projection of the shear zone by Hills and Houston (1979) and Karlstrom (1979).

Rocks south of the Mullen Creek - Nash Fork shear zone are composed of 1.7-1.8 billion-year-old amphibolite gneisses (Peterman and others, 1968), 1.6-1.8 billion-year-old mafic intrusive complexes (G.L. Snyder, personal communication), 1.6-1.7 billion-year-old granites (Hills and Houston, 1979) and 1.42 billion-year-old Sherman Granite (Subbarayudu, 1975).

The oldest rocks south of the shear zone are amphibolite gneisses and metasediments about 1.8 billion years old

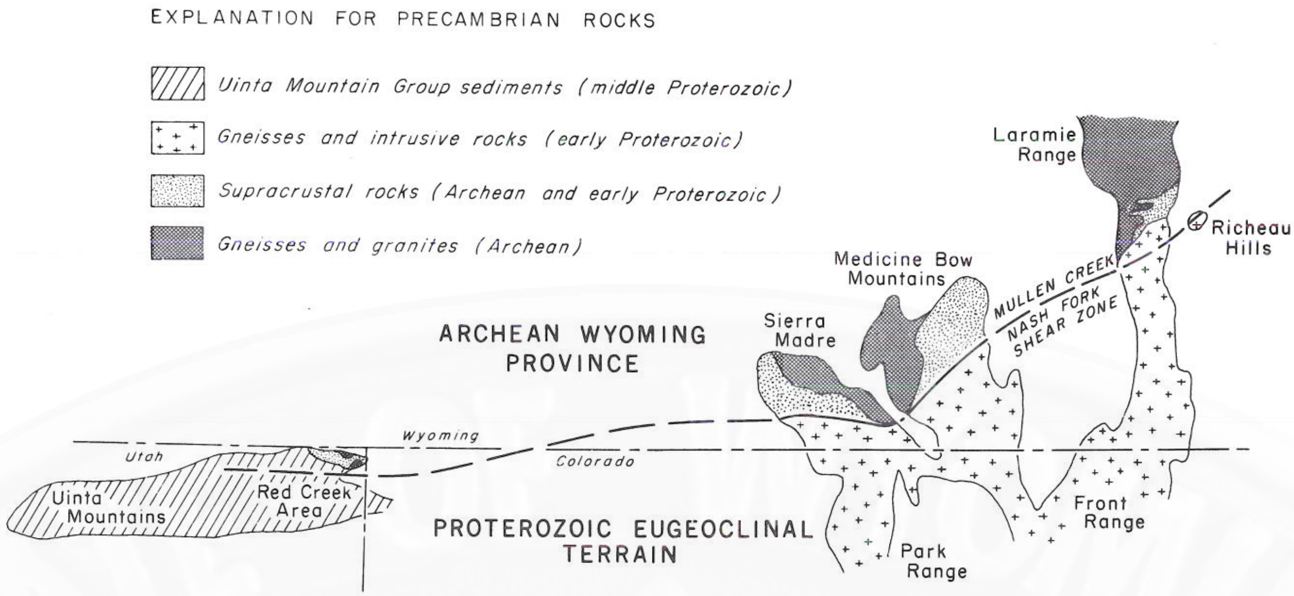
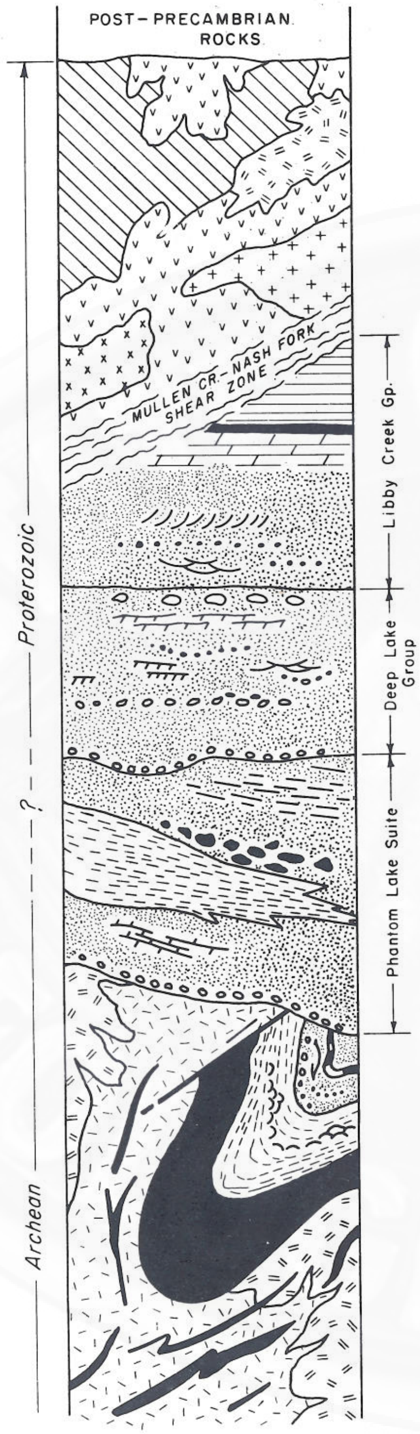



*Figure 4. Precambrian terrains of southeast Wyoming, northern Colorado, and northeastern Utah.*

(Peterman and Hedge, 1968) intruded by mafic igneous rocks 1.8 billion years ago (Snyder, 1980). These gneisses and metasediments are described by Snyder as amphibolite gneisses and metapelitic rocks that were most likely deposited in a back-arc basin and were derived chiefly from the volcanic arc (Graff, 1978; Hills and Houston, 1979). Syn- and post-kinematic granites (1.6-1.7 billion years old) intrude the amphibolitic gneisses; they range in composition from granodioritic to granitic. In the Laramie Range, these gneisses and metasediments are preserved as large, mappable inclusions in the Sherman Granite (Darton and others, 1910). In this report the sheared migmatites of the Richeau Hills are correlated with the 1.8-billion-year-old amphibolitic gneisses of the Front Range (Peterman and Hedge, 1968).

The Laramie anorthosite-syenite complex is younger than the Mullen Creek - Nash Fork shear zone and has apparently destroyed the geologic record of the shearing in the area intruded by that complex. The youngest Precambrian rock south of the shear zone is the 1.4-billion-year old Sherman Granite (age from Hills and Houston, 1979). The granite is unsheared where it is exposed about two thirds of a mile from, and on strike with, sheared migmatites of the Richeau Hills.

Archean rocks of the Wyoming Province occur only north of the boundary defined by the Mullen Creek - Nash Fork shear zone (Figures 5 and 6). These rocks include gneissic terrains, Late Archean granites, and supracrustal sequences. Granite-gneiss terrains are complexly intermixed plagioclase-quartz-biotite gneisses which are probably paragneisses that have been invaded by late Archean granites. The potassium-poor paragneisses have been radiometrically dated as about 2.9 billion years old (Peterman and Hildreth, 1977; Divis, 1976), but have high $Sr^{87}/Sr^{86}$ initial ratios which suggest that these gneisses represent metamorphosed clastic sedimentary piles. Peterman and Hildreth (1977) suggest that if the high $Sr^{87}/Sr^{86}$ initial values are projected to an assumed initial ratio reason-




PROTEROZOIC GNEISSES AND INTRUSIVE ROCKS. Amphibolitic gneiss and metasedimentary rocks of volcanogenic origin which have been invaded by (oldest to youngest) mafic igneous complex, syn- and post-kinematic granite, Laramie anorthosite-syenite complex, and the Sherman Granite.

LIBBY CREEK GROUP. Shale, greenstone, and carbonate rock underlain by nearshore marine clastics.

DEEP LAKE GROUP. Fluvial quartzite rock with minor amounts of carbonate, shale, and paraconglomerate (tillite?). Basal uraniferous quartz-pebble conglomerate.

PHANTOM LAKE METAMORPHIC SUITE. Dominantly quartzite and volcanic rock. Volcanics include amphibolite schist and garnet amphibolite gneiss. Clastics include quartzite and shale with minor amounts of carbonate, granite-boulder paraconglomerate, and basal(?) uraniferous quartz-pebble conglomerate.

ARCHEAN GRANITE-GNEISS AND SUPRACRUSTAL ROCKS. Quartz-plagioclase-biotite and hornblende gneiss intruded by K-rich granite between 2.7 and 2.55 b.y. ago. Infolded greenstone belts included mafic and ultramafic rocks, basalt, pillow basalt and andesitic volcanics, conglomerate, quartzite, calc-silicates, marble, banded iron formation, and metapelite. Mafic dikes are of several ages.

*Figure 5. Schematic stratigraphic column for Precambrian rocks, southeast Wyoming.*

able for igneous rocks, then an original date of crystallization, or separation from a mantle source, of more than 3.2 billion years ago is indicated. These gneissic complexes are depositional basement for ensialic Archean supracrustal piles.

The gneissic terrain was invaded by large granite batholiths about 2.55-2.65 billion years ago. Emplacement of the potassium-rich granites was a doming event that folded supracrustal sequences deposited on the early gneisses. These late Archean granites are in part anatectic; Stuckless (1979) calculates that, at the time of emplacement, uranium concentration in these granites exceeded that in typical granites. Such concentration makes these late Archean granites likely source rocks for the uranium and thorium found in the conglomerates of the ensialic sequences at the southern edge of the Archean craton.

Deposited on and folded into the Archean granite-gneiss complex terrain are supracrustal sequences that form greenstone belts. Such belts are described in central Wyoming by Bayley (1963) and Condie (1976) and also occur in the Sierra Madre and the Laramie Range. The greenstone belt in the central Laramie Range contains a lower mafic and ultramafic volcanic sequence, a middle sequence of amphibolites and metabasalts, and an upper section of conglomerates, graywackes, marbles, iron formations, and metapelites.

These belts are folded into arcuate, locally overturned, synclinal keels that are preserved between domes of granitic rock. Sediments exposed in the greenstone belts are immature and indicate deposition in a rapidly subsiding trough. Mature fluvial rocks are absent.

Overlying the granite-gneiss complex and greenstone belts along the southern edge of the Wyoming Province is a clastic wedge more than nine miles thick (Hills and Houston, 1979). This sequence, the Snowy Range Supergroup, contains Archean and early Proterozoic metasedimentary rocks which can be divided into four sedimentation units (Graff, 1979). Each unit is a fining-upward sequence with a basal conglomerate. The lower two cycles contain basal uraniferous quartz-pebble conglomerates while the upper two cycles are characterized by paraconglomerates that may be of glacial origin and which are not radioactive. Cycles are formed of thick sequences of clastic sedimentary rocks which are dominated by fluvial quartzites.

# STRATIGRAPHY

## Introduction

Archean metasediments and gneisses to middle Proterozoic igneous complexes are exposed in the central Laramie Range (Plates 1 and 2). These units can be divided into the three groups shown in Figure 7: (1) granite-gneiss complex, (2) Archean supracrustal rocks, and (3) Proterozoic intrusive and cataclastic rocks. Only the granite-gneiss and Archean supracrustal rocks are of real interest in a discussion of the stratigraphic characteristics of the greenstone sequence.

## Granite-Gneiss Complex

The oldest rocks in the central Laramie Range are gray quartz-plagioclase-biotite gneisses which form a migmatite terrain. Inclusions of this gneiss, which vary greatly in size and degree of assimilation, are present in the granite phases that are

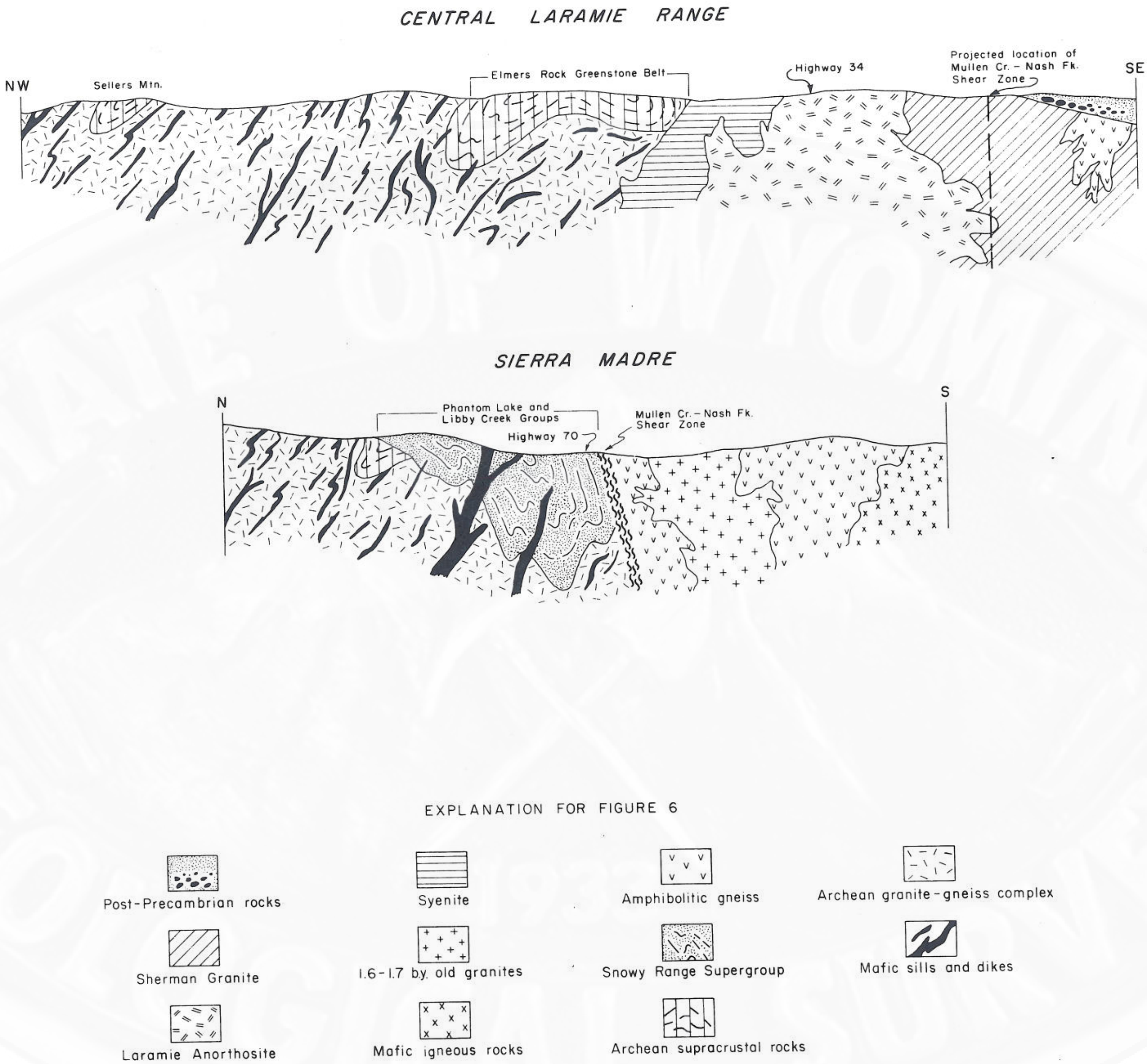



*Figure 6. Schematic cross sections of the Sierra Madre and central Laramie Range.*

involved with the doming event. Prior to that intrusion, these gneisses were isoclinally folded and ductily sheared and were probably basement for deposition of the supracrustal rocks of an Archean greenstone belt. Migmatites of the central Laramie Range probably correspond to migmatites in the northern Laramie Range that have been dated at about 3.0 billion years old (Johnson and Hills, 1976). Petrographic analysis shows the migmatites to be potassium-poor rocks which contain only minor amounts of microcline and muscovite.

Granites and quartz monzonites that intrude the basement gneiss are divisible into equigranular and porphyritic phases. Both phases occur in massive and foliated habits. Foliation in the granites is concordant with their contact with greenstone belt rocks and locally contains mylonites immediately adjoining the contact. This deformation has everywhere destroyed the original relationship of basement and supracrustal rocks. The granites may have been intruded as sheet-like bodies that domed in response to gravitational instability. The lack of migmatites near granite-greenstone contacts suggests that the granite bodies were solid when domed. Only small, local inliers of granites and small dikes of felsic gneiss (or metamorphosed felsic sediments) occur within the supracrustal rocks. These granites are potassium-rich rocks that form one point on a Rb/Sr 2.54-billion-year isochron developed by Hills and Armstrong (1974) for granite rocks of the Laramie Range. Given the relationship of the supracrustal rocks to the granite, the 2.54-billion-year-old date is a minimum age for the supracrustal rocks.

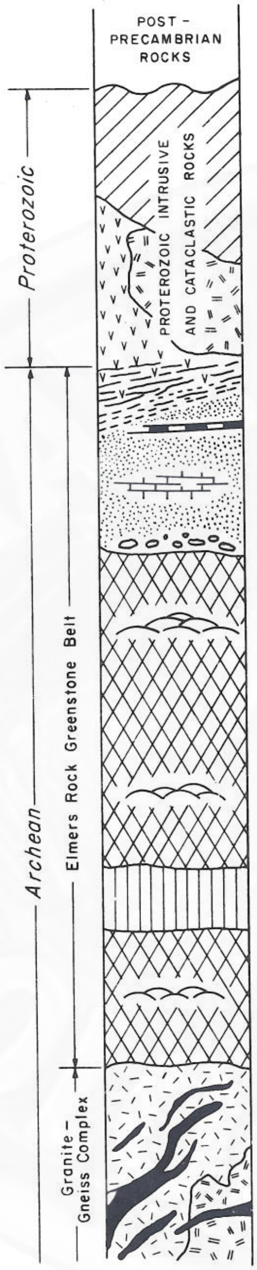
## Kennedy Dike Swarm

The granite-gneiss complex is intruded by mafic rock of highly variable composition. These dikes include pristine ultramafic bodies, diabases, ophitic diabases, amphibolites, and metamorphosed mafic bodies. Their emplacement in areas near the Kennedy School of the Bull Camp Peak quadrangle constitutes a dike swarm and is herein named the Kennedy Dike Swarm. Larger bodies within the swarm are less metamorphosed, retain original igneous textures in their center portions, and are foliated only along their contacts with granitic rocks.

Petrographic analyses of the ultramafic dikes yield 5-45 percent pyroxene, 10-45 percent plagioclase, and 0-85 percent olivine. Dike compositions range from ultramafic to amphibolitic containing as much as 60 percent hornblende. Metamorphosed dikes contain strongly foliated zones with ophitic texture preserved between sheared areas; pyroxenes are altered to clinozoisite, epidote, and hornblende. Unmetamorphosed ultramafic dike material includes olivine cumulates with olivine grains exhibiting corona structures of pyroxene.

## Elmers Rock Greenstone Belt

Supracrustal rocks of the central Laramie Range occur as synformal bodies exposed between domes of the Archean granite-gneiss complex. The largest contiguous body of supracrustal rocks occurs in the drainages of Bluegrass and Slate Creeks and spans the width of the Laramie Range. This body, herein named the Elmers Rock greenstone belt, is bounded to the north by the granite-gneiss complex and is truncated on the south by the Laramie anorthosite-syenite complex. Outliers of this body, or portions of separate similar bodies, occur at Sellers Mountain along the border zone of the Laramie Batholith (Condie, 1976), at Johnson's Mountain, at Marble Quarry Creek, and just north of Wheatland Reservoir Number 2. These outlying bodies are compatible in stratigraphy and structure with the main body of the Elmers Rock greenstone belt, and the discussion below applies to all these occurrences.




PROTEROZOIC INTRUSIVE AND CATACLASTIC ROCKS

ELMERS ROCK GREENSTONE BELT. Upper portion contains metapelites, banded iron formation, quartzite, marble, granite-boulder paraconglomerate, graywacke, and minor amounts of volcanic rock.

Middle portion includes felsic volcanics and metatuffs, calc-alkaline volcanics, pillow basalt, volcaniclastic sedimentary rock, and metabasalt.

Lower portion is composed of metabasalt, pillow(?) basalt, and ultramafic flows or sills which are now metamorphosed to actinolite-chlorite rock.

ARCHEAN GRANITE-GNEISS COMPLEX. Gray, quartz-biotite-plagioclase gneiss and migmatite intruded by granite. Granite is K-rich and occurs in equigranular and porphyritic phases. These are intruded by mafic dikes and ultramafic dikes and sills.

*Figure 7. Schematic stratigraphic column of the rocks of the central Laramie Range, Wyoming.*

The age of the greenstone belt is greater than 2.54 billion years, the age determined for granites which dome and fold the supracrustal rocks (Hills and Armstrong, 1974). Cobbles of the gray quartz-biotite-plagioclase gneiss, which occur in paraconglomerates within supracrustal rocks, are similar to the gray gneiss of the migmatite terrain. Cobbles of gray gneiss and the gray gneiss of the migmatite terrain are here correlated with the 3.02 billion-years-old gneiss (Johnson and Hills, 1976) of the northern Laramie Range. If this correlation is valid, then the age of the belt is between about 2.54 and 3.02 billion years.

The supracrustal sequence can be divided into two groups (Figure 7), a lower group of mafic, ultramafic and amphibolite rocks and an upper group of metasedimentary rocks. The belt is dominated by amphibolites of igneous or volcaniclastic origin; these comprise about 60-70 percent of the outcrop area. The metasedimentary rocks are chiefly metapelites with lesser amounts of marble, quartzite, comglomerate, and other immature sediments.

The lower group is a monotonous sequence of layered hornblende schist and gneiss that is several miles thick. Amphibolite within this sequence is platy to massive, fine- to coarse-grained rock, basaltic to andesitic in composition. In general it is hornblende- and plagioclase-bearing rock containing some quartz, sphene, and cummingtonite, a composition suggesting a rather mafic original composition. Rocks north of Bluegrass Creek which are low in the section appear to be the most mafic in character. Pillow structures are identified by compositional zoning in ovoid form and are evidence of subaqueous deposition for at least some of the flows. Mafic amphibolites have a pervasive hornblende lineation which is generally down the dip of schistosity.

Within the flow sequence are numerous unlayered, irregular amphibolite bodies which may have originally been gabbroic intrusions; contact relationships are not preserved. Intercalated with the amphibolitic flows is a string, 150 to 500 feet thick, of actinolite-chlorite pods, which extends for nearly nine miles along strike. These rocks also contain some hornblende, cummingtonite, garnet, magnetite, and spinel (hercynite), are locally serpentinized, and are here interpreted as metamorphosed ultramafic flows or sills. The whole-rock chemistry of samples from these flows is compatible (Table 2) with the chemistry of komatiites of eastern Finland as presented by Blais and others (1978), and similar to the chemistry of constituents of what Windley and Bridgwater (1977) have called "high-grade supracrustal belts" that are common to nearly all Archean terrains.

In the center of the exposed portion of the belt is a three-cornered dome exposing felsic amphibolite. This dome structure upwarps a sequence of flows which are dominated by coarsely recrystallized amphibolite-plagioclase rocks interlayered with horizons of volcaniclastic graywackes. These graywackes contain primary sedimentary structures including conglomeratic facies, graded bedding, channels, and cross bedding. Graywacke beds are several feet to tens of feet thick. All facies of these sedimentary rocks represent sedimentologically immature clastic debris. Lenticular felsic bodies reaching a thickness of about 150 feet occur just south of the Boyd Ranch. Petrographic analyses give a composition of 35-40 percent potassium feldspar, 30-35 percent quartz, 10-15 percent plagioclase, 10 percent muscovite, less than five percent biotite, and some opaques. These felsic bodies represent fine-grained arkosic sediments or perhaps rhyolitic precursors. Such an interlayering of very immature sediments with intermediate calc-alkaline flows probably represents the transition of deposition from chiefly volcanic to chiefly sedimentary rock.

*Table 2. Table of chemical analyses of komatiites. Total iron is calculated as FeO. Analyses of Finnish komatiites from Blais and others, 1978. Oxides are given in weight percent.*

| Oxide | Analyses of komatiites, eastern Finland | | Analyses of "komatiites", Elmers Rock greenstone belt, Wyoming | |
|---|---|---|---|---|
| $SiO_2$ | 47.84 | 46.58 | 45.33 | 47.69 |
| $TiO_2$ | 0.29 | 0.40 | 0.19 | 0.11 |
| $Al_2O_3$ | 6.86 | 8.08 | 3.27 | 2.50 |
| FeO | 10.73 | 10.75 | 21.59 | 18.74 |
| MnO | 0.02 | 0.17 | 0.33 | 0.27 |
| MgO | 26.67 | 26.01 | 29.04 | 28.73 |
| CaO | 7.21 | 7.45 | 0.26 | 2.42 |
| $Na_2O$ | 0.01 | 0.18 | 0.12 | 0.30 |
| $K_2O$ | 0.10 | 0.03 | 0.03 | 0.06 |
| $P_2O_5$ | 0.11 | 0.07 | ----- | ----- |
| TOTAL | 99.84 | 99.72 | 100.16 | 100.82 |

The amphibolites are overlain by a metasedimentary sequence that is repeated by tight folding. The metasedimentary rocks are thickest in the Cooney Hills area where they may be up to two miles thick, and are thinnest in the western portion of the belt where they are only several feet thick. Although the exact stratigraphic order is not implied in the following discussion, the general order of succession is.

Directly overlying the mafic and komatiitic flows or sills is paraconglomerate containing gray gneiss boulder clasts. Clasts are matrix supported in a graywacke to amphibolitic graywacke matrix. Clasts have been stretched in the plane of foliation and locally folded about a nearly vertical fold axis. Conglomerate lenses are up to 65 feet thick except at fold hinges where thickening has occurred as a result of folding. Paraconglomerate may change facies along strike to graywacke layers or may pinch out into mafic flows. Shearing in the plane of foliation has occurred along the limbs of folds; intervening layers of amphibolitic rock often completely separate lenses of paraconglomerate. Pink granite is not present as clasts, and deposition of the paraconglomerate, therefore, preceded the unroofing of the pink granite.

Metagraywacke is stratigraphically interspersed with the paraconglomerate, with amphibolites (metaflows) that occur above the paraconglomerate, and with other overlying metasediments. The graywacke is clastic, quartz-, amphibole-, and plagioclase-bearing sediment which locally retains primary sedimentary structures such as graded bedding and possible channeling.

The upper portion of the metasedimentary sequence is dominated by metapelite. Metapelite is dark, schistose, high-alumina rock which contains all three aluminosilicates and biotite, plagioclase, garnet, and quartz. Because of its high degree of metamorphism and original small grain size, its sedimentary structures are not preserved. Interlayered with the metapelite are numerous thin layers of dirty quartzite, marble, quartzite and associated marble, banded iron formation, and quartz-pebble conglomerate. Dirty quartzite and graywacke are a gradational series of rocks and locally grade into each other or into metapelite. The quartzite is highly iron stained and forms rusty gossan outcrops. Marble is locally thickened at fold hinges but is usually only a few feet thick away from highly folded areas. Organoform structures, possibly stromatolites, are preserved in the marble at several locations. Sinuous bands of quartzite and associated marble occur in the upper part of the metapelite. These persistent bands are folded and contain fuchsite-rich quartzite that has been locally quarried for facing stone. Banded iron formation occurs in at least two irregular layers within the metapelitic sequence. These layers are up to 100 feet thick and are continuous for several miles. Both silicate and oxide layers are present. Oxide layers are principally quartz with as much as 40 percent magnetite and hematite. Silicate layers are composed of cummingtonite-grunerite, garnet, and quartz, with minor iron oxide.

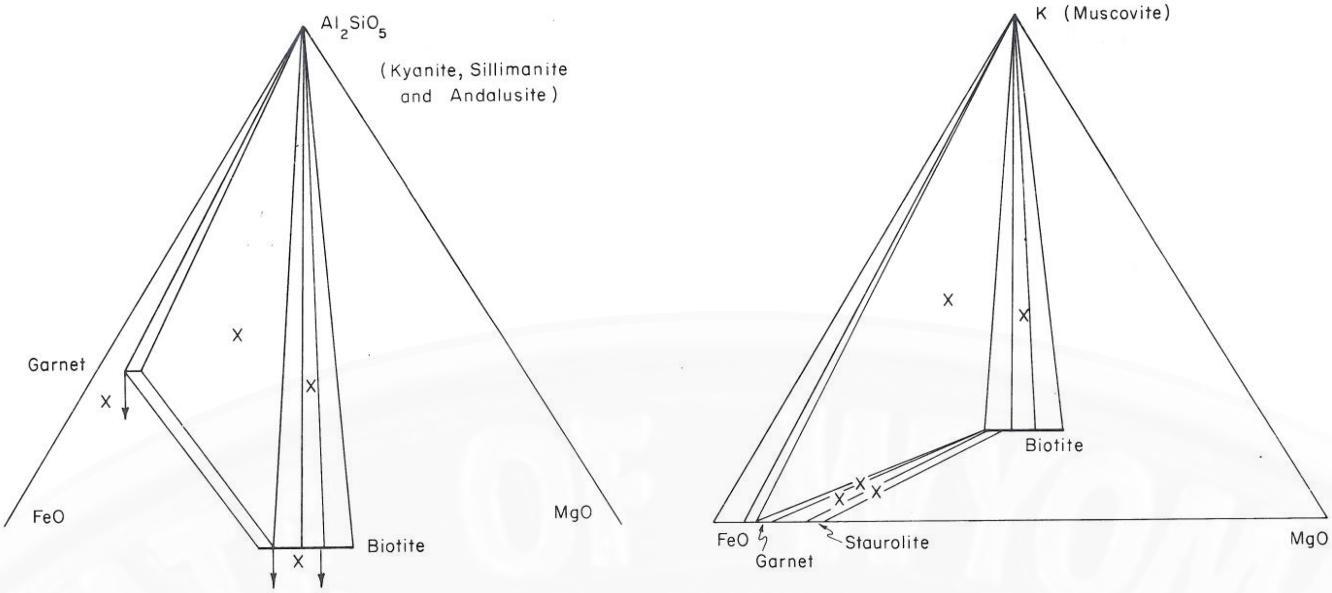
Thin layers of quartz-pebble conglomerate up to seven feet thick occur near Squaw Mountain and Halleck Canyon and are quite similar. Conglomerate in both areas contains flattened quartz pebbles in a matrix of microcline, quartz, and muscovite. Conglomerate near Halleck Canyon is more micaceous and contains sillimanite which was formed during the intrusion of the hornblende syenite. The original matrix of this conglomerate was most likely a feldspathic sand with a high clay content.

Felsic gneiss occurs as pods, usually concordant with layering, throughout the metasedimentary sequence. Precursors of this gneiss are uncertain; they may be metamorphosed felsic volcanic rocks, sedimentary layers, sheared pegmatities, or aplitic dikes.

## METAMORPHIC GRADE

All rocks of the supracrustal sequence have been metamorphosed at amphibolite facies conditions. Textures are generally granoblastic polygonal. In all but the most micaceous metapelite, the initial stages of segregation into mafic and felsic layers are evident.

The three $Al_2SiO_5$ polymorphs, andalusite, sillimanite, and kyanite, commonly coexist in the metapelite. At the highest grade, andalusite and sillimanite are stable in the southern part of the belt, sillimanite and kyanite in the northeastern part. This suggests that pressure conditions were near those of the $Al_2SiO_5$ triple point, between 4.0 and 5.5 kilobars (7.8 and 10.6 mile depths; Thompson, 1976). A common assemblage in the metapelites (Figure 8) is sillimanite-garnet-biotite-muscovite-quartz, which indicates that the temperature of the reaction muscovite + staurolite = sillimanite + biotite + garnet + $H_2O$ was exceeded at highest grade. Hence, at 5.5 kilobars the maximum temperature achieved during metamorphism must have been between 580°C and 650°C (Holden, 1978). Metamorphic conditions were similar throughout the entire supracrustal belt except for a slight increase in pressure (but not temperature) toward the northeast.




AFM projection of stable pelitic assemblages. All assemblages contain plagioclase, quartz, muscovite (projection phase) and ilmenite.

KFM projection of stable assemblages. All assemblages contain quartz, plagioclase, ilmenite, and aluminum silicate (projection phase).

*Figure 8. Stable metamorphic assemblages, Elmers Rock greenstone belt, Laramie Range, Wyoming.*

## STRUCTURE

The structural setting of the Elmers Rock greenstone belt is arcuate synformal bodies of supracrustal rocks which wrap around intruding granite domes. Such a structural style for greenstone belts is described for the Barberton greenstone belt of South Africa by Anhaeusser and others (1969) and for greenstone belts of the Rhodesian Archean craton by MacGregor (1951). MacGregor (1951) emphasizes morphological characteristics of arcuate cuspate synforms which have been enveloped by domal granitic intrusions. Structural descriptions of the African greenstone belts and those of other cratonic areas are highly compatible with structural features observed in the Elmers Rock greenstone belt.

Granites which dome and fold the supracrustal sequence are older than about 2.6 billion years and contain xenoliths of earlier gneissic rocks. A domal form is recorded as a circular spread in schistosity within the granites, a circular or irregular distribution of dikes within the dome, and layering in the supracrustal sequence over, or peripheral to, the granite domes. Foliation within the granite near contact with supracrustal rocks has been rotated parallel to the contact. Mylonite formed within the granite domes during intrusion is positioned near and parallel to the contact between the dome and the belt.

The belt is formed by branching, synformal keels of volcanic, volcaniclastic, and metasedimentary rock whose axial traces are shallowly plunging curvilinear features. Synforms are locally open or overturned, but in all cases exhibit well developed down-dip lineation. Schistosity parallels bedding; regionally, dips are steep, and shearing parallel to schistosity is locally evident. Boundaries of the belt with the granite are highly strained features. Penetrative deformation within the greenstone belt is the result of Archean events, most noticeably the intrusion of the enveloping granite bodies.

## ECONOMIC GEOLOGY

Greenstone belts are important hosts for several metals and industrial minerals. Gold, in particular, is enriched in anomalous amounts in these supracrustal terrains, so that the terms *gold belt* and *greenstone belt* are essentially synonymous. Within Wyoming, nearly all historic gold production was won from supracrustal rocks of the South Pass greenstone belt near the southern tip of the Wind River Range (Hausel, 1980).

Other types of mineralization commonly reported in these terrains worldwide are iron, copper, zinc, silver, nickel, chromite, asbestos, talc, and diamond. Generally, the Archean supracrustals are uranium poor although bordering granite-gneiss complexes may be enriched in radioactive elements.

### Greenstone Belt Mineralization

The stratigraphic sequence of a model greenstone belt can be divided into an underlying predominately ultramafic to mafic igneous rock series, a middle mafic to calc-alkaline igneous series, and an overlying sedimentary series. Characteristic mineral deposits are associated with each series.

Mineralization characteristically associated with underlying ultramafic rocks includes nickel sulfides in magnesian-rich rocks (dunites and peridotites). These deposits occur as magmatic segregates in the olivine-rich magma (Arndt, 1976). Asbestos and talc occur as hydrothermal alteration products of mafic and ultramafic rocks. Chromite, when found in economic tonnages, occurs in stratiform ultramafic intrusives (peridotites and gabbroic anorthosites). Gold and silver are related to post-depositional regional fractures, quartz-bearing fissures close to or within meta-igneous rocks. The ultimate source of the gold is assumed to have been the vast piles of mafics and ultramafics (Viljoen and others, 1970).

Important mineral deposits of the middle igneous series are stratiform copper-zinc massive sulfides. These sulfides also carry some gold and silver. They are restricted to calc-alkaline metaigneous rock.

Both the sedimentary and volcanic series of greenstone belts often have banded iron formation interstratified with a variety of volcanic and sedimentary units. Some of this iron formation may contain anomalous gold (Fripp, 1976; Hausel, 1982).

Finally, in many greenstone successions worldwide, metals are found in late tectonic pegmatite, and diamond occurs in kimberlite — these ultrabasic intrusives have intermittently invaded the old cratons throughout geologic history (Watson, 1976).

Although no significant mineralization has been found in the Elmers Rock greenstone belt, the present study is the result of preliminary reconnaissance; more detailed investigations would be required to prove the existence or nonexistence of economic mineralization. The present discussion is a general summary of detailed analytical results reported by Graff and others (1981).

## Gold Mineralization

Available literature on mineral deposits in the state makes no mention of gold in the Elmers Rock supracrustals. During reconnaissance, a small group of samples was collected from arenaceous metasediments and assayed for gold. These metasediments were examined to test for possible fossil placer mineralization. The samples showed no anomalous gold.

The only known historic gold prospects in the Elmers Rock belt are two mines and several prospect pits located in amphibolite schists south of Sybille Canyon.

### Woods Mine

($N\frac{1}{2}NE\frac{1}{4}$ sec. 13, T.19N., R.73W.) A pyritized, north-trending shear zone was developed by an adit with one level of mine workings in meta-amphibolite. Local residents claim that several tons of gold ore were shipped to Denver, but no production records are available. The size of the mine dump suggests that the workings were not extensive. The mine entrance has collapsed, and the workings are inaccessible. Mine dump samples show very little evidence of mineralization, with only minor disseminated pyrite.

### Whitman Mine

($SE\frac{1}{4}$ sec. 36, T.20N., R.73W.) The Whitman shaft was developed on a N30°E near-vertical shear about one foot wide. Dump samples show quartz and minor carbonate gangue, some chalcopyrite, secondary copper carbonates, and oxides. The host rock is meta-amphibolite. The mineralization is poor. Selected grab samples containing boxworks and primary copper sulfides were assayed for gold and gave only a trace (less than 0.01 oz/ton). The total amount of development for both the Woods and Whitman mines is estimated to be less than 300 feet based on the size of the mine dump spoils.

## Banded Iron Formations

Oxide-facies banded iron formations crop out in the vicinity of Moonshine Hill and Slate Creek (see Plate 1) on the northeastern edge of the belt rocks. These are fairly continuous for nearly two miles and reach a thickness of up to 100 feet. They contain 40 percent iron as magnetite and hematite alternating with layers of quartz-garnet-cummingtonite-grunerite. No samples were assayed for gold.

## Nickel, Chromium, Talc, and Asbestos

Numerous samples of mafic to ultramafic rock were sampled and tested for nickel and chromium. Within the ultramafic-mafic series of the Elmers Rock belt, the richest chromite and nickel assays were 2,700 ppm Cr and 1,600 ppm Ni (one assay of 2,200 ppm Ni was obtained from an ultramafic pod in the granite-gneiss terrain). The lack of economic nickel mineralization could reflect insufficient sampling, but could also be due to the general lack of high-magnesian lavas (dunite and peridotites containing more than 36 percent MgO) which, according to Arndt (1976), are necessary for ultramafic lavas to host nickel sulfides.

### Hallack Canyon chromite

Fields (1963) reported disseminated and veinlet chromite mineralization in ultramafics associated with steatitized and serpentinized alteration in the Hallack Canyon area. The chromite-rich rock is in a small area, about 200 feet in diameter. Chromite vein assays gave 9.3 percent elemental chromium, and a sample of disseminated chromite assayed at 0.87 percent chromium and minor molybdenum, copper, and nickel. Stratiform chromite mineralization associated with peridotite or gabbroic anorthosite has not been reported.

Some restricted occurrences of cross-fiber asbestos and some talc are also reported in altered areas near the chromite occurrences (Fields, 1963; Osterwald and others, 1966).

## Copper - Zinc

Scattered copper mineralization is reported throughout the belt, although the mineralization is very limited in extent. The lack of copper-zinc deposits undoubtedly is due to the limited outcrops of intermediate to felsic volcanics.

## Uranium Mineralization

The Archean supracrustal rocks are generally poor hosts for uranium. Metasedimentary rocks in these successions are characteristic of a tectonically active environment which resulted in deposition of immature clastic sediments. Such immature sediments are poor sites for placer uranium accumulation, unlike the miogeosynclinal type of sediments associated with stable cratonic areas developed during the Proterozoic in many regions of the world (e.g. Witwatersrand and Blind River).

The granite-gneiss complexes are better uranium exploration targets than the Archean supracrustal rocks in that many of the granitic rocks (other than potassium-poor varieties) are often anomalous in radioactivity. Anomalous radioactivity (5X background) and up to 35 ppm uranium were detected in the east-west shear zones and associated with scattered sulfide pods. North of the map areas (Plates 1 and 2) granitic rocks are reported to yield assays commonly higher than 50 ppm.

### Deer Creek area

As much as 32 percent uranium has been reported associated with sulfide pods in the Deer Creek area. These deposits are small and localized and of apparently small tonnages.

## Late-Invading Kimberlites

The Elmers Rock greenstone belt, as well as the other Wyoming greenstone belts, has not been examined for possible kimberlite intrusives. Kimberlites have been detected immediately south of the Archean supracrustal rocks (Hausel and others, 1981) within the Laramie Range anorthosite complex and within Sherman Granite. Diamond-bearing kimberlites are found further south along the Colorado-Wyoming state Line (Hausel and others, 1979; McCallum and Mabarak, 1976).

The kimberlites are assumed to be Devonian on the basis of fission-track dating (Naeser and McCallum, 1977) and Rb-Sr dating (C.B. Smith; personal communication reported in Hausel and others, 1979). Whether these ultrabasic intrusives extend into supracrustal rocks is not known.

## Other Deposits

Granitic pegmatites were not investigated during this project. Some marble and fuchsitic quartzite have been quarried and used as road metal and facing stone.

ACKNOWLEDGMENTS

This paper is one of many ideas spawned by the research work of Dr. Robert S. Houston of the University of Wyoming. We greatly appreciate his comments on the manuscript; his observations and suggestions during field trips to the Laramie Range were invaluable in the preparation of this report.

George Snyder of the U.S. Geological Survey, Denver, Colorado is currently mapping metasedimentary sequences in the Laramie Range. He graciously provided us with his insight into the geology of the Laramie Range. George also showed us critical outcrops that he had mapped in previous seasons. His comments and help greatly aided our studies.

This report is an outgrowth of research on Precambrian uranium deposits for the U.S. Department of Energy performed under contract DE-AC13-76GJ01664.

## REFERENCES CITED


Anhaeusser, C.R., 1971, The Barberton Mountain Land, South Africa - a guide to the understanding of Archaean geology of western Australia: Geol. Soc. Australia, Spec. Pub. 3, p. 57-70.

Anhaeusser, C.R., Mason, R., Viljoen, M.J., and Viljoen, R., 1969, A reappraisal of some aspects of Precambrian shield geology: Geol. Soc. Amer., Bull., v. 80, p. 2175-2200.

Arndt, N.T., 1976, Ultramafic rocks of Munro Township: economic and tectonic implications: Geol. Assoc. Canada, Spec. Paper 14, p. 617-657.

Bayley, R.W., 1963, A preliminary report on the Precambrian iron deposits near Atlantic City, Wyoming: U.S. Geol. Survey, Bull. 1142-C, 23 p.

Bothner, W.A., 1967, Petrology and structural geometry and economic geology of the Cooney Hills, Platte County, Wyoming: unpub. PhD thesis, Dept. Geology, Univ. Wyoming, 164 p.

Blais, S., and others, 1978, The Archaean greenstone belts of Karelia (eastern Finland) and their komatiitic and tholeiitic series, *in* Windley, B.F., and Naqvi, S.M., editors, Archaean geochemistry: Elsevier, p. 87-107.

Carmichael, D.M., 1978, Metamorphic bathozones and bathograds: a measure of the depth of post-metamorphic uplift and erosion on the regional scale: Amer. Jour. Sci., vol. 278, p. 769-797.

Condie, K.C., 1976, The Wyoming Archean Province in the western United States, *in* Windley, B.F., editor, The early history of the earth: New York, Wiley, p. 499-510.

Darton, N.H., Blackwelder, E., and Sieventral, C.E., 1910 Laramie-Sherman Folio: U.S. Geol. Survey, Geol. Atlas No. 173, 17 p.

Divis, A.F., 1976, Geology and geochemistry of Sierra Madre Range, Wyoming: Colo. School Mines, Quart., vol. 71, no. 3, 127 p.

Engel, A.E.J., 1963, Geologic evolution of North America: Science, vol. 140, p. 143-152.

Fields, E.D., 1963, Precambrian rocks of the Hallack Canyon area, Albany County, Wyoming: unpub. MS thesis, Dept. Geology, Univ. Wyoming, 91 p.

Fleckenstein, M., 1980, Precambrian geology of Squaw Mountain, central Laramie Range, Wyoming: unpub. MS thesis, Colorado School Mines, 88 p.

Fripp, R.E.P., 1976, Stratabound gold deposits in Archaean banded iron-formation, Rhodesia: Econ. Geol., vol. 71, p. 58-75.

Goodwin, A.M., 1968, Archaean protocontinental growth and early crustal history of the Canadian Shield: 23rd Int. Geol. Congr., Proc., vol. 1, p. 69-89.

Graff, P.J., 1978, Geology of the lower part of the Early Proterozoic Snowy Range Supergroup, Sierra Madre, Wyoming, with chapters on Proterozoic regional tectonics and uraniferous quartz-pebble conglomerates: unpub. PhD thesis, Dept. Geology, Univ. Wyoming, 85 p.

Graff, P.J., 1979, A review of the

stratigraphy and uranium potential of Early Proterozoic (Precambrian X) metasediments in the Sierra Madre, Wyoming: Univ. Wyoming, Contribs. to Geol., vol. 17, no. 2, p. 149-157.

Graff, P.J., Sears, J.W., and Holden G.S., 1980, the Uinta Arch Project - investigations of uranium potential in Precambrian and older metasedimentary rocks in the Uinta and Wasatch Ranges, Utah and Colorado: U.S. Dept. Energy, open-file rept. GJBX-179(80), 180 p.

Graff, P.J., Sears, J.W., and Holden, G.S., 1981, Investigation of uranium potential of Precambrian metasedimentary rocks, central Laramie Range, Wyoming: U.S. Dept. Energy, open-file rept. GJBX-22(81), 99 p.

Hagner, A.F., 1951, Anorthosite of the Laramie Range, Albany County, Wyoming, as a possible source of alumina: Geol. Survey Wyoming, Bull. 43, 15 p.

Hausel, W.D., 1980, Gold districts of Wyoming: Geol. Survey Wyoming, Rept. Invest. 23, 71 p.

Hausel, W.D., 1982, Ore deposits of Wyoming: Geol. Survey Wyoming, Prelim. Rept. 19, 39 p.

Hausel, W.D., Glahn, P.R., and Woodzick, T.L., 1981, Geological and geophysical investigations of kimberlites in the Laramie Range of southeastern Wyoming: Geol. Survey Wyoming, Prelim. Rept. 18, 13 p.

Hausel, W.D., McCallum, M.E., and Woodzick, T.L., 1979, Exploration for diamond-bearing kimberlite in Colorado and Wyoming: an evaluation of exploration techniques: Geol. Survey Wyoming, Rept. Invest. 19, 29 p.

Hills, F.A., and Armstrong, R.L., 1974, Geochronology of Precambrian rocks in the Laramie Range and implications for the tectonic framework of Precambrian in southern Wyoming: Precambrian Research, vol. 1, p. 213-225.

Hills, F.A., and Houston, R.S., 1979, Early Proterozoic tectonics of the central Rocky Mountains, North America: Univ. Wyoming, Contribs. to Geol., vol. 17, no. 2, p. 89-110.

Hodge, D.S., 1966, Petrology and structural geometry of Precambrian rocks in the Bluegrass area, Albany County, Wyoming: unpub. Ph.D. thesis, Dept. Geology, Univ. Wyoming, 135 p.

Holden, G.S., 1978, The Slate Creek metamorphic terrain, Albany County, Wyoming: conditions of metamorphism and mineral equilibria in metapelites: unpub. Ph.D. thesis, Dept. Geology, Univ. Wyoming, 95 p.

Houston, R.S., and Karlstrom, K.E., 1980, Uranium-bearing quartz-pebble conglomerates exploration model and United States resource potential: U.S. Dept. Energy, open-file rept. GJBX-1(80), 510 p.

Houston, R.S., and McCallum, M.E., 1961, Mullen Creek - Nash Fork shear zone, Medicine Bow Mountains, southeastern Wyoming (abs.): Geol. Soc. Amer., Spec. Paper 68, p. 91.

Houston, R.S., et al., 1968, A regional study of rocks of Precambrian age in that part of the Medicine Bow Mountains lying in southeastern Wyoming - with a chapter on the relationship between Precambrian and Laramide structure: Geol. Survey Wyoming, Mem. 1, 167 p.

Johnson, R.C., and Hills, F.A., 1976, Precambrian geochronology and geology of the Box Elder Canyon area, northern Laramie Range, Wyoming: Geol. Soc. Amer., Bull., vol. 87, p. 809-817.

Karlstrom, K.E., 1981, Late Archean and Early Proterozoic geologic history of metasedimentary rocks of the Medicine Bow Mountains, Wyoming: unpub. Ph.D. thesis, Dept. Geology, Univ. Wyoming, 183 p.

Karlstrom, K.E., 1979, The Wyoming Province: Univ. Wyoming, Contribs.

to Geol., vol. 17, no. 1, map.

McCallum, M.E., and Mabarak, C.D., 1976, Diamond in State-Line kimberlite diatremes, Albany County, Wyoming - Larimer County, Colorado: Geol. Survey Wyoming, Rept. Invest. 12 36 p.

MacGregor, A.M., 1951, Some milestones in the Precambrian of southern Africa: Proc. Geol. Soc. S. Afr., vol. 54, p. 27-71.

McGrew, L.W., 1967, Geologic map of the Natwick SW quadrangle, Platte County, Wyoming: U.S. Geol. Survey, GQ 623.

McGrew, L.W., 1967, Geologic map of the Natwick quadrangle, Platte County, Wyoming, U.S. Geol. Survey, GQ 624.

McGrew, L.W., 1967, Geologic map of the Richeau Hills quadrangle, Platte County, Wyoming: U.S. Geol. Survey GQ 625.

McGrew, L.W., 1967, Geologic map of the Squaw Rock quadrangle, Platte County, Wyoming: U.S. Geol. Survey, GQ-626.

Naeser, C.W., and McCallum M.E., 1977, Fission track dating of kimberlitic zircons (abs.): Extended Abstracts, Second Int'l Kimberlite Conf., Santa Fe, N.M., p. 242-245.

Osterwald, F.W., Osterwald, D.B., Long, J.S., Jr., and Wilson, W.H., 1966, Mineral resources of Wyoming: Geol. Survey Wyoming, Bull. 50, 287 p. (revised by W.H. Wilson).

Peterman, Z.E., and Hedge, C.E., 1968, Chronology of Precambrian events in the Front Range, Colorado: Canadian Jour. Earth Sci., vol. 5, p. 749-755.

Peterman, Z.E., Hedge, C.E., and Braddock, W.A., 1968, Age of Precambrian events in northeastern Front Range, Colorado: Jour. Geophys. Research, vol. 73, p. 2277-2296.

Peterman, Z.E., and Hildreth, R.A., 1977, Reconnaissance geology and geochronology of the Granite Mountains, Wyoming: U.S. Geol. Survey, open-file rept. 77-140, 86 p.

Smith, B.D., 1967, Geologic and geophysical investigation of an area of Precambrian rocks, central Laramie Range, Albany County, Wyoming: unpub. MS thesis, Dept. Geology, Univ. Wyoming, 104 p.

Snyder, G.L., 1980, Geologic map of the northernmost Park Range and southernmost Sierra Madre, Jackson and Routt Counties, Colorado: U.S. Geol. Survey, map I-1113.

Stuckless, J.S., 1979, Uranium and thorium concentrations in Precambrian granites as indicators of uranium province in central Wyoming: Univ. Wyoming, Contribs. to Geol., vol. 17, no. 2, p. 173-178.

Subbarayudu, G.V., 1975, The Rb-Sr isotopic composition and origin of the Laramie anorthosite-syenite complex, Laramie Range, Wyoming: unpub. PhD thesis, State Univ. New York (Buffalo), 109 p.

Thompson, A.B., 1976, Mineral reactions in pelitic rocks, Part II. Calculation of some P-T-X (Fe-Mg) phase relations: Amer. Jour. Sci., vol. 276, p. 425-454.

Toogood, D.J., 1967, Repeated folding in the Precambrian basement of the Laramie Mountains, Albany County, Wyoming: unpub. MS thesis, Dept. Geology, Univ. Wyoming, 165 p.

Viljoen, R.P., Sauger, R., and Viljoen, M.J., 1970, Some thoughts on the origin and processes responsible for the concentrations of gold in the early Precambrian of southern Africa: Minerala Deposita 5, p. 164-180.

Watson, J., 1976, Mineralization in Archaean provinces, *in* Windley, B.F., editor, The early history of the earth: New York, Wiley, p. 443-453.

Windley, B.F., 1977, The evolving continents: New York, Wiley, 385 p.

Windley, B.F., and Bridgwater, D., 1977, The evolution of Archean low- and high-grade terrains, *in* McCall, G.J.H., editor, The Archean: Stroudsburg, Pa., Dowden, Hutchinson, and Ross, 505 p.

STATE OF WYOMING

GEOLOGICAL SURVEY