New Stratigraphic Subdivisions and Redefinition of Subdivisions of Late Archean and Early Proterozoic Metasedimentary and Metavolcanic Rocks of the Sierra Madre and Medicine Bow Mountains, Southern Wyoming

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1520

Prepared in cooperation with the U.S. Department of Energy, Wyoming Geological Survey, and Geology Department of the University of Wyoming

New Stratigraphic Subdivisions and Redefinition of Subdivisions of Late Archean and Early Proterozoic Metasedimentary and Metavolcanic Rocks of the Sierra Madre and Medicine Bow Mountains, Southern Wyoming

By ROBERT S. HOUSTON, KARL E. KARLSTROM,
PAUL J. GRAFF, *and* ANDREW J. FLURKEY

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1520

Prepared in cooperation with the U.S. Department of Energy, Wyoming Geological Survey, and Geology Department of the University of Wyoming

Stratigraphic terminology and descriptions are presented for Late Archean and Early Proterozoic rocks of the Sierra Madre and Medicine Bow Mountains, southern Wyoming

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON: 1992

U.S. DEPARTMENT OF THE INTERIOR

MANUEL LUJAN, JR., *Secretary*

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, *Director*

Library of Congress Cataloging-in-Publication Data

New stratigraphic subdivisions and redefinition of subdivisions of late Archean and early Proterozoic metasedimentary and metavolcanic rocks of the Sierra Madre and Medicine Bow Mountains, southern Wyoming / by Robert S. Houston ... [et al.]
p. cm. — (U.S. Geological Survey professional paper ; 1520)
Includes bibliographical references.
Supt. of docs. no.: I 19.16 : 1520
1. Rocks, Metamorphic—Sierra Madre (Wyo. and Colo.) 2. Rocks, Metamorphic—Medicine Bow Mountains (Colo. and Wyo.) 3. Geology, Stratigraphic—Archaean. 4. Geology, Stratigraphic—Proterozoic. 5. Geology—Wyoming.
I. Houston, Robert Stroud. 1923– . II. Series.
QE475.A2N48 1991 91–9160
552′.4′097878—dc20 CIP

For sale by the Books and Open-File Report Sales, U.S. Geological Survey,
Federal Center, Box 25425, Denver, CO 80225

CONTENTS

ILLUSTRATIONS

TABLES

NEW STRATIGRAPHIC SUBDIVISIONS AND REDEFINITION OF SUBDIVISIONS OF LATE ARCHEAN AND EARLY PROTEROZOIC METASEDIMENTARY AND METAVOLCANIC ROCKS OF THE SIERRA MADRE AND MEDICINE BOW MOUNTAINS, SOUTHERN WYOMING

By ROBERT S. HOUSTON, KARL E. KARLSTROM, PAUL J. GRAFF, and ANDREW J. FLURKEY

ABSTRACT

Archean rocks of the Sierra Madre and Medicine Bow Mountains consist of a quartzo-feldspathic gneiss basement (more than 2,700 Ma) overlain by a thick succession of Late Archean supracrustal rocks. The oldest supracrustal rocks are the Vulcan Mountain Metavolcanics of the Sierra Madre and the Overland Creek Gneiss of the Medicine Bow Mountains. These units form small (4–14 km^2) areas of highly deformed, amphibolite-grade metavolcanic rocks that may represent parts of greenstone belts. These greenstone successions are overlain transitionally or are in fault contact with the Late Archean Phantom Lake Metamorphic Suite in both mountain ranges. This suite is isoclinally folded and of amphibolite grade. Stratigraphic reconstructions suggest that it is 2 km thick and contains about 60 percent metavolcanic rocks and 40 percent siliciclastic rocks, predominantly arkosic and quartz arenitic quartzites. The Phantom Lake Metamorphic Suite is transitional in character between Archean greenstone belts and Proterozoic-type platform successions. The Phantom Lake Suite is considered Late Archean because the lowest unit (Jack Creek Quartzite) is intruded by the 2,700-Ma (Rb-Sr whole-rock date) Spring Lake Granodiorite of the Sierra Madre. The Spring Lake Granodiorite intrudes the Vulcan Mountain Metavolcanics in two areas. In the northern Medicine Bow Mountains, undated granite that may correlate with either a 2,700-Ma (U-Pb zircon date) granitic orthogneiss of the Sierra Madre or the 2,450-Ma (U-Pb zircon date) Baggot Rocks Granite of the Medicine Bow Mountains intrudes both the Overland Creek Gneiss and Colberg Metavolcanics of the Phantom Lake Suite. We consider both of the Medicine Bow successions Late Archean because we correlate the Overland Creek Gneiss with the Vulcan Mountain Metavolcanics of the Sierra Madre and the Phantom Lake Suite of the Medicine Bow Mountains with the same suite in the Sierra Madre. The Phantom Lake Suite is formally subdivided into five formations in the Medicine Bow Mountains and three formations in the Sierra Madre.

The basal Phantom Lake Suite in the Sierra Madre, the Deep Gulch Conglomerate Member of the Jack Creek Quartzite, contains radioactive pyritic quartz-pebble conglomerates that are interpreted to be fluvial fossil placer deposits. Evidence for braided-stream deposition of the conglomerates and placers includes: (1) coarsening- and fining-upwards sequences with gravel lenses on scour surfaces; (2) low-amplitude trough crossbedding within gravel lenses; (3) associated lenticular matrix-supported conglomerate believed to represent alluvial-fan debris flows; and (4) association of heavy-mineral suites with gravel layers and scour surfaces. Principal radioactive heavy minerals of the conglomerates are monazite, huttonite, and zircon; the principal nonradioactive heavy mineral is pyrite. These deposits are thorium rich and not of economic importance at present.

Late Archean rocks in both mountain ranges are unconformably overlain by as much as 10 km of quartz-rich Early Proterozoic metasedimentary rocks: the Snowy Pass Supergroup in the Medicine Bow Mountains and the Snowy Pass Group in the Sierra Madre. New correlations and terminologies are suggested within and between these two sequences.

A rubidium-strontium whole-rock date of 1,900–2,150 Ma on the Gaps Intrusion gives a new minimum age for the Snowy Pass Supergroup. The dated outcrops intrude the Sugarloaf Quartzite of the lower part of the Libby Creek Group in the Medicine Bow Mountains. Felsic intrusions and gabbros that are believed to correlate with the Gaps Intrusion intrude the Copperton Formation of the middle part of the Snowy Pass Group in the Sierra Madre.

INTRODUCTION

The Sierra Madre and Medicine Bow Mountains of southern Wyoming have one of the most complete successions of Late Archean (2.8–2.5-Ga) and Early Proterozoic (2.5–1.7-Ga) metasedimentary and metavolcanic rocks in North America. Late Archean metasedimentary and metavolcanic rocks exceed 5,000 m in thickness, and Early Proterozoic metasedimentary rocks exceed 10,000 m in thickness. These rocks are exposed in the northern Sierra Madre in Tps. 14–16 N.,

Manuscript approved for publication, December 19, 1990.

Rs. 84–88 W., and in the northern Medicine Bow Mountains in Tps. 14–19 N., Rs. 77–81 W. (pl. 1).

The Late Archean and Early Proterozoic metasedimentary and metavolcanic rocks are either in fault contact or lie unconformably on an older quartzofeldspathic gneiss terrane that contains recognizable remnants of metasedimentary (quartzite and conglomerate) and metavolcanic rocks (basalt and mafic tuffs). Two largely metavolcanic successions have been defined that are believed to overlie this basement and that perhaps represent parts of greenstone belts. These successions are referred to as the Overland Creek Gneiss in the Medicine Bow Mountains and the Vulcan Mountain Metavolcanics in the Sierra Madre. The basement gneisses, Overland Creek Gneiss, and Vulcan Mountain Metavolcanics are believed to form the basement for a Late Archean volcano-sedimentary-rock succession named the Phantom Lake Metamorphic Suite. This suite is transitional in lithology between Archean greenstone-belt rock types and miogeoclinal-type metasedimentary rocks of the overlying Deep Lake and Libby Creek Groups, which are more characteristic of the Early Proterozoic. However, contacts between Archean units are poorly defined, and transitional relationships may exist between basement gneisses, some of the metavolcanic gneisses of the "greenstone belts," and metavolcanics of the Phantom Lake Suite.

The major emphasis of this report is the description and definition of the Archean Overland Creek Gneiss, Vulcan Mountain Metavolcanics, and Phantom Lake Metamorphic Suite. Early Proterozoic metasedimentary rocks of the Deep Lake Group (Karlstrom and Houston, 1979a, 1979b) and the Libby Creek Group (Houston and others, 1968; Lanthier, 1979) are discussed in less detail because these rocks have been described recently (Karlstrom and others, 1983). However, our latest mapping has resulted in some revision of terminology and areal distribution of the Deep Lake Group and Libby Creek Group, and these revisions are reviewed here.

The southern limit of the Archean gneiss terranes and Late Archean and Early Proterozoic supracrustal sequences in the Sierra Madre and Medicine Bow Mountains is the Cheyenne belt (Houston, Karlstrom, Hills, and Smithson, 1979), a zone of mylonitic rocks that trends northeast in the Medicine Bow Mountains and east-west in the Sierra Madre (pl. 1). This boundary forms part of the southern margin of the Archean Wyoming Province and was interpreted by Hills and Houston (1979) and Karlstrom, Houston, and others (1981) to be a suture separating cratonic rocks to the north from accreted 1,800- to 1,600-Ma island-arc materials to the south. There is no record of pre-1,900-Ma events in rocks south of the Cheyenne belt and, inasmuch as this report emphasizes Archean geologic history, those terranes are not considered in detail here.

ACKNOWLEDGMENTS

This manuscript has been improved substantially by careful technical reviews of George Snyder and Ogden Tweto.

HISTORY

This report is based on long-term studies of the Precambrian rocks of southern Wyoming sponsored by the Geological Survey of Wyoming (Houston and others, 1968) and on recent, more intensive stratigraphic and sedimentological studies sponsored by the U.S. Geological Survey and U.S. Department of Energy (Karlstrom, Houston, and others, 1981). The foundation for stratigraphy of Precambrian rocks in the Medicine Bow Mountains was established by Blackwelder (1926) and in the Sierra Madre by Spencer (1904). Contributors to studies of the Geological Survey of Wyoming include McCallum (1964), King (1963), and Childers (1957) in the Medicine Bow Mountains and Ebbett (1970), Short (1958), and Weid (1960) in the Sierra Madre. Contributors to the studies of the U.S. Geological Survey and U.S. Department of Energy are Karlstrom (1977) and Lanthier (1978) in the Medicine Bow Mountains and Graff (1978), Kratochvil (1981), and Gwinner (1979) in the Sierra Madre.

Studies sponsored by the U.S. Department of Energy were designed to evaluate the potential of Late Archean and Early Proterozoic metasedimentary sequences for uranium- and gold-bearing fossil placers of the type found in the Witwatersrand, South Africa, and at Elliott Lake, Ontario, Canada. Much of the stratigraphic information presented here is an outgrowth of the uranium investigations. Part of the uranium evaluation involved diamond drilling of favorable units to test uranium grades at depth. Drill-hole locations are shown on plate 1, and stratigraphic information from this drilling is incorporated into the following discussions.

Independent studies of the stratigraphy, petrology, geochemistry, and geochronology of rocks of the Sierra Madre were conducted by Divis (1976, 1977). Divis' map interpretations are contradicted by our mapping in three important respects. (1) He correlated the entire metasedimentary sequence north of the Cheyenne belt in the Sierra Madre with the Proterozoic Libby Creek Group of the Medicine Bow

Mountains. In contrast, we recognize in the Sierra Madre correlatives of the Archean Phantom Lake Metamorphic Suite, Early Proterozoic Deep Lake Group, and Early Proterozoic Libby Creek Group of the Medicine Bow Mountains. (2) He suggested that most of the Proterozoic terrane south of the Cheyenne belt (referred to as Big Creek Gneiss and Green Mountain Formation by Divis) was older than the metasedimentary section to the north. In contrast, new dates of 2,000 Ma on the Gaps Intrusion indicate that the Libby Creek Group is older than 2,000 Ma, whereas the oldest reliable date from the southern terrane is about 1,800 Ma (Hills and Houston 1979; Premo, 1983). In addition, samarium-neodymium isotope data suggest that the northern Colorado Precambrian terranes were derived from the mantle about 1,800 Ma without contamination from the older continental crust (De Paolo, 1981). (3) Divis interpreted the structure of the metasedimentary rocks as an overturned anticlinorium. We have mapped (Houston and Ebbett, 1977) a major overturned synclinorium in the Archean Phantom Lake Suite unconformably overlain by gently folded Proterozoic rocks in the west and steeply dipping homoclinal succession in the east (pl. 1).

Because of conflicting interpretations, we have not maintained Divis' terminology in our studies except in two instances: (1) we adopt his name "Bridger Peak Quartzite" for quartzites at Bridger Peak. However, we map extensions of those quartzites very differently because of varying structural interpretations; (2) we adopt the name "Slaughterhouse Marble," except that we designate the unit "Slaughterhouse Formation" in view of the presence of interbedded phyllites.

ROCKS OF ARCHEAN AGE

QUARTZO-FELDSPATHIC GNEISS

Characteristics of the Archean gneissic terrane of this area have been discussed in some detail in earlier papers (Houston and others, 1968; Houston and others, 1975; Divis, 1976). Here we describe only features of Archean basement rocks that are pertinent to our discussion of Late Archean metasedimentary and metavolcanic rocks.

The Archean gneiss terrane of the Sierra Madre and Medicine Bow Mountains crops out principally in the northern and eastern Sierra Madre and northwestern Medicine Bow Mountains (pl. 1). The quartzo-feldspathic gneisses range from distinctly layered biotite gneisses to massive quartzo-feldspathic gneisses. The quartzo-feldspathic gneiss probably includes both para- and orthogneiss, but the proportions of each are not known, and in many areas we cannot confidently distinguish gneissic basement rock from foliated Archean intrusions of the Spring Lake Granodiorite and red-pink orthogneiss (discussed later) that are known to crosscut the Archean supracrustal rocks. The chemical composition of the gneiss is poorly known, but two of three rock analyses of Divis (1976, p. 48) from the northern Sierra Madre are trondhjemitic. The age of quartzo-feldspathic gneiss has been shown to be Archean (Hills and others, 1968; Divis, 1976), with rubidium-strontium whole-rock dates ranging from 2,550±50 Ma to 2,630±100 Ma; these are probably minimum ages, almost certainly metamorphic, because Premo (1983) dated a red-pink orthogneiss that intrudes the quartzo-feldspathic gneiss of the Sierra Madre as 2,683±5 Ma by the uranium-lead zircon method. As noted by Hills and Houston (1979, p. 95), these Archean quartzo-feldspathic gneisses have been overprinted by at least two metamorphic or thermal episodes, about 1,700 Ma and about 1,400 Ma, so deciphering their Archean thermal history is difficult. Thus, the Early and Middle Archean history of the Medicine Bow Mountains and Sierra Madre remains somewhat obscure pending more detailed geologic and geochronologic studies of the gneiss terranes.

ROCKS OF LATE ARCHEAN AGE

VULCAN MOUNTAIN METAVOLCANICS

As named and defined here, the Vulcan Mountain Metavolcanics (unit Wv, pl. 1) include a highly deformed rock succession of amphibolite grade that consists primarily of metavolcanic rocks. This formation, named for Vulcan Mountain (pl. 1), crops out in the north-central Sierra Madre in a body that extends northwest from South Spring Creek Lake to Strawberry Creek roughly parallel to the East Fork Savery Creek (pl. 1, Tps. 14, 15 N., R. 86 W.). These exposures are designated the type area. The length of the outcrop is about 14 km, and the width is about 1 km (pl. 1).

Major rock types include fine-grained amphibolite, metabasalt, and hornblende gneiss, but quartzite, chlorite schist, and marble are also present. Excellent exposures of metavolcanic rocks are in N½ sec. 10, T. 14 N., R. 86 W., between South Spring Creek Lake and North Spring Creek Lake where some of the best-developed pillow basalts of either the Sierra Madre or Medicine Bow Mountains are preserved (fig. 1). Marble, quartzite, and schist are well exposed in a

FIGURE 1.—Two outcrops of pillow basalt of the Vulcan Mountain Metavolcanics near South Spring Creek Lake, sec. 10, T. 14 N., R. 86 W., Sierra Madre, Wyoming. Structures right side up.

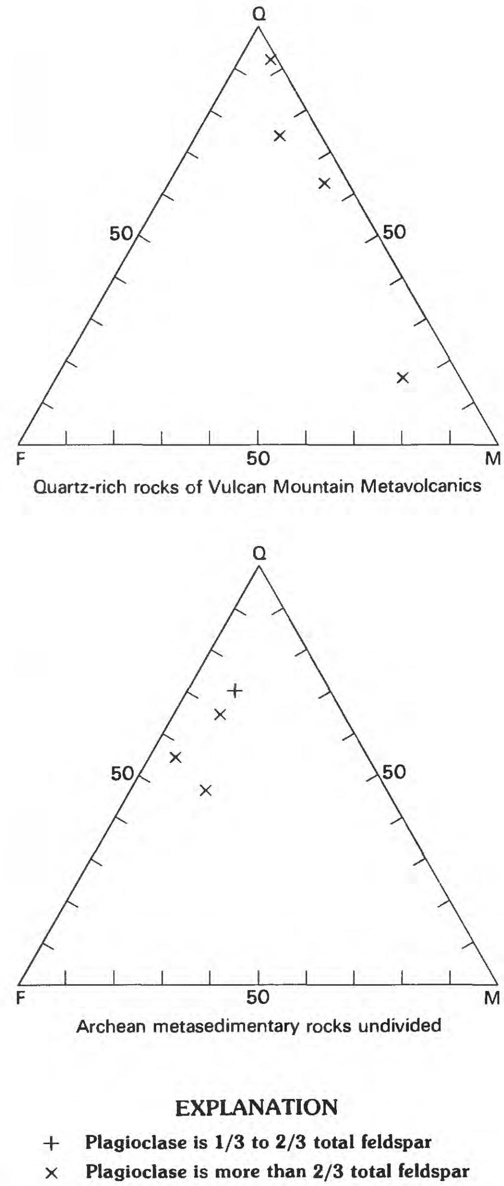


FIGURE 2.—Ternary diagrams showing the composition of Archean metasedimentary rocks, Sierra Madre, Wyoming. Method used from Folk (1968). Q, quartz; F, feldspar; M, mica plus chlorite.

cirque south of North Spring Creek Lake (sec. 4, T. 14 N., R. 86 W.). Pillow basalts and interbedded thin marbles suggest a subaqueous origin for at least part of the unit.

Petrographic data of several lithic types are given in table 1. The metabasalts (table 1) consist primarily of hornblende with minor quartz, plagioclase, and epidote. Two volcaniclastic samples contain approximately equal amounts of quartz and hornblende, suggesting derivation from mafic rocks or an intermediate composition source. Metasedimentary rocks include a biotite schist and subargillaceous quartzite (fig. 2). Feldspar is scarce in most rocks of this unit. The mineralogy of the samples reflect epidote-amphibolite to amphibolite facies of metamorphism (Miyashiro, 1973).

The Vulcan Mountain Metavolcanics are tightly folded, and fold shapes indicate a series of nappes whose axial surfaces strike northwest and dip 30°–50° SW. Younging criteria are uncommon in these rocks so that the stratigraphic succession is uncertain. We estimate a thickness of 360 m for the formation, but structural complexities make this figure highly questionable. Contacts with the underlying quartzo-feldspathic gneiss and the overlying Phantom Lake Metamorphic Suite are believed to be unconformities

TABLE 1.—*Modal compositions of samples of the Vulcan Mountain Metavolcanics, Sierra Madre, Wyoming*

[Modes, in percent, from visual estimates. Rock names are field classifications. Tr, trace; --, not determined. SM6 samples are from drill hole SM6, sec. 25, T. 15 N., R. 87 W. TS samples are surface samples from N½ sec. 10, T. 14 N., R. 86 W.]

Sample No.	Quartz	Plagioclase	Chlorite	Biotite	Muscovite	Epidote	Garnet	Opaque minerals	Carbonate	Hornblende	Sphene
Metabasalts											
TS241	15	1	--	3	--	5	--	--	--	75	1
TS245	17	5	Tr	--	--	10	--	1	2	65	--
TS183	5	10	Tr	--	--	--	--	--	--	85	--
Mean (3)	12	5	Tr	1	--	5	--	Tr	1	75	Tr
Volcaniclastic rocks											
SM6 (443.4)	40	2	1	20	--	--	1	--	2	34	--
TS184	44	5	5	3	--	--	1	2	--	40	--
Mean (2)	42	3.5	3	11.5	--	--	1	1	1	47	--
Metapelites and quartzites											
SM6 (458)	89	1	--	2	4	--	--	1	3	--	--
SM6 (530)	15	10	5	63	--		--	2	5	--	--
Mean (2)	52	6	2	32	2	--	--	2	4	--	--

or faulted unconformities, although contact relationships are poorly known because of poor exposure and the presence of mafic intrusive rocks occupying the contacts in some places.

The Vulcan Mountain Metavolcanics are Late Archean as indicated by intrusion by the 2,700-Ma Spring Lake Granodiorite (fig. 20).

OVERLAND CREEK GNEISS

A succession of hornblende and biotite gneisses that crop out over an area of 4 km^2 in the extreme northeast Medicine Bow Mountains is here named the "Overland Creek Gneiss" (unit Wo, pl. 1) after Overland Creek near the village of Arlington. The maximum mapped thickness of the gneiss is about 1,200 m. Stratigraphic thickness is unknown because of isoclinal folding in the exposed section and fault contacts with adjacent units. Outcrops near the junction of Overland and Rock Creeks, T. 19 N., R. 79 W., Carbon County, are designated the type area. Rocks of the Overland Creek Gneiss are nowhere in contact with the quartzofeldspathic gneiss terrane of the northwestern Medicine Bow Mountains, so age relationships between these units are uncertain. Contact relationships between the Overland Creek Gneiss and rocks of the Phantom Lake Metamorphic Suite are also poorly known; most contacts are either faults or are invaded by gabbroic sills. We interpret the Overland Creek Gneiss to be older than the Phantom Lake Suite because of its position in the core area of the refolded French Joe's anticlinorium and because it tends to be more highly deformed and metamorphosed than rocks of the Phantom Lake Suite. However, there are areas where lithologies appear to be transitional between the two sequences so that age relationships remain obscure.

The Overland Creek Gneiss is invaded by pink gneissic granite in the lower parts of Rock Creek, near Arlington (pl. 1). This granite is undated and may correlate with either the 2,700-Ma pink orthogneiss of Premo (1983) or the 2,430-Ma Baggot Rocks Granite of W.R. Premo (oral commun., 1985). We consider the Overland Creek Gneiss as Late Archean because we correlate it with the Vulcan Mountain Metavolcanics, which are intruded by the 2,700-Ma Spring Lake Granodiorite.

We interpret the hornblende gneiss and amphibolite as volcanic because of their mafic compositions and because a few outcrops of amphibolite have structures that resemble amygdules. Locally, the biotite gneiss is medium bedded and has layers of quartzite, matrix-supported conglomerate, and garnet schist (west side of Rock Creek near Arlington); we suggest that they are metagraywackes (turbidites).

Petrographic data from the Overland Creek Gneiss are summarized in table 2. Hornblende gneisses, which make up about 80 percent of the unit, are dominated by hornblende needles with interstitial quartz, plagioclase (An_{53}-An_{60}), and epidote (with or without sphene, chlorite, magnetite, and rutile). Garnet forms large porphyroblasts in some samples. Biotite gneisses (table 2) are dominated by plagioclase, quartz, biotite, and

TABLE 2.—*Modal compositions of samples of the Overland Creek Gneiss, Medicine Bow Mountains, Wyoming*

[Modes, in percent, for the first five samples are from point-counted thin sections from King (1963); other data from visual estimates. Tr, trace; --, not determined]

Sample No.	Amphibole	Quartz	Plagioclase	Epidote	Sphene	Opaque minerals	Garnet
K26	75.4	14.4	8.9	Tr	--	1.2	--
K52	85.0	3.9	5.2	4.9	Tr	Tr	--
K129	29.1	37.0	24.9	--	Tr	3.7	5.1
K141	74.0	6.8	12.0	3.0	4.2	Tr	--
K744	70.3	16.3	9.8	.3	Tr	3.3	--
K80–14	64	5	30	--	--	1	--
Mean	66.3	13.9	15.3	1.4	0.7	1.5	0.9

Sample No.	Plagioclase	Quartz	Biotite	Muscovite	Potassium feldspar	Chlorite	Kyanite	Apatite
K80–2*	41	31	8.4	17.7	--	1.3	0.5	Tr
K80–3*	48	35	13	--	4	Tr	--	--

*Biotite gneiss.

muscovite (with or without kyanite, chlorite, orthoclase, apatite, and magnetite) (King, 1963). The petrology is compatible with volcanic (basalt), plutonic (gabbro), and sedimentary or volcaniclastic (graywacke or tuff) protoliths, and all these rock types may be present in the unit. We suggest that the Overland Creek Gneiss may be a remnant of an Archean greenstone belt.

PHANTOM LAKE METAMORPHIC SUITE

A tentative definition of a succession of rocks referred to as the Phantom Lake Metamorphic Suite was made by Karlstrom and Houston (1979a, 1979b) for the Medicine Bow Mountains and by Graff (1979) for the Sierra Madre. The term was applied to a sequence of metasedimentary and metavolcanic rocks exposed in the vicinity of Phantom Lake in sec. 16, T. 16 N., R. 80 W., in the Medicine Bow Mountains. Here the sequence is overlain unconformably by rocks of the Early Proterozoic Deep Lake Group and was inferred to be younger than Archean basement rocks. More detailed mapping, and stratigraphic and sedimentological studies have allowed us to further refine this sequence. In this report we formally adopt the Phantom Lake Metamorphic Suite and define and name five lithostratigraphic subdivisions or formations in the Medicine Bow Mountains and three lithostratigraphic subdivisions or formations in the Sierra Madre. The various rock units are discussed below in inferred order of age. However, primary features indicating direction of stratigraphic younging are not well preserved in these rocks, and because of structural complexities, we are not completely confident of the age sequence.

PHANTOM LAKE METAMORPHIC SUITE OF THE MEDICINE BOW MOUNTAINS

In the northern Medicine Bow Mountains, rocks of the Phantom Lake Metamorphic Suite crop out in Tps. 17–19 N., Rs. 78–79 W. (pl. 1), where they are overlain unconformably by rocks of the Early Proterozoic Deep Lake Group. They also crop out in the core of anticlines near the center of T. 17 N., R. 79 W., and in the western part of T. 16 N., R. 80 W. (Arrastre anticline), northeast and south of Phantom Lake (pl. 1). The various lithologies of the Phantom Lake Metamorphic Suite can be best observed on a foot trail that follows Rock Creek from the vicinity of Arlington (T. 19 N., R. 79 W.) to a locality about 1 km south of the confluence of Rock Creek and Deep Creek where the rocks of the Phantom Lake Metamorphic Suite are overlain unconformably by basal beds of the Deep Lake Group. Rocks of the upper part of the Phantom Lake Metamorphic Suite can be best seen on a jeep trail that enters the Medicine Bow Mountains in S½ sec. 24, T. 19 N., R. 79 W., follows Overland Creek, and exits at the Sand Lake access road about 2½ km southwest of Colberg Cabin. The newly defined lithostratigraphic subdivisions of the Phantom Lake Metamorphic Suite, in probable order of decreasing age, are the Stud Creek metavolcaniclastics, Rock Mountain Conglomerate, Bow Quartzite, Colberg Metavolcanics, and Conical Peak

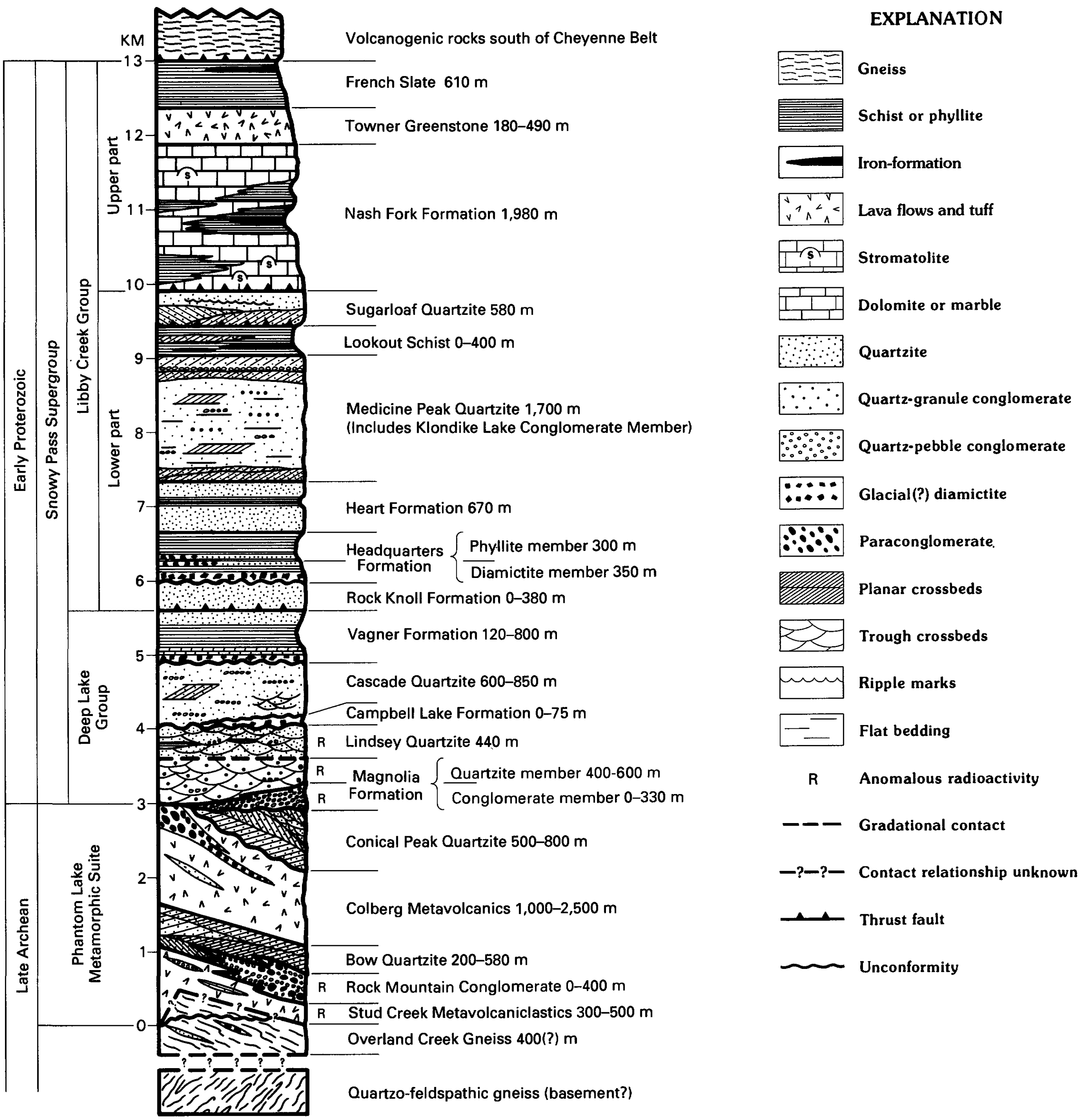


FIGURE 3.—Stratigraphic column showing lithology and thickness of metasedimentary rocks in the Medicine Bow Mountains, Wyoming.

Quartzite (fig. 3). An approximate maximum thickness for rocks of the Phantom Lake Metamorphic Suite in the Medicine Bow Mountains is 4,780 m. Rocks of the Phantom Lake Metamorphic Suite are isoclinally folded in much of their outcrop area following multiple episodes of folding (Karlstrom and Houston, 1979a, 1979b; Karlstrom and others, 1981). The rocks were metamorphosed to the amphibolite facies. They are of Late Archean age.

STUD CREEK METAVOLCANICLASTICS

The oldest known unit of the Phantom Lake Metamorphic Suite, here named the "Stud Creek Metavolcaniclastics" for Stud Creek, crops out in two localities

TABLE 3.—*Modal compositions of samples of the Stud Creek Metavolcaniclastics, Medicine Bow Mountains, Wyoming*

[Modes, in percent, for samples K325, K526, K537, K156, K700 are from point-counted thin sections from King (1963); other data from visual estimates. Tr, trace; --, not determined]

Sample No.	Quartz	Plagioclase	Amphibole	Epidote	Biotite	Muscovite	Calcite	Chlorite	Opaque minerals	Staurolite	Garnet	Hematite	Chloritoid
Pelitic schists—Northern area													
K325	26.9	--	--	10.6	34.2	--	26.5	--	Tr	--	--	--	--
K526	37.4	--	--	.3	24.9	32.3	2.6	--	2.1	--	--	--	--
K78–14	80.1	--	--	.4	7.4	9.6	1.4	--	1	--	--	--	--
K78–87	46	--	--	--	25	3	24	--	2	--	--	--	--
K78–88	27.6	51	--	Tr	16	9	--	--	1.4	--	--	--	--
K537	68.8	--	--	6.8	13	10.6	--	--	.8	--	--	--	--
Pelitic schists—Southern area													
K80–8	45	12	--	--	8	8	8	--	--	--	--	--	--
K80–10	55	--	--	14	12	5	4	--	Tr	5	--	--	--
K80–11	87	--	--	--	--	12	--	--	1	--	--	--	--
K78–5	47	50	Tr	--	--	--	--	2	1	--	--	--	--
K78–6	48	--	--	--	--	38	--	9	2	3	--	--	--
K78–7	44	--	--	--	Tr	56	--	Tr	Tr	--	--	--	--
Amphibole schists—Northern area													
K156	5	1.8	87.9	0.2	--	--	--	--	5.1	--	--	--	--
K157	19.7	13.9	55.8	4	--	--	--	0.2	6.4	--	--	--	--
K78–15	30	--	46	--	--	1	4	--	2	--	15	--	2
Amphibole schists—Southern area													
60–46	44	--	29	23	3	--	1	--	Tr	--	--	--	--
60–49	5	41	46	1	--	--	--	--	3	--	--	3	--
K700	15	--	54	30	--	--	1	--	--	--	--	--	--
K80–9	34	--	60	1	2	--	.5	0.5	2	--	--	--	--

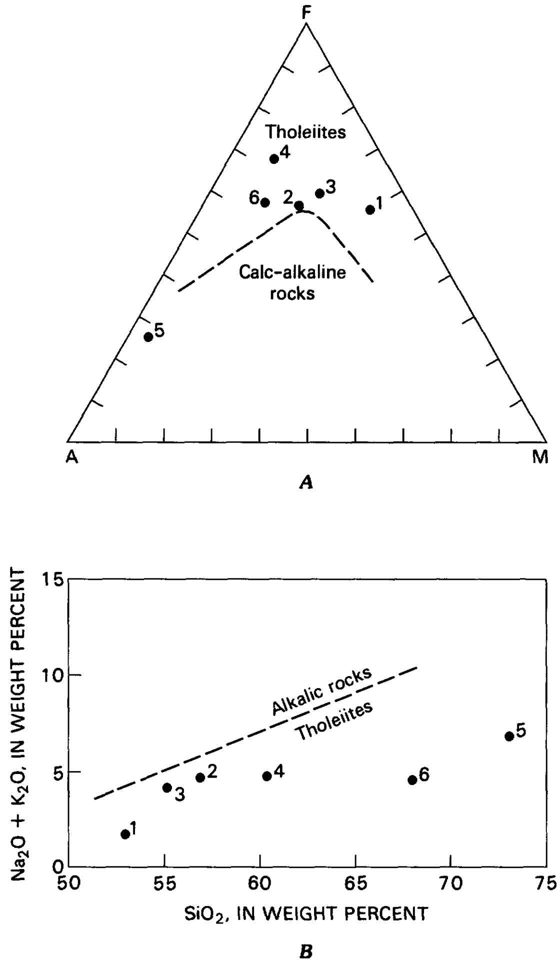


FIGURE 4.—Plots showing composition of metavolcanic rocks from the Stud Creek Metavolcaniclastics and Colberg Metavolcanics, Medicine Bow Mountains, Wyoming. A, A, (Na_2O+K_2O); F, (FeO+Fe_2O_3); M, MgO; tholeiitic-calc-alkaline trend line from Irvine and Baragar (1971). *B*, Tholeiitic-alkalic trend line from MacDonald (1968). Numbers refer to table 4.

in the core of a large overturned, doubly plunging anticlinorium, French Joe's anticlinorium (unit Ws, T. 18 N., R. 79 W., pl. 1) in the Medicine Bow Mountains. The northern outcrop area, centered near Rock Mountain (sec. 1, T. 18 N., R. 79 W.), is in the south-plunging part of the structure; the southern outcrop area, centered near Stud Creek (sec. 15, T. 18 N., R. 79 W.), is in the north-plunging and highly faulted part of the fold (pl. 1). The southern outcrop area is designated as the type area. Both outcrop areas are characterized by a heterogeneous assemblage of metavolcanic and metasedimentary rocks.

Petrographic data are summarized in table 3, and geochemical analysis of one metabasalt is given in table 4. In a general way, the wide variety of lithologies can be lumped into four groups: pelitic schists (50 percent), amphibolitic schists (30 percent), quartzites and conglomerates (20 percent), and calcareous rocks (local). Pelitic schists (table 3) are predominantly biotite- and muscovite-rich quartz schists, but there are also schists containing garnet, staurolite, chloritoid, or kyanite. Pelitic rocks were probably tuffs, graywackes, and volcanogenic shales. Amphibolite schists include plagioclase-rich varieties that were probably basalts and quartz-rich rock and include garnet amphibole quartz schist, which was probably mafic tuffs. One sample (table 4, no. 1) has the chemical composition of a tholeiitic basalt (fig. 4). Quartzites include fine-grained micaceous quartzites, fuchsitic quartzites, granule conglomerates, and quartz-rich schistose paraconglomerates. Both types of conglomerates are slightly radioactive in the southern outcrop area (twice background gamma radiation and as much as 21 ppm U; 29 ppm Th). Calcareous rocks range from impure marble to calcareous pelitic schist and are also radioactive in one isolated area (170 ppm U and 16 ppm Th in one locality near Rock Mountain).

Sedimentary features are poorly preserved in the quartzites, conglomerates, and calcareous rocks; bedding is only locally recognizable, and crossbeds were seen in only a few places. Rocks of the Stud Creek Metavolcaniclastics probably represent depositional environments ranging from fluvial (as suggested by radioactive conglomerates) to shallow marine (carbonates), but the large variability of rock types, rapid facies changes, the absence of thick and continuous layered graywackes, and the absence of pillow basalts suggest to us that subaerial deposition and volcanism may have predominated.

Stratigraphic relationships between facies within the Stud Creek Metavolcaniclastics and the overall thickness of the unit are difficult to interpret because of isoclinal folds, the inferred presence of large strike faults in the southern outcrop area, and the strong superposed folding in the northern outcrop area. Similarly, stratigraphic relationships with the underlying Overland Creek Gneiss and overlying Rock Mountain Conglomerate are complicated, and the contact with the Rock Mountain Conglomerate may be unconformable or it may be gradational. Nevertheless, we estimate a maximum exposed stratigraphic thickness ranging from 330 m (northern area) to 500 m (southern area).

ROCK MOUNTAIN CONGLOMERATE

The Rock Mountain Conglomerate, a newly designated unit, crops out on Rock Mountain and near the extreme northwestern limit of Precambrian

TABLE 4.—*Chemical analyses of samples of metabasalts and metatuffs from the Stud Creek Metavolcaniclastics and Colberg Metavolcanics, Medicine Bow Mountains, Wyoming*

[Analyses in percent except U_3O_8 and thorium, which are in parts per million. Analyzed by Steve Boese, University of Wyoming, 1979. < , less than; --, not determined]

	Metabasalts			Metatuffs		
	1	2	3	4	5	6
SiO_2	52.9	56.7	55.1	60.3	72.9	67.8
Al_2O_3	13.3	14.0	13.3	12.7	12.2	12.1
CaO	10.42	7.9	7.07	4.97	1.64	.48
Na_2O	1.61	4.43	3.97	4.28	6.80	4.25
K_2O	.14	.30	.20	.48	.10	.40
Fe_2O_3*	11.90	11.75	13.94	14.07	2.42	9.30
TiO_2	.9	1.0	1.0	1.0	.5	.7
MgO	7.44	4.11	5.38	2.19	.45	2.12
MnO	.19	.14	.19	.21	.06	.08
P_2O_5	.06	.17	.13	.13	.21	.21
Total	98.9	100.5	100.3	100.3	97.3	97.4
U_3O_8	0.1	0.6	0.8	2.2	3.7	2.5
Th	<5	<5	<5	<5	<5	5
Molecular norms*						
Q	12.07	4.64	3.57	13.20	27.61	31.65
Or	.85	1.80	1.20	2.90	.60	2.50
AB	5.85	39.95	39.95	39.30	62.35	40.00
AN	34.65	17.48	18.05	14.35	2.53	1.08
Hy	27.52	15.71	23.67	17.89	1.79	16.64
Di	15.36	16.66	13.25	8.06	3.54	--
MT	2.24	2.14	2.54	2.60	.44	1.76
IL	1.32	1.38	1.4	1.42	.72	1.02
AP	.13	.35	.27	.27	.43	.45
Co	--	--	--	--	--	4.9

*Fe^{+3}/Fe^{+2} approximated at 0.15 (from Cox and others, 1979).

SAMPLE DESCRIPTIONS

1. Sample SR0–25: Metabasalt, Stud Creek Metavolcanics; north side of Carlson Creek, NW¼ sec. 22, T. 18 N., R. 79 W.
2. Sample SR60–44: Andesitic basalt, Colberg Metavolcanics; 1,500 ft S. 15° E. of hill 8981, sec. 3, T. 18 N., R. 79 W.
3. Sample K78–99: Amygdaloidal andesitic basalt, Colberg Metavolcanics; northeast of Colberg Cabin; 1,400 ft south of hill 8981, SE¼ sec. 3, T. 18 N., R. 79 W.
4. Sample SR59–3: Andesitic basalt tuff, Colberg Metavolcanics; northeast of Arrastre Lake, SE¼NW¼ sec. 10, T. 16 N., R. 80 W.
5. Sample SR79–8: Rhyolitic tuff, Colberg Metavolcanics; east of Colberg Cabin at top of hill 9317, sec. 10, T. 18 N., R. 79 W.
6. Sample SR79–9: Rhydacitic tuff, Colberg Metavolcanics; same locality as SR79–8.

outcrop (unit Wr, secs. 27 and 33, T. 19 N., R. 79 W., pl. 1). The type locality is on the south and west sides of Rock Mountain. The unit is absent in the Stud Creek area as a continuous stratigraphic unit, although lithologically similar conglomerates occur as lenses within the Stud Creek Volcaniclastics. The conglomerates are locally anomalously radioactive in outcrop (20,000 counts per minute or five times local background and contain as much as 270 ppm U and 95 ppm Th) and were sampled extensively and drilled in two places near Rock Mountain to test their favorability as a uranium target. The results, discussed in detail in Karlstrom and others (1981), indicate that the unit contains thin, lenticular radioactive conglomerates but is not generally a favorable target for uranium.

Petrographic data for the Rock Mountain Conglomerate are summarized in table 5 and shown graphically in figure 5. The unit is predominantly granular to pebbly muscovitic quartzite and quartzose schist with paraconglomerate (matrix-supported conglomerate) beds ranging from less than a meter to several hundred meters in thickness. Paraconglomerates contain stretched clasts of quartz, quartzite, amphibolite, and schist in a strongly foliated quartz-muscovite (locally arkosic) matrix. Particularly striking are bright-green fuchsitic schist clasts. The paraconglomerate is locally garnetiferous. Contact relationships with the underlying Stud Creek Metavolcaniclastics are not exposed, but the conglomerates and quartzites in the two units are similar enough to suggest an intertonguing (or gradational) relationship.

TABLE 5.—*Modal compositions of samples of the Rock Mountain Conglomerate, Medicine Bow Mountains, Wyoming*

[Modes, in percent, for K240 are from point-counted thin sections from King (1963); other data are visual estimates. Tr, trace ; --, not determined]

Sample No.	Quartz	Muscovite	Potassium feldspar	Plagioclase	Opaque minerals	Garnet	Zircon	Biotite	Chlorite
				Rock Mountain area (eastern outcrop area)					
K240	56.6	21.8	0.1	25.1	0.2	--	--	--	--
MB15–498	72	25	--	--	3	--	--	--	--
MB15–600	65	32	2	--	1	--	--	--	--
MB15–750	52	28	--	18	2	--	--	--	--
MB15–775	68	30	--	2	Tr	--	--	--	--
MB15–825	68	20	--	11	1	--	--	--	--
K78–91	83	10	--	--	2	5	Tr	--	Tr
K78–92	47	46	--	--	1	--	Tr	--	6
K78–93	47	48	--	3	2	--	--	--	Tr
MB10–430	53	27	--	9	2	2	--	--	7
MB10–455	58	39	--	--	Tr	Tr	Tr	3	Tr
Mean	61	30	Tr	6	1	1	Tr	Tr	1
				Foote Creek area (western outcrop area)					
SR78–3	60	27	--	--	1	2	--	--	--
SR78–5	49	28	20	--	3	--	--	--	--
K80–5	65	33	--	--	--	2	--	--	--
SR78–16	37	4	16	40	3	--	--	Tr	Tr
SR78–17	40	--	8	30	Tr	--	--	22	Tr
SR78–18	25	--	--	12	3	([1])	--	--	--
Mean[2]	50	18	9	16	--	1	--	4	--
Grand mean	58	26	3	9	2	1	--	2	1

[1]Plus 60 percent amphibole.
[2]Without sample SR78–18.

The stratigraphic thickness of the Rock Mountain Conglomerate is estimated to be about 400 m in both outcrop areas.

The Rock Mountain Conglomerate was penetrated in two drill holes, MB10 and MB15, both near Rock Mountain (Karlstrom and others, 1981). In hole MB10 pebbly chlorite schist and poorly sorted sercitic quartzite of the uppermost Rock Mountain Conglomerate appears gradational with quartzites and thin conglomerates of the overlying Bow Quartzite. Hole MB15 penetrated 118 m of a coarsening-upwards succession ranging from poorly sorted quartzite at the base to paraconglomerate in the upper half. In general, the Rock Mountain Conglomerate coarsens to the east and upwards.

The lack of sedimentary structures in the Rock Mountain Conglomerate, poorly exposed contact relationships, and complex structure make interpreting the depositional environment difficult. However, we tentatively interpret the unit to be a prograding alluvial-fan deposit (Rust, 1979) on the basis of poor sorting, coarse grain sizes, coarsening-upwards successions, the presence of anomalously high radioactivity that may reflect fossil-placer accumulation of uranium- and thorium-bearing heavy minerals, and the limited lateral extent of the unit. The source was apparently a nearby, probably fault-bounded terrane containing metasedimentary and metavolcanic rocks such as are found in both the Stud Creek Volcaniclastics and the Overland Creek Gneiss.

BOW QUARTZITE

The Bow Quartzite, here named after the Bow Ranger Station (sec. 21, T. 18 N., R. 80 W., Medicine Bow Mountains), is a key unit in deciphering the stratigraphy and structure of the Phantom Lake Metamorphic Suite because it contains abundant planar crossbeds and some oscillation ripple marks that indicate the direction of stratigraphic top. The unit is well exposed throughout the northern Medicine Bow Mountains where it defines the limbs of French Joe's anticlinorium (T. 18 N., R. 79 W., pl. 1). Exposures of the Bow in T. 18 N., R. 79 W., in the extreme northern part of the Medicine Bow Mountains where it overlies the Rock Mountain Conglomerate, are designated the type locality.

Petrographic data from the Bow Quartzite are summarized in table 6 and figure 5. The unit contains quartzites (95 percent), quartz-pebble conglomerates

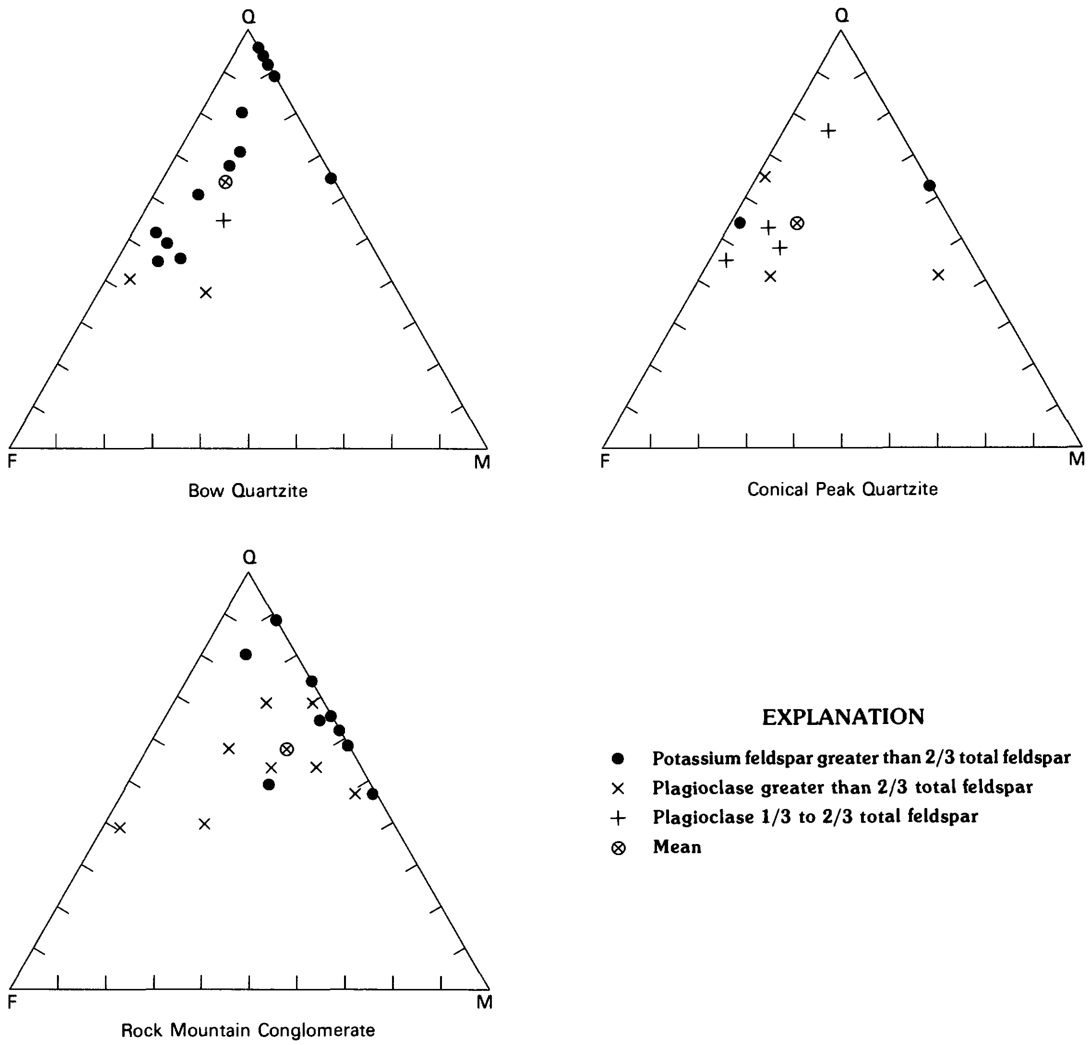


FIGURE 5.—Ternary diagrams showing composition of sand- and granule-size fractions of siliciclastic rocks of the Phantom Lake Metamorphic Suite, Sierra Madre and Medicine Bow Mountains, Wyoming. Modes from visual estimates. Q, quartz; F, feldspar; M, mica.

(local), biotite and hornblende schists and phyllites (local), and quartz-rich carbonates (local). The quartzites are mainly white, very fine grained to fine grained (average grain size 0.1–0.2 mm), foliated muscovitic arkoses and subarkoses. Some contain appreciable biotite and amphibole, and many contain zircon and altered opaque minerals (probably pyrite altered to hematite). The unit ranges from 200 to 580 m in thickness with an average thickness of about 350 m. The lower contact, with the Rock Mountain Conglomerate, is not exposed in the Rock Mountain area but appears to be gradational in drill hole MB10. In contrast, the contact in the extreme northwestern area of the Medicine Bow Mountains is sharp and apparently conformable.

The most prevalent sedimentary structures in the unit are medium- to large-scale planar crossbeds (amplitude about 0.5–1 m; mean inclination 23°). When combined for the entire unit (and after unfolding about statistically defined local fold axes), these crossbeds yield a bimodal paleocurrent distribution with a prominent mode directed southwest and a secondary mode directed northeast (Karlstrom and others, 1983). However, individual outcrop areas show distributions that are somewhat scattered but are dominated by one mode or the other. Several oscillation ripple marks in the unit confirm a bimodal current pattern but record east-west-directed currents. Multiple ripple sets in one outcrop show east-west- and north-south-directed current oscillations.

TABLE 6.—*Modal compositions of samples of the Bow Quartzite, Medicine Bow Mountains, Wyoming*

[Modes, in percent, from visual estimates. Tr, trace; --, not determined]

Sample No.	Quartz	Potassium feldspar	Plagioclase	Muscovite	Biotite	Chlorite	Amphibole	Opaque minerals	Zircon	Garnet	Calcite
Rock Creek area[1]											
60–53	80	11	--	7	1	--	--	1	--	--	--
SR78–7	50	42	--	6	2	--	--	Tr	Tr	Tr	Tr
K80–15	45	46	--	5	4	--	--	Tr	Tr	--	--
K80–16	33	--	--	--	5	--	60	2	--	--	Tr
K80–17	61	23	--	8	2	--	--	1	--	--	--
MB10–105	52	30	13	2	1	--	--	--	Tr	--	2
MB10–155	55	14	13	4	11	--	--	1	--	1	1
MB10–194	45	39	2	3	10	--	--	Tr	--	1	--
MB10–230	40	4	50	1	4	1	--	Tr	--	--	--
MB10–280	37	--	40	--	9	13	--	1	--	--	Tr
Mean	50	21	12	4	5	2	7	1	Tr	Tr	Tr
Carlson Creek area[2]											
K78–18	71	16	--	13	--	--	--	Tr	Tr	--	--
60–28	68	18	--	13	--	--	--	1	Tr	--	--
Mean	70	17	--	13	--	--	--	Tr	Tr	--	--
Arrastre Creek area[3]											
59–10	92	--	--	8	--	--	--	Tr	--	--	--
ACx	95	--	--	5	--	--	--	Tr	--	--	--
AC2	65	--	--	25	--	--	--	Tr	--	--	--
AC3	90	--	--	8	--	--	--	2	--	--	--
AC4	92	--	--	3	--	5	--	Tr	--	--	--
AC7	90	--	--	10	--	--	--	Tr	--	--	--
Mean	87	--	--	10	--	1	--	Tr	--	--	--
Grand mean	64	14	7	7	3	1	4	Tr	Tr	Tr	Tr

[1]Northern area, T. 18–19 N. Mean grain size 0.2 mm.
[2]T. 17 N., R. 79 W. Mean grain size 0.15 mm.
[3]T. 16 N., R. 80 W. Mean grainsize 0.13 mm.

We interpret most of the Bow Quartzite to have been shallow marine sediments. The generally fine grain sizes suggest low-energy deposition, large-scale planar crossbeds may represent sand waves, and the bimodal paleocurrent distribution probably represents ebb and flood tides. These data are compatible with the interpretation of a tidally influenced deltaic depositional environment for the unit. We envision a river-fed embayment or estuarine location for deposition of the Bow Quartzite sediments with early, fluvial deposition of the Rock Mountain Conglomerate in the northeastern area, close to a tectonically active highlands, changing to marine deposition to the south and higher in the section. The source area was contributing mainly sedimentary and volcanic detritus during deposition of the Rock Mountain Conglomerate, but appreciable potassium feldspar in the Bow Quartzite suggests that granitic rocks also contributed detritus during its deposition. Thus, the source area probably consisted of Archean granitic gneisses and older metasedimentary and metavolcanic rocks.

COLBERG METAVOLCANICS

The Colberg Metavolcanics, named in this report after the old townsite of Colberg (location of Colberg Cabin, pl. 1), include a heterogeneous assemblage of metavolcanic rocks including: amygdaloidal metabasalts (fig. 6), a few poorly preserved pillow basalts, volcaniclastic schists, fragmental metavolcanic rocks ranging in composition from rhyolitic to basaltic, paraconglomerates, and thin quartzites. The unit crops out in large areas of the northern Medicine Bow Mountains (unit Wc, Tps. 16–19 N., Rs. 78–80 W., pl. 1). The type locality is east of Colberg Cabin, sec. 10, T. 18 N., R. 79 W. The most distinctive units within the Colberg Metavolcanics are the paraconglomerates (fig. 7), which are composed of varying proportions of rounded granite boulders (as large as about 50 cm in diameter), quartzite boulders, and stretched mafic volcanic-rock clasts in an amphibole, biotite, and quartz matrix. The paraconglomerate unit has a stratigraphic thickness as great as about 400 m, within which the conglomerates themselves are complexly interbedded with volcanic rocks and quartzites. The entire Colberg Metavolcanics unit ranges in thickness from a feather edge in the northwest part of the Medicine Bow Mountains to a mapped thickness of 2,500 m in the north-central part of the mountains. Contacts with the overlying Conical Peak Quartzite and the underlying Bow Quartzite are interpreted as conformable but are not well exposed.

Petrographic data from the Colberg Metavolcanics are shown in table 7. Fine-grained amphibolites, which were mapped as metabasalt because of their massive character and local presence of amygdules, show a wide compositional range including: plagioclase-amphibole rocks that were probably basaltic and basaltic andesite flows (the Arrastre Lake area); quartz-rich amphibolites that probably represent reworked mafic to andesitic tuffs (the northern area); and amphibole- and biotite-rich quartzites that were probably metagraywackes (west of Rock Creek). Basaltic rocks locally contain amygdules filled with quartz, epidote, clinozoisite, or calcite (fig. 6). Paraconglomerate and schistose units commonly contain garnet. Plagioclase compositions determined by King (1963) on samples from the northern area range from An_{49} to An_{58} (the mean of seven samples was An_{54}).

Chemical compositions of metabasalts and metatuffs from the Colberg Metavolcanics are shown in table 4. Sample 1, from the Stud Creek Metavolcaniclastics, is a low-potassium basaltic andesite. Samples 2 and 3 are low-potassium andesite and low-potassium basaltic andesite, respectively. The tuffs range in composition from low-potassium andesite (sample 4) to low-potassium rhyodacite (sample 6) and low-potassium rhyolite (sample 5). An AFM plot (fig. 4) of the samples shows an iron-enrichment trend characteristic of tholeiitic magmas (Irvine and Baragar, 1971), except that sample 5 is anomalously high in sodium and deficient in magnesium and iron. All six samples fall in the tholeiitic field in alkali-silica plots (fig. 4) (MacDonald, 1968).

The depositional history of the Colberg Metavolcanics is not well known. We interpret the unit to be partly marine because it contains quartzites that we interpret as marine on the basis of textural and structural evidence directly above and below the unit. However, we have found very few pillow basalts and this fact, combined with the wide variety of lithologies and rapid facies changes in the unit, seems more compatible with subaerial volcanism and volcaniclastic deposition. The depositional environment of the paraconglomerate provides an interesting and unsolved problem. We envision deposition of the Colberg paraconglomerate to have taken place in alluvial or possibly submarine channels and fans that developed adjacent to fault scarps bounding volcanic highlands. If so, the Colberg Metavolcanics may contain complexly interbedded subaerial and submarine rocks.

CONICAL PEAK QUARTZITE

The Conical Peak Quartzite (unit Wcp, pl. 1), a new unit named after Conical Peak (sec. 4, T. 18 N., R. 79 W., pl. 1) is the youngest unit in the Phantom Lake Metamorphic Suite in the Medicine Bow Mountains. It occupies the core of the Foote Creek syncline in the

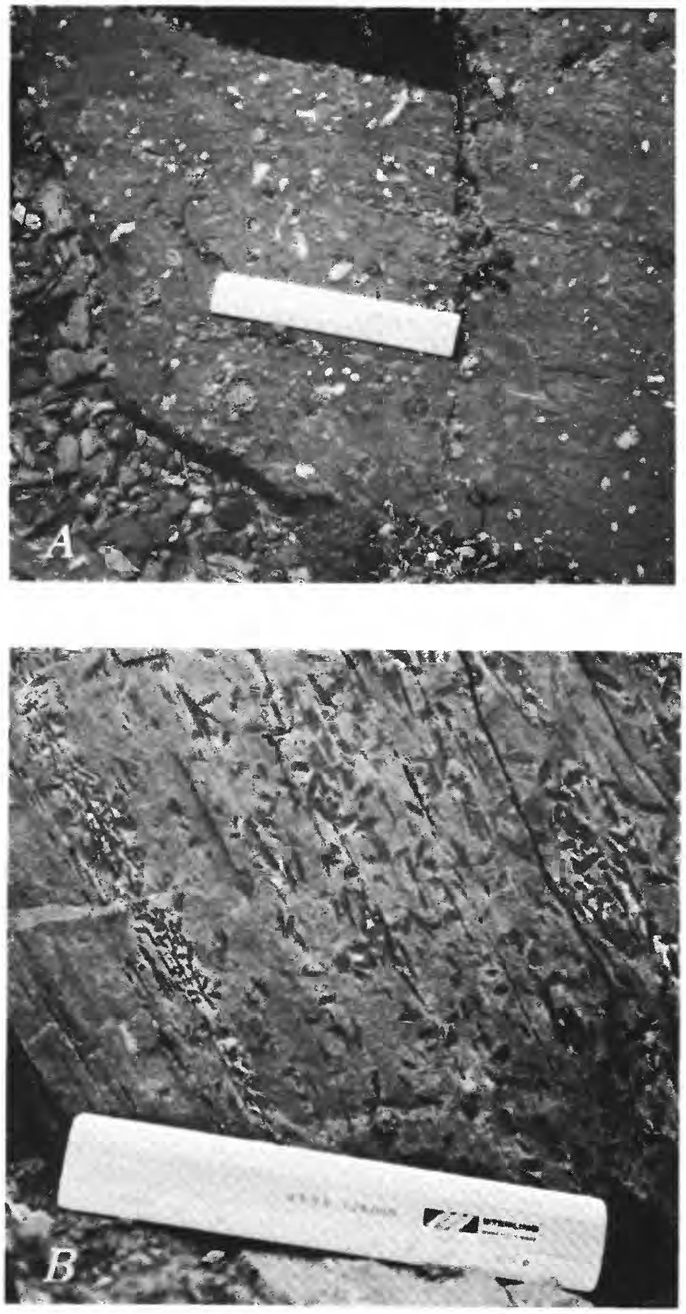


FIGURE 6.—Colberg Metavolcanics, Medicine Bow Mountains, Wyoming. *A*, Amygdules of quartz, with minor epidote and clinozoisite, in metabasalt, S½ sec. 10, T. 18 N., R. 79 W. *B*, Amphibole schist from Rock Creek trail, about 1,000 m upstream from the confluence of Rock Creek and Deep Creek. Rulers are 7 in. long.

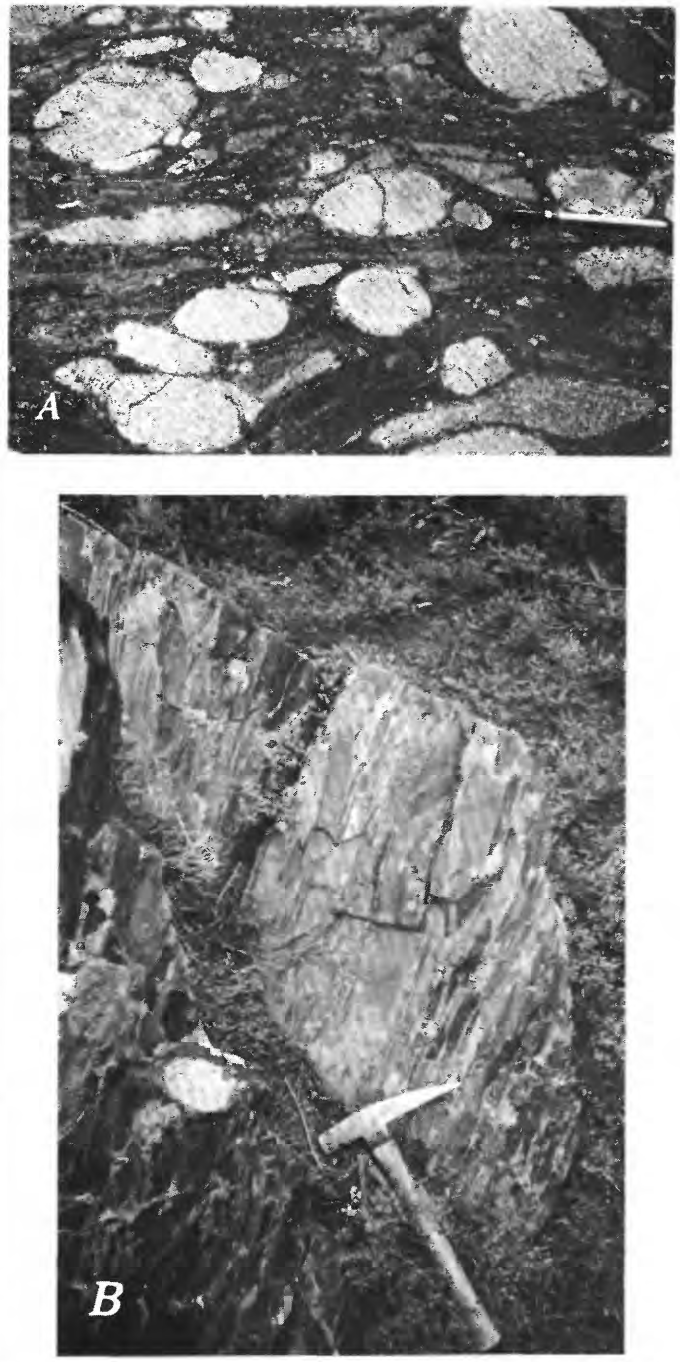


FIGURE 7.—Paraconglomerate from the Colberg Metavolcanics, T. 18 N., R. 79 W., Medicine Bow Mountains, Wyoming. *A*, Granite-boulder paraconglomerate from sec. 25; note that granite boulders are relatively undeformed, and mafic schist clasts are strongly stretched parallel to foliation. *B*, Paraconglomerate dominated by basaltic clasts; from sec. 24.

northern Medicine Bow Mountains and unconformably underlies the Magnolia Formation of the Deep Lake Group in the northeastern and central parts of the Medicine Bow Mountains (pl. 1). The type locality is in the core of the Foote Creek syncline, Tps. 18 and 19 N., R. 79 W. Like the Bow Quartzite, crossbeds in the Conical Peak Quartzite provide key information for stratigraphic and structural interpretations of the Phantom Lake Suite. The predominant lithology is white, foliated, fine-grained micaceous subarkose. The unit also contains some calcareous quartzite near the North Fork of Rock Creek. Metabasalts that crop out

TABLE 7.—*Modal compositions of samples of the Colberg Metavolcanics, Medicine Bow Mountains, Wyoming*

[Modes, in percent, for samples K336, K348, K402, K406, K413, K419 are from point-counted thin sections from King (1963); other data are from visual estimates. Tr, trace; --, not determined; Do., ditto]

Sample No.	Amphibolite	Plagioclase	Quartz	Biotite	Epidote	Opaque minerals	Sphene	Garnet	Muscovite	Zircon	Probable protolith
					Northern area						
K336	52.5	--	20.1	19.9	7.5	--	--	--	--	--	Mafic tuff
K348	64.5	4.8	26.8	--	1.1	2.7	--	--	--	--	Do.
K402	78.2	6.2	12.8	--	1.7	1.2	--	--	--	--	Basalt or tuff.
K406	38.1	7.4	24.5	19.0	9.0	--	0.7	--	--	--	Mafic tuff.
K413	75.8	11.9	5.3	--	4.5	1.6	.9	--	--	--	Basalt.
K419	89.0	.5	8.1	--	.8	1.7	--	--	--	--	Basalt or tuff.
K80–12	--	--	46	7	--	--	--	--	47	Tr	Graywacke.
					Rock Creek area						
SR78–26A	55	20	20	--	5	Tr	--	--	--	--	Amygdaloidal basalt.
SR78–26B	10	--	55	35	Tr	--	--	--	--	--	Graywacke.
SR78–27	--	2	84	--	--	3	--	--	3	(1)	Subarkose.
K78–80	--	--	67	5	--	--	--	--	28	--	Immature sandstone.
K78–83	50	20	25	--	5	--	--	--	--	--	Amygdaloidal basalt.
K78–84	--	--	60	10	--	2	--	3	25	--	Immature sandstone.
					Arastre Lake area						
TS57B	--	65	10	35	--	Tr	--	5	--	--	Amygdaloidal basalt.
TS57C	30	55	10	--	--	5	--	--	(2)	--	Basalt.
TS84	9	72	10	7	--	2	--	--	--	--	Amygdaloidal basalt.
TS95	18	64	--	--	5	3	--	--	(3)	--	Do.
TS151	25	66	--	5	3	1	--	T	(2)	--	Basalt.
Mean of 10 samples of metabasalt.[4,5]	60	8	16	Tr	Tr	Tr	3	--	--	--	
Mean of 4 samples of metatuff (?).[4,6]	Tr	7	35	Tr	Tr	3	Tr	Tr	13	--	

[1]Plus 3 percent.
[2]Plus apatite.
[3]Plus 10 percent calcite.
[4]From Houston and others (1968).
[5]Plus 6 percent calcite.
[6]Plus 26 percent chlorite.

TABLE 8.—*Modal compositions of samples of the Conical Peak Quartzite, Medicine Bow Mountains, Wyoming*

[Modes, in percent, from visual estimates. Tr, trace; --, not determined]

Sample No.	Quartz	Potassium feldspar	Plagioclase	Muscovite	Biotite	Opaque minerals	Zircon	Calcite	Garnet
				Conical Peak area[1]					
59–43	76	7	7	9	--	Tr	--	--	Tr
				Onemile Creek area[2]					
K289	53	45	--	1	Tr	1	Tr	--	--
K290	41	1.5	7	50	--	Tr	--	--	--
				North Fork Rock Creek area[3]					
60–9	65	8	25	2	--	--	--	--	--
				Medicine Bow River area[4]					
60–32	62	--	--	36	--	2	--	--	--
SR78–40	40	28	17	9	3	2	1	--	--
SR78–41	48	19	19	9	3	2	Tr	5	--
MB13–146.2	49	26	11	5	2	2	Tr	5	--
MB13–380	45	30	21	--	3	1	--	--	--
Mean	53	18	12	13	1	1	T	1	--

[1]T. 18 N., R. 79 W. Mean grain size 0.1 mm.
[2]T. 18 N., R. 78 W. Mean grain size 0.2 mm.
[3]T. 17 N., R. 79 W. Mean grain size 0.1 mm.
[4]N½ T. 17 N., Rs. 79–80 W. Mean grain size 0.2 mm.

above quartzites of the Conical Peak near North Fork Rock Creek are also considered part of the Conical Peak Quartzite. The Conical Peak Quartzite lies conformably on the rocks of the Colberg Metavolcanics.

Petrographic data for the Conical Peak Quartzite are summarized in table 8 and figure 5. The quartzites are very similar to those of the underlying Bow Quartzite in grain size (uniformly very fine to fine) but differ compositionally by having more plagioclase in the mode (table 8) and somewhat more potassium feldspar (fig. 5).

One possibility for the additional plagioclase is that the Conical Peak Quartzite was derived from reworking of Bow Quartzite sediments with the addition of detrital plagioclase from the underlying Colberg Metavolcanics. If so, a disconformity may be between the Colberg Metavolcanics and the Conical Peak Quartzite, a relationship that is also suggested by drastic thickness changes in the Colberg Metavolcanics in the northern Medicine Bow Mountains. The maximum exposed stratigraphic thickness of the Conical Peak Quartzite is about 800 m.

Crossbedding in the Conical Peak Quartzite (fig. 8) is mainly large scale and planar (amplitude about 1 m; mean inclination 22.6°), but trough crossbeds are also present near Onemile Creek and the Medicine Bow River. The paleocurrent distribution measured for the entire unit shows a bimodal distribution with currents directed northeast and southwest (Karlstrom and others, 1983). These modes are interpreted to represent ebb and flood currents in a shallow-marine depositional environment. The unit is similar to the underlying Bow Quartzite, and we interpret it to be marine for many of the same reasons: fine grain sizes, large-scale planar crossbeds, and bimodal paleocurrents.

PHANTOM LAKE METAMORPHIC SUITE OF THE SIERRA MADRE

Rocks of the Phantom Lake Metamorphic Suite (fig. 9) underlie a greater area in the Sierra Madre than in the Medicine Bow Mountains. They crop out in S½ T. 16 N., R. 87 W., and N½ T. 15 N., R. 87 W., and extend from the vicinity of Dexter Peak (sec. 21, T. 15 N., R. 87 W.) east to sec. 25, T. 14 N., R. 84 W., in a roughly east-west belt of outcrops (pl. 1). The Phantom Lake Metamorphic Suite is tectonically thinned from west to east and is reduced from an outcrop width of approximately 8 km in the west to a feather edge in the east. Some of the best exposures of basal beds of the Phantom Lake Metamorphic Suite are in the northwestern Sierra Madre in sec. 7, T. 15 N., R. 87 W., on the north side of East Fork Savery Creek. The best exposures of beds of the middle and upper part of the suite are in cirques north and south of Bridger Peak (sec. 14, T. 14 N., R. 86 W., pl. 1) in the north-central Sierra Madre. Rocks of the Phantom Lake Metamorphic Suite exceed 2 km in thickness in the Sierra Madre.

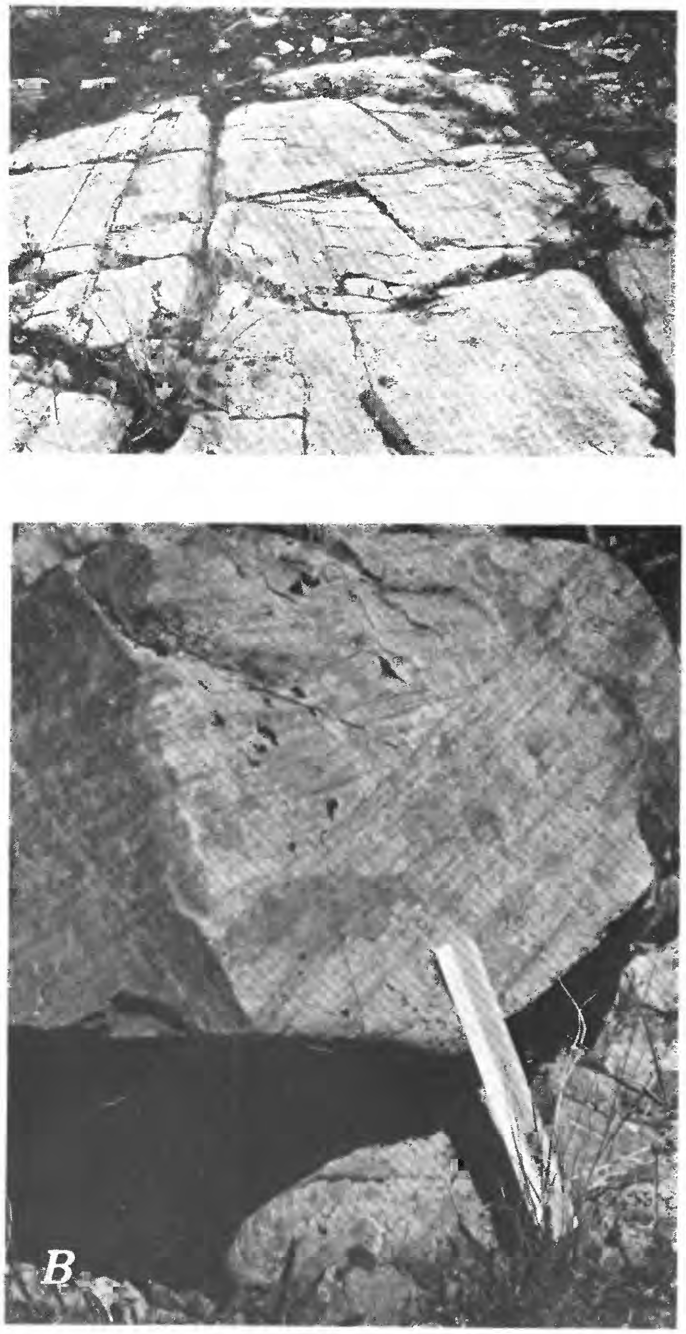


FIGURE 8.—Conical Peak Quartzite, Medicine Bow Mountains, Wyoming. *A*, 1.5-m-thick planar crossbed set is truncated by overlying phyllite layer (right) and is tangential to underlying phyllite layer (left); hammer handle is subparallel to foresets; from sec. 11, T. 17 N., R. 80 W. *B*, Large-scale inverted trough crossbedding near Conical Peak; sec. 4, T. 18 N., R. 79 W.

Rocks of the Phantom Lake Metamorphic Suite in the Sierra Madre are similar to those in the Medicine Bow Mountains except that metavolcanic rocks (especially metabasalts and tuffs) are less abundant in the Sierra Madre, and metagraywacke and volcaniclastic rocks are more abundant (fig. 9).

The Phantom Lake Metamorphic Suite is in recumbent folds and nappes and has been subjected to several episodes of deformation, as in the Medicine Bow Mountains. Preservation of younging criteria is variable, so the known stratigraphic order of beds in the succession is not definite. From the available criteria on tops of beds and mapping data, a large recumbent syncline (the Divide Peak synclinorium) has been defined in the Phantom Lake Metamorphic Suite (pl. 1). Three lithostratigraphic units defined in this report, in *probable* order of age from oldest, are: Jack Creek Quartzite, Silver Lake Metavolcanics, and Bridger Peak Quartzite.

JACK CREEK QUARTZITE

The Jack Creek Quartzite (unit Wj, pl. 1), modified from the Jack Creek Formation of Graff (1978), is named after Jack Creek in the northern Sierra Madre. It is herein defined to include all the metasedimentary rocks above the Vulcan Mountain Metavolcanics at the base of the Phantom Lake Metamorphic Suite (beneath the Silver Lake Metavolcanics). It consists predominantly of white quartzite but contains lenses of gray and green phyllite, marble, paraconglomerate, quartz-pebble conglomerate, and metagraywacke. The Deep Gulch Conglomerate Member is a newly named pyritic and radioactive quartz-pebble conglomerate that is present at the base of the Jack Creek Quartzite. This member is exposed on the west and north edges of the Divide Peak synclinorium (pl. 1) and is discussed in detail below. The Deep Gulch Conglomerate Member is of particular interest because it contains the richest fossil-placer deposits of uranium and thorium found to date in the Archean sequences of southern Wyoming and because it forms the base of one of the most continuous stratigraphic successions in the Phantom Lake Suite. Excellent exposures of the upper parts of the Jack Creek Quartzite can be found in the canyon of Jack Creek and the cirque above North Spring Creek Lake (secs. 5, 8, and 9, T. 14 N., R. 86 W.). A measured section (fig. 10) from the Carrico Ranch area (sec. 7, T. 15 N., R. 87 W.) is defined as the type section of the Jack Creek Quartzite. Because of faulting, this is probably not a complete section. Drill holes JP1, JP2, JP3, JP4, SM1, SM1A, SM2, SM2D, and SM3 intersected the Deep Gulch Conglomerate Member of the Jack Creek Quartzite (E½ T. 15 N., R. 87 W., pl. 1). Drill-holes SM4A and SM4B (we believe) intersected the upper contact of the Jack Creek Quartzite (center T. 15 N., R. 87 W., pl. 1). The Jack Creek Quartzite, including the Deep Gulch Conglomerate Member, averages about 700 m thick in the Divide Peak syn-

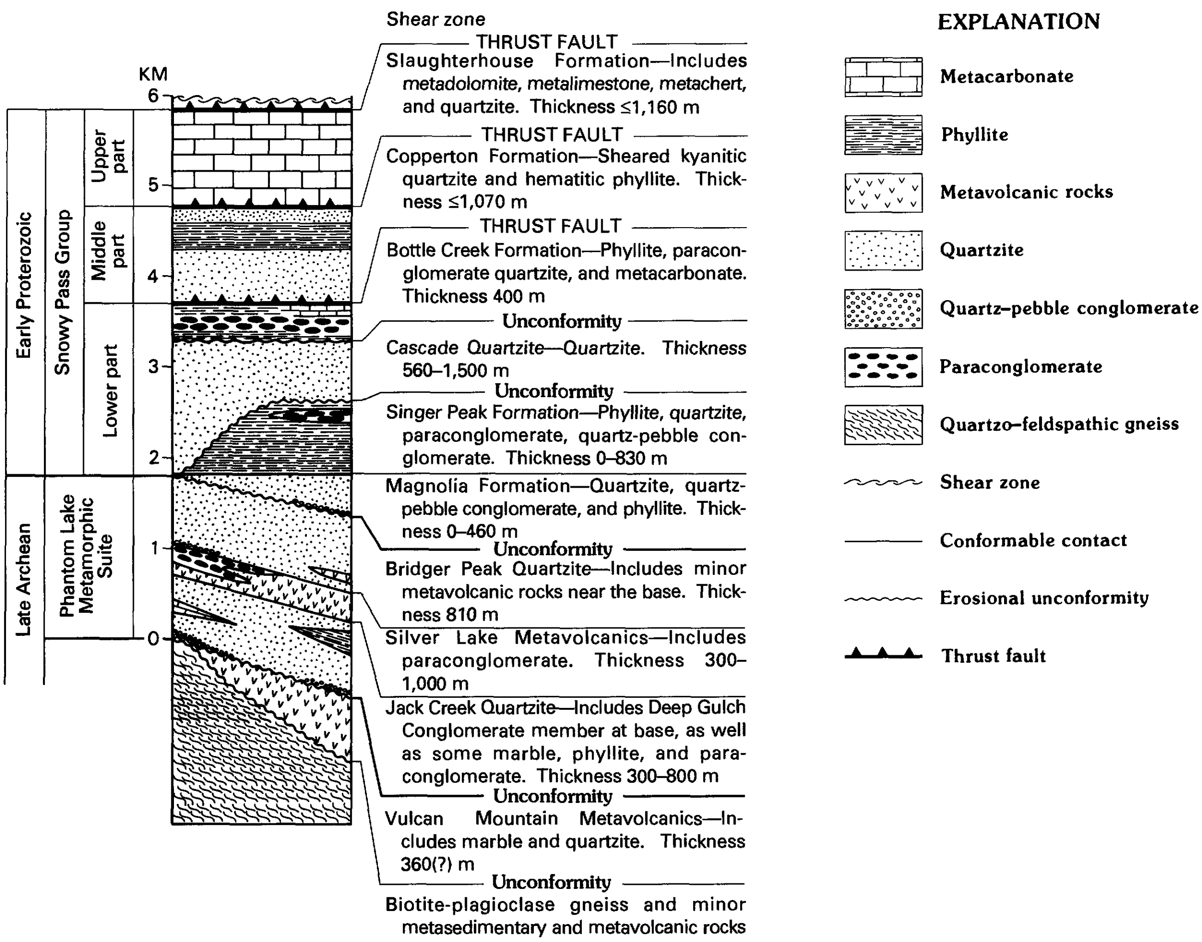


FIGURE 9.—Generalized stratigraphic column for Precambrian rocks in the Sierra Madre, Wyoming.

clinorium (pl. 1). It is about 300 m thick near South Spring Creek Lake.

DEEP GULCH CONGLOMERATE MEMBER

The basal 110 m of the Jack Creek Quartzite in the northwestern Sierra Madre, recognized at Dexter Peak, Carrico Ranch, and Deep Gulch, and in exposures northeast of Deep Gulch (pl. 1), is herein defined as the Deep Gulch Conglomerate Member. This distinctive lithologic unit has been divided into three units that can be recognized in most outcrops of the Carrico Ranch area and at Deep Gulch, where the Deep Gulch Conglomerate Member is best exposed. The type section (fig. 11) is near Carrico Ranch, NE¼ sec. 12, T. 15 N., R. 88 W.

The lower unit (unit 1, fig. 11) is an arkose that is medium to coarse grained and poorly sorted, and is interbedded with muscovite-rich arkose, thin quartz-pebble conglomerate layers, and thin arkosic conglomerate layers. The arkosic conglomerate layers of unit 1 contain abundant granite clasts and angular potassium-feldspar pebbles. Both the arkosic conglomerate and quartz-pebble conglomerate layers are slightly radioactive (2–3 times background). Unit 1 is overlain by arkose and subarkose of unit 2, which is coarse grained and rich in muscovite. The arkose and subarkose contain well-developed small-scale trough crossbeds and lenticular beds of quartz-granule conglomerate, quartz-pebble conglomerate, and arkosic conglomerate. These conglomerates are also slightly radioactive (2–5 times background). Unit 3, the upper unit, contains pyritic and radioactive quartz-pebble conglomerates (as high as 60 times background) interbedded with granular to pebbly subarkosic quartzites. These conglomerates in unit 3 are at the base of the fining-upward stratification sequences and pass upsection into coarse-grained subarkose having well-developed trough and planar crossbeds. Beds of quartz-pebble conglomerate are 17 to 55 cm thick (fig.

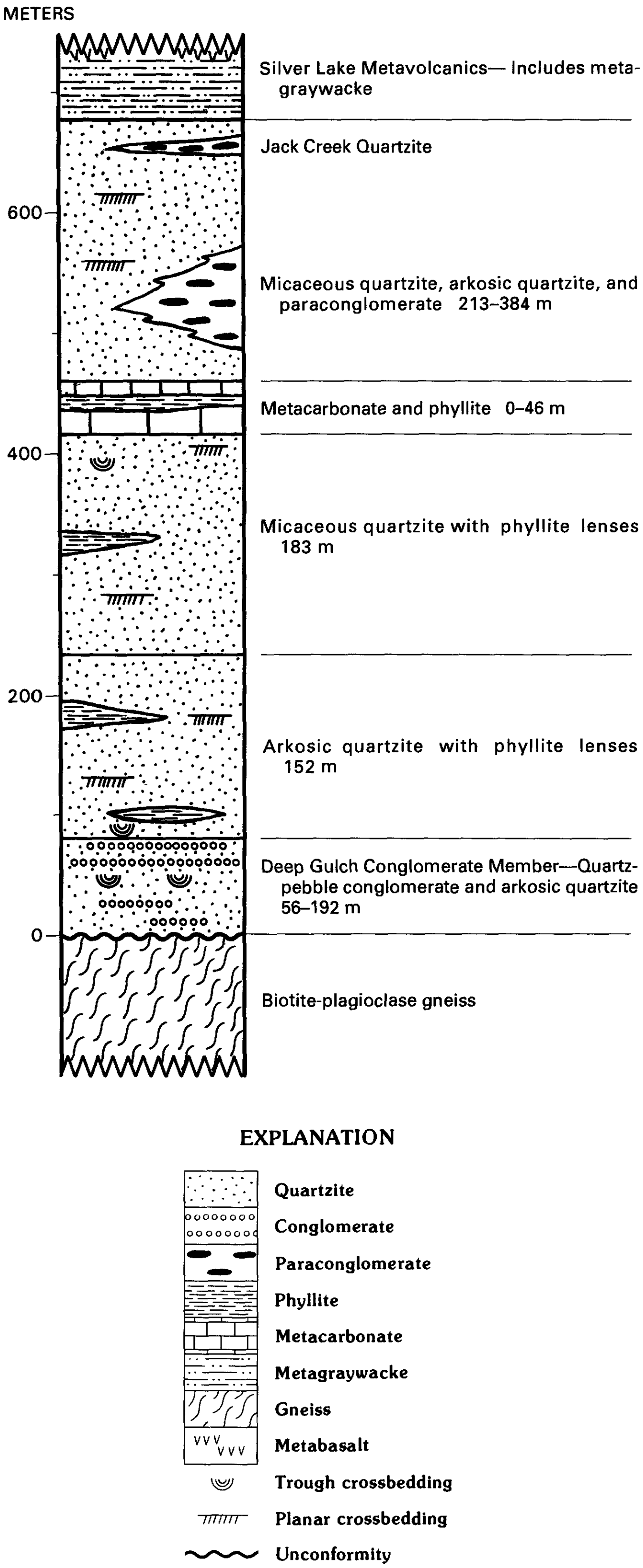


FIGURE 10.—Type section, the Jack Creek Quartzite in the Carrico Ranch area, sec. 7, T. 15 N., R. 87 W., northwestern Sierra Madre, Wyoming.

12); individual beds can be traced as far as 2 km in the Carrico Ranch area, and one bed may extend through the entire outcrop area of unit 3, a distance of 7 km (Kratochvil, 1981).

Paraconglomerate is not present interbedded with units of the Deep Gulch Conglomerate Member at the Carrico Ranch locality, but lenses of paraconglomerate have been identified in beds that underlie the Deep Gulch Member at the Deep Gulch locality and as discontinuous lenses higher in the Jack Creek Quartzite succession. Highly deformed paraconglomerates are also present in the rocks below the Deep Gulch Conglomerate Member at Deep Gulch.

Potassium feldspar clasts characterize the sediments of unit 1. Large potassium-feldspar pebbles (in excess of 10 mm in diameter) are common, and about 40 percent of the pebbles are larger than 2 mm. In general, perthite and microcline are the most common varieties of potassium feldspar. Plagioclase (An_{15-33}) grains are all less than 0.5 mm in diameter; albite grains are rare. The sorting of the conglomerates in unit 1 is poor. Potassium feldspar grains are generally larger than the quartz grains, except in the quartz-pebble conglomerates.

Figure 13 shows the quartz-feldspar-mica plus chlorite composition of 16 samples of unit 1. As shown, the composition varies from arkose to subarkose. The matrix of the conglomerates is composed of quartz (medium to fine grained), muscovite, and feldspar, with plagioclase making up 31 percent of the matrix feldspars and only 18 percent of the total feldspar present. Muscovite accounts for 64 percent of the total mica content with biotite making up the remaining 36 percent.

The ternary quartz-feldspar-mica plus chlorite diagram for unit 2 (fig. 13) shows that the percentage of feldspar is lower than for unit 1, and unit 2 quartzites vary in composition between quartzarenite and subarkose. Also, the size of the potassium-feldspar grains is smaller than those in unit 1. Most of the potassium-feldspar clasts are less than 2 mm (granule size), although larger clasts are not uncommon, especially in lag gravels. The percentage of plagioclase decreased from 18 percent in unit 1 to 13 percent in unit 2. As in units 1 and 3, polycrystalline quartz clasts are common and are interpreted as vein quartz. The percentage of mica is quite variable, from 1 to 19 percent, and muscovite is the major mica mineral. Biotite makes up 15 percent of the mica in unit 2.

The composition of unit 3 ranges from subarkose to arkose (fig. 13; table 9). Although the amount of plagioclase in the matrix of the quartz-granule and pebble conglomerates is lower than for units 1 and 2 (a maximum of 2 percent; table 9), the total amount of

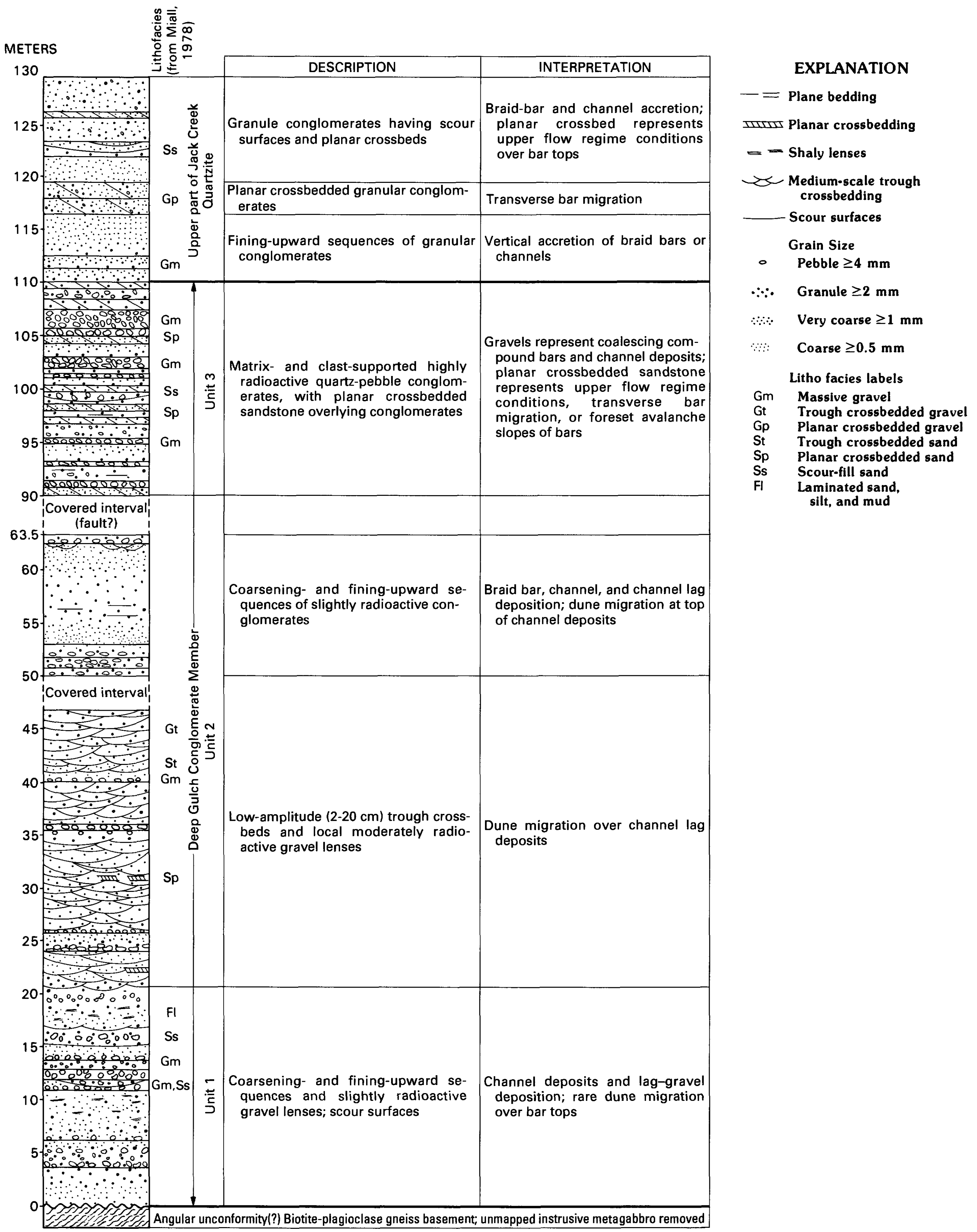


FIGURE 11.—Measured type section and paleoenvironmental interpretation of the Deep Gulch Conglomerate Member of the Jack Creek Quartzite, Ridge 1, Carrico Ranch, Sierra Madre, Wyoming. From Kratochvil (1981).

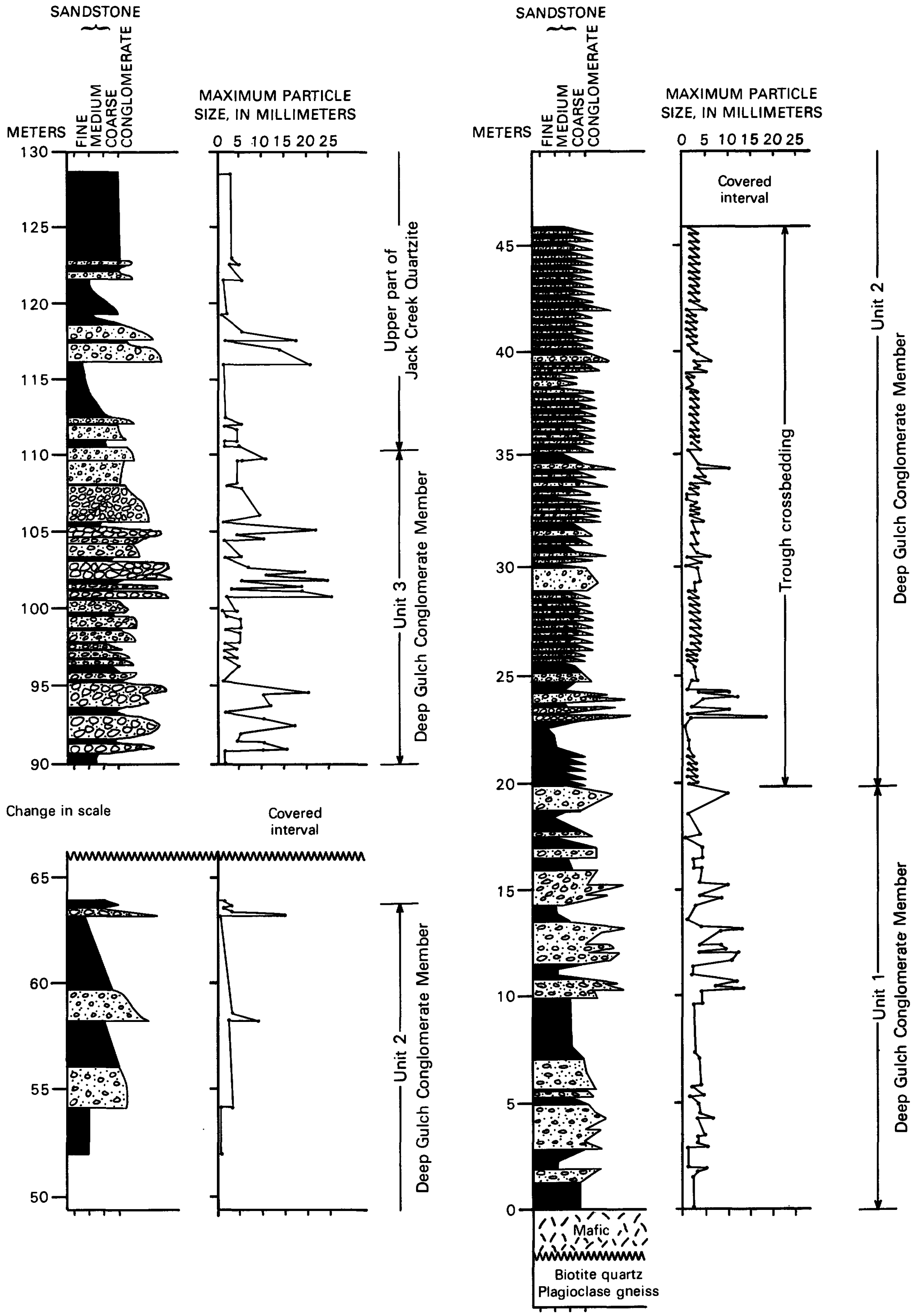


FIGURE 12.—Grain-size profile of the Deep Gulch Conglomerate Member, Jack Creek Quartzite, Wyoming. This section corresponds to that in figure 10. Maximum particle size is the mean of diameters of the 5 to 10 largest clasts. From Kratochvil (1981). Patterned areas are conglomerate and black areas are sandstone.

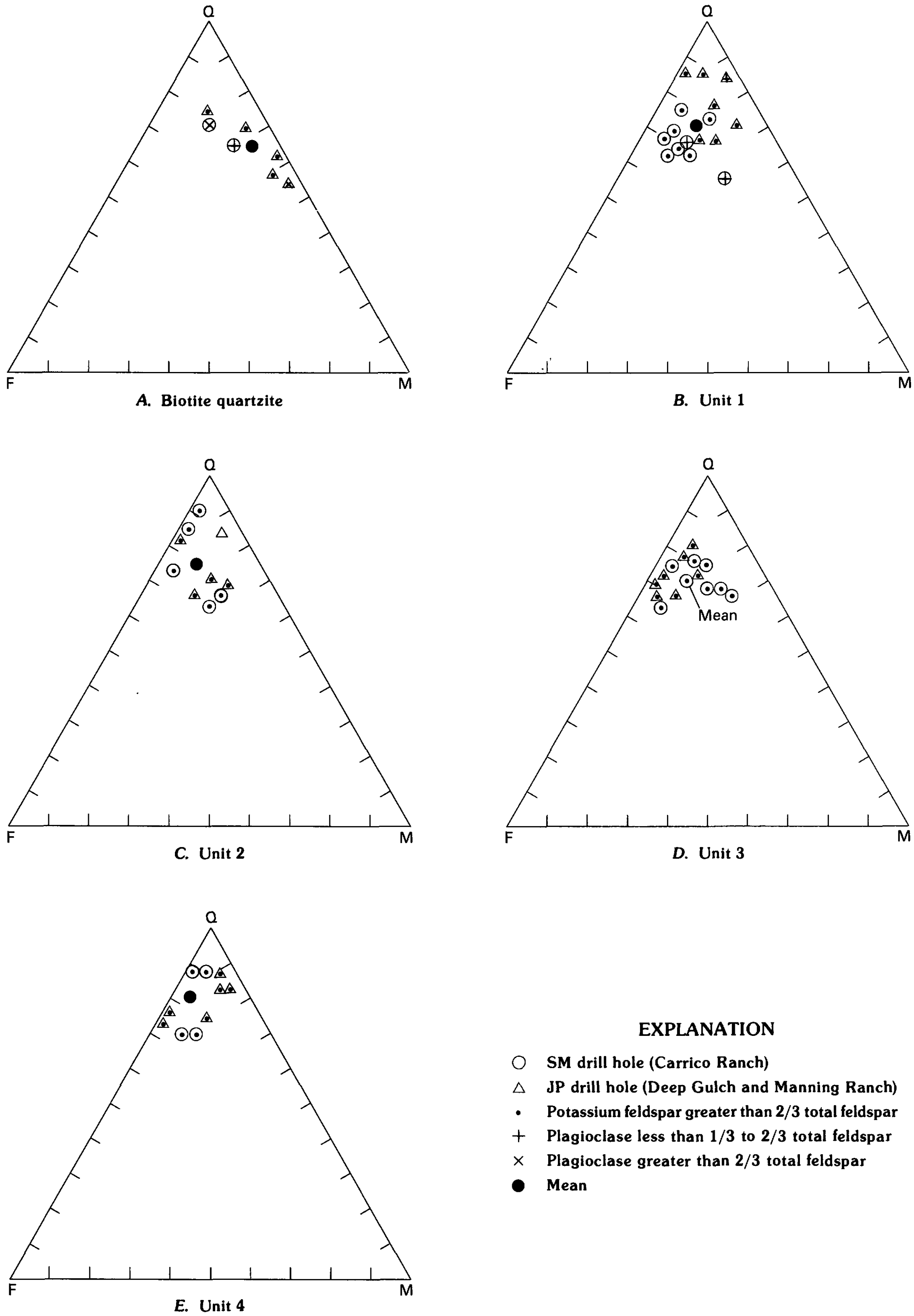


FIGURE 13.—Ternary diagrams showing composition of sand-size fraction of subsurface samples of the lower part of the Jack Creek Quartzite (biotite quartzite) and its Deep Gulch Conglomerate Member (units 1–3, fig. 10), Sierra Madre, Wyoming. Modes from point-counted thin sections. From Kratochvil (1981). Q, quartz; F, feldspar; M, mica plus chlorite.

TABLE 9.—*Modal compositions of samples of unit 3, Deep Gulch Conglomerate Member of the Jack Creek Quartzite, Sierra Madre, Wyoming*

[Modes, in percent, from point-counted thin sections. Tr, trace; --, not determined]

Drill-hole sample depth	Quartz	Quartzite	Plagioclase	Perthite	Microcline	Orthoclase	Muscovite	Chlorite	Biotite	Opaque minerals	Zircon
SM1–175.4	61	6	--	1	7	3	23	--	--	1	--
SM1–175.7	45	24	--	--	10	3	10	--	--	7	1
SM1–192.8	67	1	--	9	3	--	17	--	--	2	--
SM1–207	66	6	Tr	8	--	11	7	--	--	Tr	Tr
SM1A–541.6	60	13	Tr	9	3	8	6	--	--	1	--
SM2–149	53	13	2	7	8	12	6	--	--	Tr	Tr
SM2–150.1	57	10	Tr	Tr	6	6	17	--	--	4	Tr
SM2–187	63	14	1	10	Tr	3	Tr	9	Tr	Tr	Tr
JP1–408.7	70	2	Tr	2	21	--	2	--	--	2	--
JP1–410	56	25	--	--	13	--	3	--	--	5	Tr
JP1–412	61	15	--	Tr	19	--	5	--	--	1	--
JP1–416.5	62	6	1	--	23	--	4	--	--	2	Tr
JP1–421	71	1	1	1	19	--	4	--	--	3	Tr
JP2–311	61	4	1	Tr	11	9	9	--	--	3	1
JP4–284	62	9	1	Tr	9	9	11	--	Tr	2	Tr
Mean	61	10	0.5	3	10	4.3	8.3	0.5	Tr	2.2	Tr

feldspar is not significantly different because the amount of potassium-feldspar is greater. However, the size of potassium feldspar grains decreased. The samples selected from unit 3 are not the most radioactive of the unit but are about 5 to 7 times the background radiation.

Quartzite rock fragments are more common in unit 3 than in the other units, and black and green chert fragments were also observed. The amount of quartzite increases as the percentage of pyrite increases. Quartz is the most common mineral present in the matrix, and potassium feldspar, muscovite, pyrite, plagioclase, and a variety of heavy minerals occur in decreasing abundance.

Opaque minerals, primarily pyrite, constitute as much as 7 percent of the samples that were examined in thin section. In rock slabs and polished thin sections, opaque minerals constitute as much as 30 percent of the rock (figs. 14, 15). Pyrite-grain morphology varies greatly, from euhedral to subrounded equant and elongate grains. Aggregates of pyrite grains are also present. Pyrite-grain size ranges from 0.01 to 2.0 mm in diameter. Rare veinlets of pyrite as long as 2 mm were observed between pyrite grains.

The heavy-mineral suite from the radioactive quartz-pebble conglomerates in unit 3 consists of radioactive and nonradioactive minerals (table 10). Pyrite is the most common heavy mineral associated with the suite. The majority of heavy mineral grains are concentrated at the base of clast-supported conglomerates, and some heavy minerals are also concentrated at the base of matrix-supported conglomerates. Radioactive minerals include zircon, the most abundant mineral, and lesser amounts of monazite, monazite-huttonite(?), and huttonite(?). The shape of zircon, monazite, monazite-huttonite(?), and huttonite(?) mineral grains is subrounded to euhedral. This grain morphology may be either a metamorphic texture due to recrystallization or a feature of the detrital origin of these minerals.

The Deep Gulch Conglomerate Member is interpreted as a fluvial succession deposited in a braided river system (fig. 11). Unit 1 is a sequence that represents a reworked grus that is believed to have been deposited unconformably in channels and braid bars on gneissic basement. Unit 2 generally coarsens upwards and contains abundant trough crossbeds and fining-upward stratification sequences. Unit 2 is interpreted to represent aggrading channels in a braided river system. Unit 3 contains the major radioactive conglomerate zones in the Deep Gulch. These zones are interpreted to represent deposition of gravels on longitudinal bars in braided rivers that developed on prograding wet alluvial fans. The coarsening-upwards succession of units 2 and 3 appears to represent faulting and uplift along the basin margins, and the most radioactive conglomerate layers of unit 3 are interpreted to represent compound longitudinal gravel bars that were relatively long lived. Continued reworking of sediment in these bars, in response to progradation of the fan system, caused heavy minerals to be concentrated there.

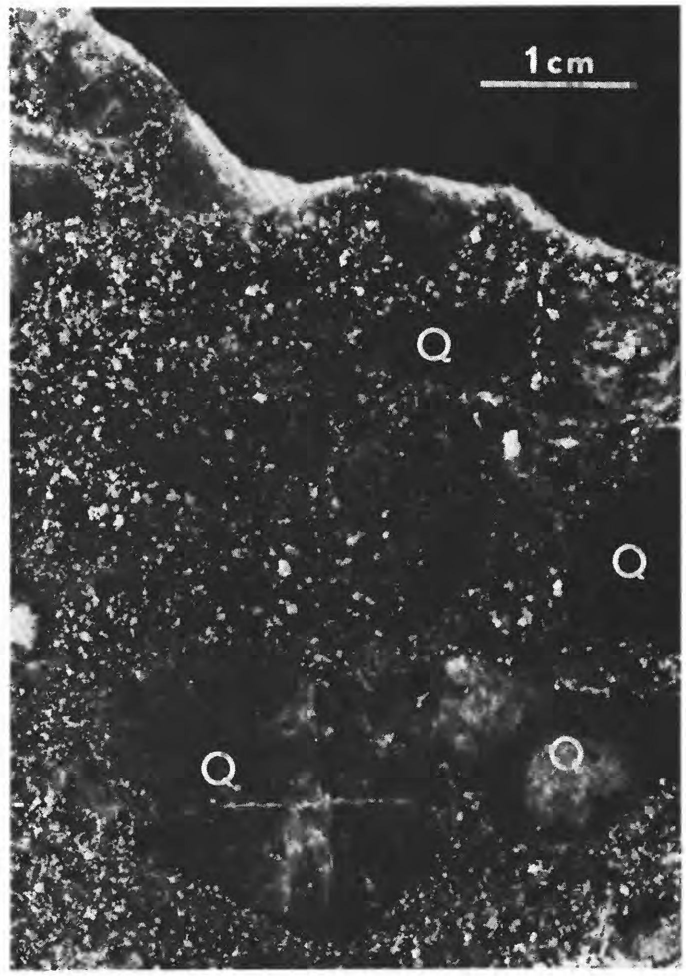


FIGURE 14.—Basal quartz-pebble conglomerate from drill hole SM 2, Deep Gulch Conglomerate Member of the Jack Creek Quartzite, Sierra Madre, Wyoming. (Drill core is from a depth of 165.5 ft.) The small, bright euhedral to subhedral pyrite grains (light gray) are concentrated in the matrix. The large euhedral pyrite grains have probably been recrystallized. The large gray and white clasts (Q) are quartz and quartzite pebbles. This drill-core sample has the highest thorium assay (2,600 ppm Th, 220 ppm U, sample 158460) of any from the Deep Gulch Conglomerate Member. Maximum pebble size in this conglomerate is 35 mm; mean size of the pyrite grains is 0.44 mm.

UPPER PART OF THE JACK CREEK QUARTZITE

Petrographic data from units of the Jack Creek Quartzite above the Deep Gulch Conglomerate

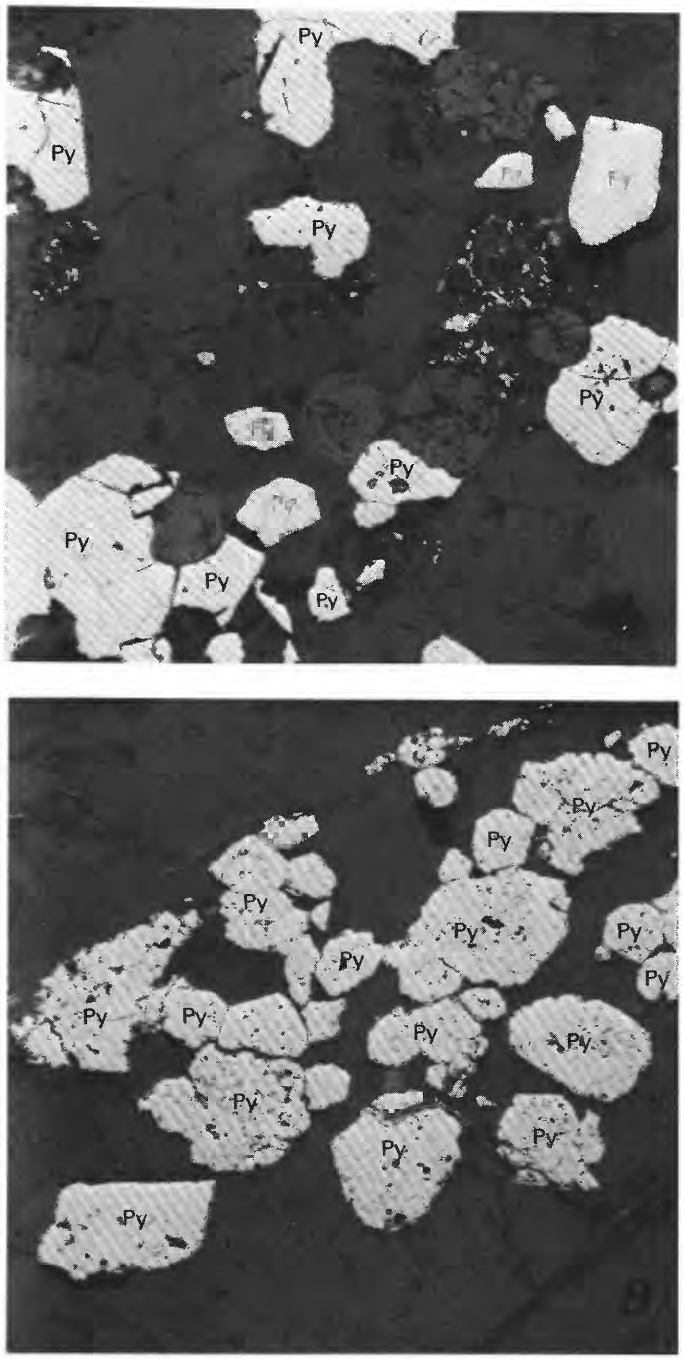


FIGURE 15.—*A*, Heavy minerals in quartz-pebble conglomerate of the Deep Gulch Conglomerate Member, Carrico Ranch, Sierra Madre, Wyoming: Py, pyrite; Zi, zircon; MH, monazite-huttonite(?) mixture. *B*, Subhedral grains of pyrite (Py) in pyrite-rich layer of quartz-pebble conglomerate of the Magnolia Formation, Onemile Creek locality, Medicine Bow Mountains. Gray grains are silicate minerals—mostly quartz and feldspar. Grain diameters of pyrite (Py) are about 0.22 mm.

Member are shown in table 11. The quartzites are generally arkosic, argillaceous, or subargillaceous (fig. 16). Plagioclase is the predominant feldspar with very

TABLE 10.—*Heavy-mineral suite from unit 3, Deep Gulch Conglomerate Member, Sierra Madre, Wyoming*

Nonradioactive minerals	Radioactive minerals
Pyrite	Zircon
Ilmenorutile	Monazite
Apatite	Monazite-huttonite(?)
Marcasite	Huttonite(?)
Sphene	
Ilmenite	
Anatase	
Rutile	
Garnet	

little potassium feldspar. Muscovite and biotite are commonly present with generally minor amounts of chlorite, epidote, carbonate, and garnet. Metapelites consist primarily of muscovite, chlorite, or biotite with quartz and garnet. Plagioclase, epidote, staurolite, and kyanite are present locally (table 11). Metacarbonates are commonly very siliceous. This siliceous material is probably detrital and is arkosic (fig. 16). The metacarbonates are unusual in that potassium feldspar is abundant. Jack Creek Quartzite rocks are generally of the epidote-amphibolite facies (Miyashiro, 1973).

Sedimentary structures are well preserved in much of the outcrop area of the Jack Creek Quartzite. Whereas trough crossbedding is prominent in the Deep Gulch Conglomerate Member, tabular, planar crossbedding predominates elsewhere. Plane beds are common, and wedge-shaped and herringbone cross-stratification has been observed. Paleocurrent directions were measured, and attempts were made to restore bedding to prefolding attitudes by assuming folding took place by flexural slip (from Ramsey, 1961). However, the complex nature of the folding leaves doubt about paleocurrent directions, because it is probable that simple unfolding about a plunging fold axis is too simplistic in these rocks. A predominant north-northeast paleocurrent trend is suggested for the sediments of the Jack Creek Quartzite above the Deep Gulch Conglomerate Member (fig. 17*C*). This northeast direction is similar to that of broadly correlative sediments of the Bow Quartzite in the Medicine Bow Mountains (discussed earlier).

In the Carrico Ranch area, the Jack Creek Quartzite consists of the 100-m-thick Deep Gulch Conglomerate Member overlain by about 500 m of relatively clean, fine- to medium-grained, sericitic quartzites (fig. 10). Beds of phyllite and metacarbonate are present locally. The metacarbonate is commonly coarse grained,

TABLE 11.—*Modal compositions of samples of the upper part of the Jack Creek Quartzite, Sierra Madre, Wyoming, excluding the Deep Gulch Conglomerate Member*

[Modes, in percent, from visual estimates. Tr, trace; --, not determined]

Sample No.	Quartz	Plagioclase	Potassium feldspar	Muscovite	Chlorite	Biotite	Epidote	Carbonate	Opaque minerals	Tremolite
				Quartzites						
SM41	65	30	--	--	5	--	--	--	--	--
SM73	65	10	10	15	--	--	--	--	--	--
SM89	68	20	5	--	1	5	--	--	--	--
SM96	94	--	--	5	--	--	--	--	--	--
Meta-1	90	5	--	5	--	--	--	--	Tr	--
TS205	20	55	--	--	--	15	10	Tr	--	--
TS207	60	30	--	8	--	2	--	--	--	--
TS209	55	25	--	5	--	5	--	10	--	--
SM4A–99.5	68	15	--	15	--	2	--	--	--	--
SM4A–133.5	69	10	--	20	Tr	1	--	--	--	--
SM4A–156.5	79	5	--	10	3	3	--	--	--	--
SM4A–311.5	76	10	--	10	--	2	2	Tr	--	--
SM4A–321	80	3	--	15	1	1	--	Tr	--	--
SM4A–497.5	68	15	--	10	2	5	--	Tr	--	--
SM4B–184	53	5	--	40	--	2	--	--	--	--
SM4B–241.2	60	3	--	15	5	2	--	Tr	Tr	--
SM6–103.1	96	--	--	3	--	1	--	--	--	--
SM6–165.5	67	10	10	10	--	1	--	2	--	--
SM6–299.5[1]	66	--	--	10	2	10	--	10	1	--
SM6–310[2]	65	--	5	15	--	15	--	Tr	--	--
SM6–340[3]	51	--	10	35	--	3	--	--	1	--
Mean (21)	67	12	2	12	1	4	1	1	Tr	--
				Calcareous rocks						
SM90	3	2	--	2	--	4	--	89	Tr	--
Metra–2	29	10	1	--	--	--	35	10	--	15
Metra–3	25	15	20	5	--	15	--	20	--	--
Metra–4	20	10	10	--	--	--	15	35	--	10
Carb–1	20	10	--	--	Tr	Tr	--	70	Tr	10
Carb–2	10	10	10	10	--	10	--	50	Tr	--
Mean (6)	18	10	7	3	Tr	5	8	46	Tr	6
				Metapelites						
SM4[3]	10	--	--	--	83	5	--	--	2	--
SM69[4]	40	5	--	25	10	5	--	--	--	--
SM70[5]	27	--	--	60	2	--	--	--	1	--
SM6–178.7[6]	5	Tr	--	--	15	44	5	--	--	--
Mean (4)	20	1	--	21	28	14	1	--	1	--

[1]Contains 1 percent tourmaline.
[2]Contains traces of apatite and zircon.
[3]Contains trace of zircon.
[4]Contains 15 percent garnet.
[5]Contains 5 percent garnet and 5 percent staurolite.
[6]Contains 30 percent garnet and 1 percent kyanite.

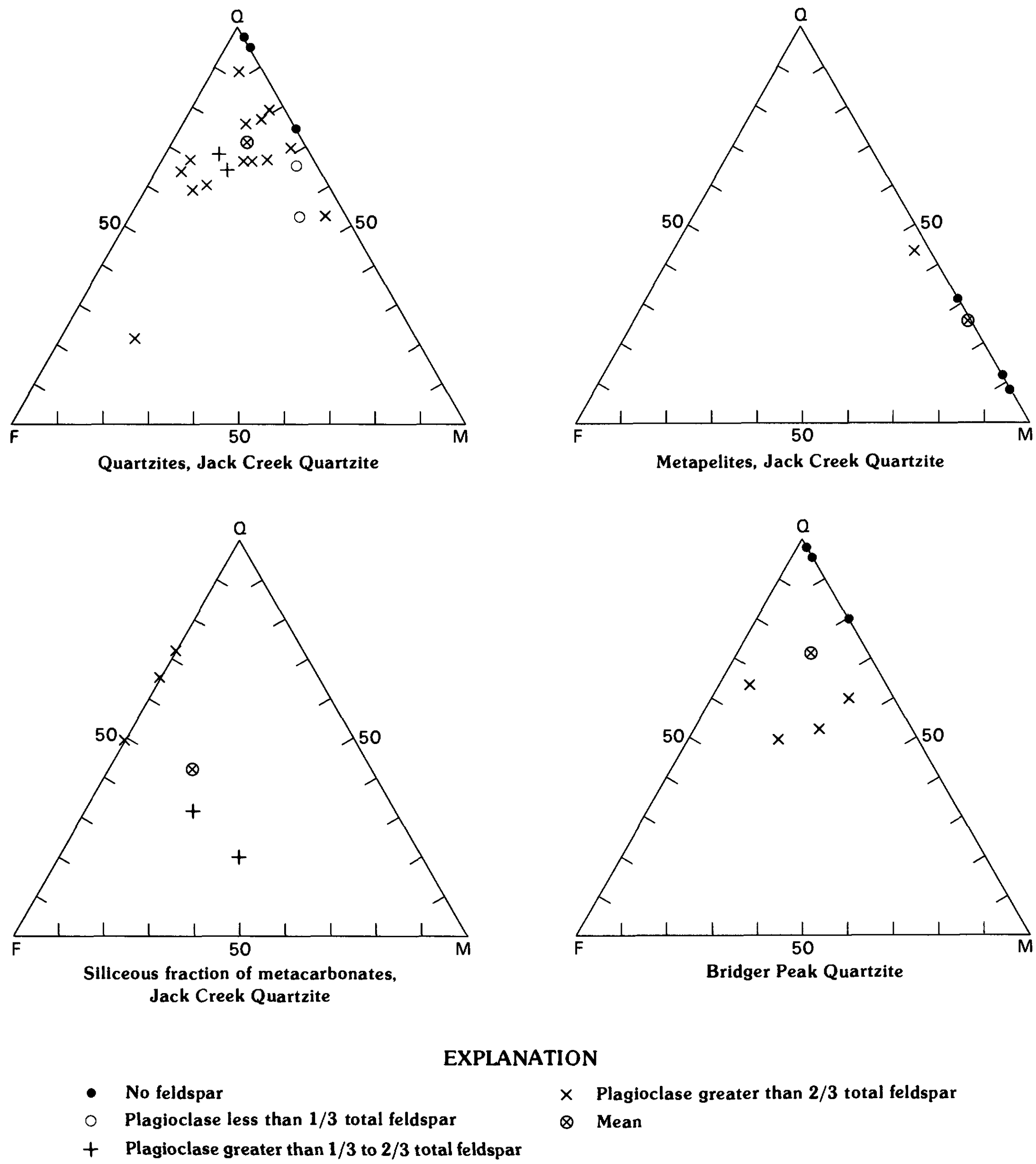


FIGURE 16.—Ternary diagrams showing composition of the upper part of the Jack Creek and the Bridger Peak Quartzites, Sierra Madre, Wyoming. Q, quartz; F, feldspar; M, mica plus chlorite.

contains abundant clastic detritus (including a chert-pebble conglomerate) and appears crossbedded in places, all suggesting deposition in shallow water. One structure resembling organic bioherms was noted. Petrographic data are lacking for the quartzites of this section, but field evidence suggests that these sediments are much more mature than the fluvial sediments of the Deep Gulch Conglomerate Member at the base. The interbedded phyllites and metacarbonates and broadly dispersed paleocurrent distribution (fig. 17A) suggest marine deposition for these rocks.

On strike with the metacarbonate and only a few hundred meters to the southwest, the Jack Creek Quartzite consists of interbedded coarse-grained arkosic quartzite and paraconglomerate. Here, paleocurrents suggest a westerly source. The rapid facies change from coarse-grained, poorly sorted paraconglomerates, possibly debris flows (Bull, 1972), to marine carbonates suggests deposition in a fan-delta setting (Wescott and Ethridge, 1980).

The Jack Creek Quartzite in the cirques above North Spring Creek Lake and the upper end of the canyon of

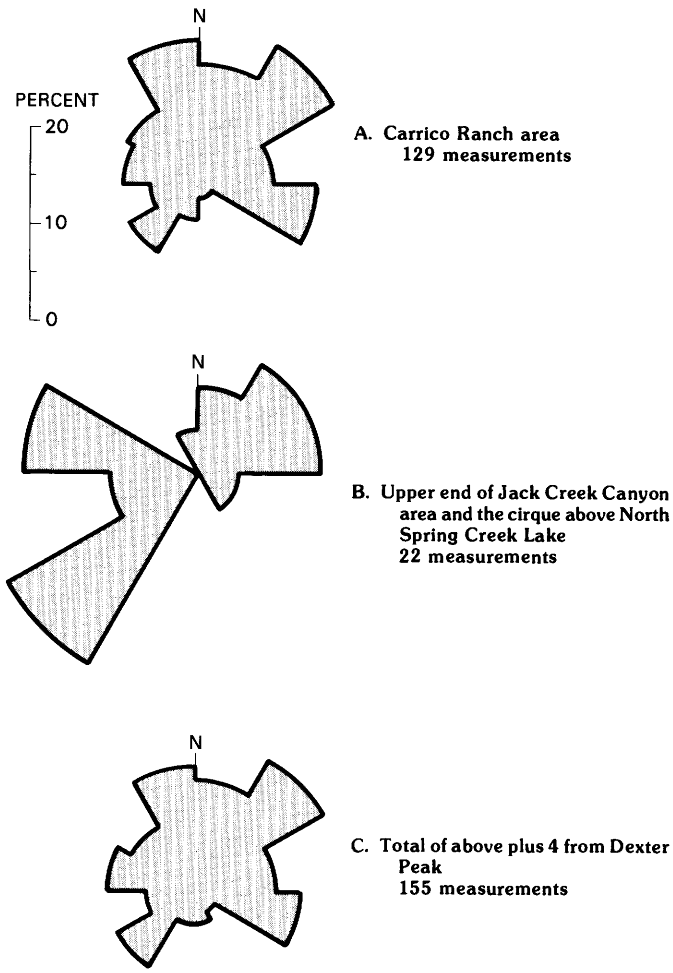


FIGURE 17.—Paleocurrent directions identified for the Jack Creek Quartzite, excluding its Deep Gulch Conglomerate Member, Sierra Madre, Wyoming. Paleocurrents are plotted in percent of total for 30° intervals. Paleocurrent measurements were restored to horizontal by assuming reclined folds with west to northwest plunge (Karlstrom and others, 1981) and flexural-slip folding. These assumptions are questionable, and uncertainty in unfolding folds makes paleocurrent data questionable.

Jack Creek does not contain a fluvial conglomerate facies at its base. Rather, the quartzites here are fine grained, sericitic, and calcareous. Several large-scale crossbeds and herringbone cross-stratifications are present along with abundant smaller scale planar crossbeds. Paleocurrent distribution is bimodal northeast-southwest (fig. 17*B*). Other metasedimentary rocks in this area include well-laminated, fine-grained, graded quartzites; thinly bedded, alternating beds of metacarbonate and very fine grained quartzite (metachert?); and phyllites. These lithologies suggest deposition on a shallow marine shelf under the influence of tidal currents.

SILVER LAKE METAVOLCANICS

The Silver Lake Metavolcanics consist of mafic metavolcanic rocks, granite-boulder paraconglomerate, biotite schist, metagraywacke, metatuff, quartzite, and metacarbonate. This newly named unit is well exposed in the cliffs between South Spring Creek Lake and Silver Lake (unit Wsm, secs. 10–13, T. 14 N., R. 86 W., pl. 1), and this area is defined as the type locality. Generally poor exposures and complex structure make it difficult to measure accurately the thickness of the unit, but throughout the study area it seems to range from 300 to 1,000 m. Contacts with the Jack Creek Quartzite and Bridger Peak Quartzite are believed to be disconformable. The paraconglomerates are thickest just south of Bridger Peak, whereas the metagraywacke and tuffaceous rocks are thickest on the north flanks of the Divide Peak synclinorium. Abrupt lateral and vertical facies changes are common. Various levels of the Silver Lake Metavolcanics were intersected by drill holes SM7, SM9, SM11, and SM12 (Tps. 14–15 N., Rs. 85–87 W., pl. 1).

Petrographic data are given in table 12. Metabasalts are dominated by either actinolite or hornblende. Chlorite, garnet, and talc commonly are present in the metabasalt rocks; chlorite, biotite, and plagioclase are common constituents of the metabasalt rocks. Several of the samples contain enough quartz to be an intermediate volcanic rock. We consider these rocks to be volcaniclastic in origin because of their fragmental character.

The paraconglomerates of the Silver Lake Metavolcanics (fig. 18) consist of metasedimentary, granitic, and metavolcanic clasts (as large as boulder size) in a matrix containing quartz, plagioclase, muscovite, chlorite, biotite, epidote, and amphibole.

Pelitic rocks of the Silver Lake Metavolcanics consist of a mixture of quartz, plagioclase, mica, and chlorite (table 12). These rocks are generally not as feldspathic as most of the Silver Lake rocks. Epidote, garnet, and actinolite may be abundant locally. The one field-identified marble is petrographically a very calcareous quartzite (table 12).

A variety of tuffaceous or volcaniclastic metasedimentary rocks is present in the Silver Lake Metavolcanics. These rocks contain abundant quartz, feldspar, and mica as well as local chlorite, epidote, garnet, carbonate, and hornblende (table 12), and they are generally arkosic (fig. 19). Most rocks are poorly sorted, and some have a distinct bimodal grain size

TABLE 12.—*Modal compositions of samples of the Silver Lake Metavolcanics, Sierra Madre, Wyoming*

[Modes, in percent, from visual estimates. Rock names are field classifications. Tr, trace; --, not determined]

Sample No.	Quartz	Plagioclase	Potassium feldspar	Muscovite	Chlorite	Biotite	Epidote	Opaque minerals	Garnet	Carbonate	Actinolite	Hornblende	Talc	Stilpnomelane	Sphene	Chloritoid
								Metabasalts								
AFCB18.2	3	--	--	--	5	3	1	1	--	Tr	--	87	--	--	--	--
AFCB18.3	27	--	--	--	1	--	2	--	5	--	--	65	--	--	--	--
AFCB18.4	1	--	--	--	14	--	--	--	--	--	85	--	--	--	--	--
AFCB7.2	2	1	--	--	--	--	3	1	--	--	--	93	--	--	--	--
AFDG3	--	--	--	--	15	--	--	--	--	--	85	--	--	--	--	
AFDG4	5	--	--	--	--	--	--	2	20	--	--	73	--	--	--	--
SM6	7	--	--	--	--	--	8	Tr	--	--	--	85	--	--	--	--
SM10	10	10	--	--	--	--	2	2	1	10	--	65	--	--	--	--
SM12	--	--	--	--	40	--	--	--	--	--	40	--	20	--	--	
SM14	--	--	--	--	5	--	--	--	--	--	95	--	--	--	--	
SM32	--	--	--	--	45	--	--	Tr	--	--	45	--	10	--	Tr	--
TS147	5	10	--	--	5	15	--	--	--	--	65	--	--	--	--	--
TS151	13	2	--	--	--	--	--	--	--	--	75	--	--	10	--	--
TS172	--	35	--	--	--	1	--	--	--	--	--	64	--	--	--	--
SM9–289	20	--	--	--	--	--	15	--	--	Tr	60	--	--	--	5	--
SM11–1004.9	15	15	--	--	Tr	5	--	--	Tr	--	--	65	--	--	--	--
Mean (16)	7	5	--	--	8	2	2	Tr	2	1	34	37	2	1	Tr	--
								Metagraywackes and metatuffs								
SM12–589	52	30	--	15	3	--	--	--	--	--	--	--	--	--	--	--
SM8	75	--	10	Tr	--	15	--	--	--	--	--	--	--	--	--	--
SM82	30	--	--	30	--	1	--	4	25	--	--	--	--	--	--	--
SM83	50	--	--	15	1	--	--	--	34	--	--	--	--	--	--	--
SM86	30	48	--	--	1	15	1	1	4	--	--	--	--	--	--	--
AFDG1	55	20	--	--	--	10	10	--	--	--	--	5	--	--	--	--
AFDG2	55	20	--	--	--	--	15	--	--	--	--	10	--	--	--	--
SM11–729	70	16	--	Tr	1	10	1	--	1	1	--	--	--	--	--	--
SM11–862	40	20	--	--	--	5	30	--	5	--	--	--	--	--	--	--
SM16	59	20	--	Tr	10	5	Tr	1	--	--	--	5	--	--	--	--
SM30	50	35	--	--	3	3	1	5	--	--	--	3	--	--	--	--
AFCB18–1	60	--	--	16	3	11	--	--	10	--	--	--	--	--	--	--
TS209	60	5	--	3	8	10	1	6	5	--	--	5	--	--	--	--
SM7–27E–2	30	4	--	--	--	1	--	--	--	--	--	65	--	--	--	--
AFDG5	48	5	--	--	1	--	1	--	--	10	--	35	--	--	--	--
SM12–640	55	15	5	20	--	5	--	--	--	--	--	--	--	--	--	--
SM12–667	78	5	10	5	--	2	--	--	--	--	--	--	--	--	--	--
TS128–8	25	35	--	--	15	--	--	--	--	25	--	--	--	--	--	--
TS175	25	60	--	3	1	3	--	--	3	5	--	--	--	--	--	--
Mean (19)	50	18	1	6	2	5	3	1	5	2	--	7	--	--	--	--

Sample No.	Quartz	Plagioclase	Potassium feldspar	Muscovite	Chlorite	Biotite	Epidote	Opaque minerals	Garnet	Carbonate	Actinolite	Hornblende	Talc	Stilpnomelane	Sphene	Chloritoid
Paraconglomerates																
SM84	40	10	--	--	1	1	--	1	2	--	45	--	--	--	--	--
TS222	59	20	--	--	--	15	1	--	--	--	--	5	--	--	--	--
TS158	5	--	--	--	--	--	10	--	--	--	--	85	--	--	--	--
TS159	20	20	--	--	2	5	--	--	--	--	52	--	--	1	--	--
TS225	40	15	--	5	4	--	20	1	--	--	--	15	--	--	--	--
TS295	50	20	--	15	--	5	6	--	--	--	--	4	--	--	--	--
TS297	2	--	--	20	41	15	--	2	--	--	--	10	--	--	--	10
TS300	15	--	--	--	2	75	3	--	3	2	--	--	--	--	--	--
TS318	45	15	--	--	3	--	--	2	--	--	35	--	--	--	--	--
TS134	84	--	--	--	5	5	--	--	1	--	--	5	--	--	--	--
TS136	72	10	--	--	1	10	--	Tr	--	5	--	2	--	--	--	--
TS133	39	20	--	--	--	Tr	--	--	1	5	--	35	--	--	--	--
TS137	57	15	--	3	3	10	2	--	5	Tr	--	5	--	--	--	--
SM7–391.8	30	--	--	--	5	50	Tr	--	10	5	--	--	--	--	--	--
SM7–442.2	53	5	--	--	--	10	--	1	Tr	1	30	--	--	--	--	--
SM9–219.5	45	45	--	--	5	3	--	Tr	Tr	2	--	--	--	--	--	--
SM9–501.5	49	20	--	--	20	7	--	1	--	3	--	--	--	--	--	--
SM9–678.3	87	5	--	--	1	5	1	2	--	--	--	--	--	--	--	--
Mean (18)	44	12	--	2	5	12	2	Tr	1	1	9	9	--	Tr	--	Tr
Metapelitic rocks																
SM–31	30	20	--	40	4	4	--	2	--	--	--	--	--	--	--	--
TS–239	40	5	--	29	15	5	3	1	--	2	--	--	--	--	--	--
SM5–573	30	12	--	1	5	35	15	--	--	2	--	--	--	--	--	--
SM7–334.5	44	10	--	--	--	35	--	--	1	--	10	--	--	--	--	--
SM7–559	72	5	--	--	--	15	5	--	3	Tr	--	--	--	--	--	--
SM9–255..5	73	5	--	--	1	20	--	1	Tr	--	--	--	--	--	--	--
SM9–430	60	10	--	2	15	5	--	3	5	--	--	--	--	--	--	--
SM9–596	55	8	--	--	--	35	--	2	--	Tr	--	--	--	--	--	--
Mean (8)	50	9	--	9	5	19	3	1	1	Tr	1	--	--	--	--	--
Marble																
SM84	70	--	--	Tr	--	Tr	--	--	--	30	--	--	--	--	--	--

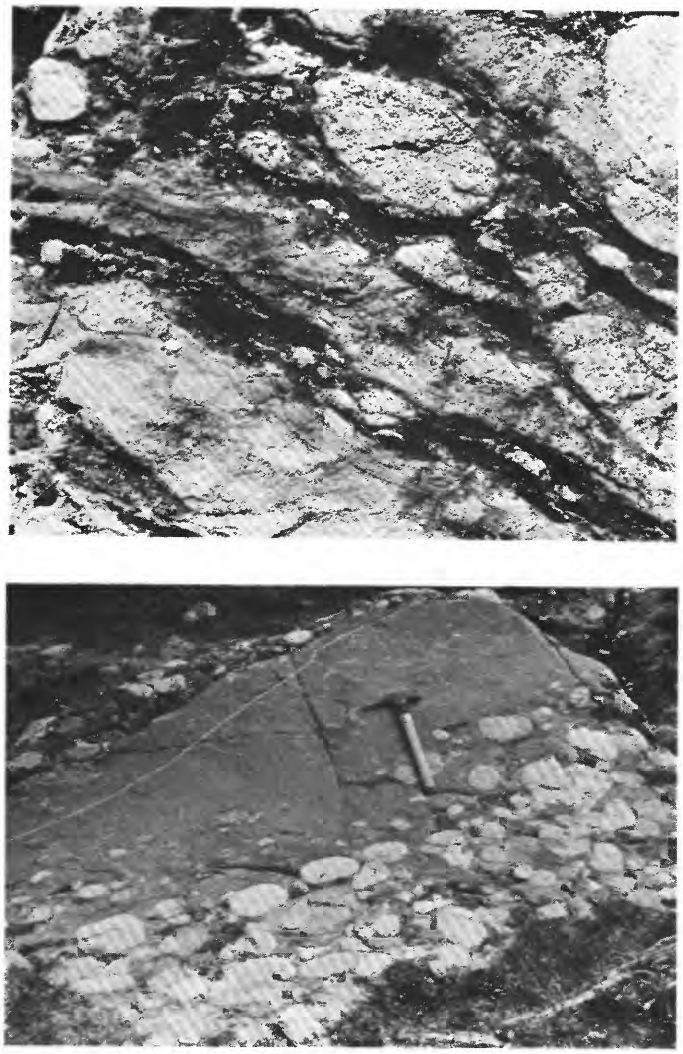


FIGURE 18.—Graded bedding in conglomerate of the Silver Lake Metavolcanics, central Sierra Madre, Wyoming. Note deformed laminae in graywacke layer in upper photograph.

distribution with large, nearly euhedral, clastic feldspar crystals in a finer grained arkosic matrix. Two samples (SM16, SM30) have a very fine grained siliceous matrix with a few coarse crystals of hornblende and feldspar. We consider these rocks to represent metamorphosed low-potassium dacitic tuffs (SiO_2 content is about 69 percent).

Few primary sedimentary or igneous structures have been observed in the Silver Lake rocks. We envision an environment consisting of scattered subaerial mafic volcanic centers shedding lava flows and tuffaceous rocks into surrounding basins. Rapid facies changes and the poorly sorted nature of the sediments suggest rapid deposition, perhaps as alluvial fans, fan deltas, mud flows, or turbidity currents. The variety of clasts in the paraconglomerates implies uplift of preexisting granitic and sedimentary strata, probably along fault scarps, in conjunction with volcanism.

BRIDGER PEAK QUARTZITE

The Bridger Peak Quartzite lies in the core of a recumbent, isoclinal syncline that extends across the Sierra Madre (unit Wbp, pl. 1). This is the youngest unit of the Phantom Lake Metamorphic Suite in the Sierra Madre; it overlies the Silver Lake Metavolcanics both conformably and disconformably. Its top is not exposed, as it is unconformably overlain by Proterozoic rocks of the Snowy Pass Group. Divis (1976, p. 26) named the Bridger Peak Quartzite for the quartzites that make up "the majority of the sediment section in the Sierra Madre Range." He considered these quartzites to be similar to the Heart Formation of the Libby Creek Group in the Medicine Bow Mountains. Our Bridger Peak Quartzite coincides with Divis' only in the Bridger Peak area; elsewhere, our evidence necessitates a different stratigraphic interpretation (pl. 1, this report, and pl. 1 of Divis, 1976). We interpret the Bridger Peak Quartzite to be part of the Phantom Lake Suite because it is unconformably overlain by the Proterozoic Snowy Pass Group, and we correlate it with the Conical Peak Quartzite of the Medicine Bow Mountains.

In most of the study area, the Bridger Peak Quartzite is about 800 m thick. The quartzite is best exposed at Bridger Peak and Vulcan Mountain and for several kilometers east of these two localities. The Bridger Peak area is designated the type locality. The unit consists primarily of white fine-grained quartzite with some phyllite layers. A few metavolcanic rocks and metacarbonate layers and at least one pyritic quartz-pebble conglomerate layer are present near the base.

The quartzite is quite variable, ranging from quartz arenite to argillaceous and arkosic quartzite (fig. 16). Quartz, plagioclase, and muscovite are the most abundant mineral species with minor amounts of chlorite and biotite (table 13). A quartz-pebble conglomerate on Vulcan Mountain contains as much as 20 percent pyrite (sample SM9–169, opaque minerals, table 13), and as much as 35 ppm U and 40 ppm Th. The metavolcanic rocks consist primarily of epidote, amphibole, and quartz (table 13).

Little is known about the depositional environment of the Bridger Peak Quartzite. The few sedimentary structures observed were medium- to large-scale planar crossbeds and small-scale trough crossbeds. Paleocurrent analysis is limited and suggests that in one area sediment transport was predominantly to the northwest. This analysis is subject to the same structural difficulties as in the Jack Creek Quartzite.

TABLE 13.—*Modal compositions of samples of the Bridger Peak Quartzite, Sierra Madre, Wyoming*

[Modes, in percent, from visual estimates. Rock names are field classifications. Tr, trace; Do., ditto; --, not determined]

Sample No.	Quartz	Plagioclase	Potassium feldspar	Muscovite	Chlorite	Biotite	Epidote	Opaque minerals	Garnet	Carbonate	Actinolite	Hornblende	Rock name
						Quartzites							
TS117	99	--	--	--	1	--	--	--	--	--	--	--	Quartzite.
TS119	99	--	--	--	1	--	--	--	--	--	--	--	Do.
TS121	64	30	--	1	5	--	--	--	--	--	--	--	Do.
SM9–169	64	--	--	10	1	5	--	20	--	--	--	--	Do.
SM9–163	60	10	--	25	--	5	--	--	--	--	--	--	Do.
SM5–674.6	50	30	--	15	--	5	--	--	--	Tr	--	--	Do.
SM5–708	50	20	--	20	2	5	--	--	Tr	3	--	--	Do.
Mean (7)	69	13	--	10	1	3	--	3	Tr	Tr	--	--	--
						Miscellaneous rocks							
TS114	15	--	--	--	--	--	55	Tr	--	--	30	--	Metabasalt.
TS115	5	--	--	--	Tr	--	55	--	--	--	40	--	Do.
TS122	28	--	--	--	70	2	--	Tr	--	--	--	--	Schist.
AFMi–1	40	5	15	5	--	--	--	--	--	35	--	--	Marble.
SM5–511.3	10	15	--	--	5	--	2	--	--	Tr	--	68	Volcaniclastic rock.

The pyritic quartz-pebble conglomerate at Vulcan Mountain is lithologically similar to the fluvial sediments of the Deep Gulch Conglomerate Member, suggesting that the basal part of the Bridger Peak Quartzite may also be partly fluvial in origin. The genesis of the bulk of the unit remains uncertain. The more mature texture and mineral content suggest waning volcanism and tectonic activity during deposition.

INTRUSIVE ROCKS

Quartzo-feldspathic basement gneiss and supracrustal rocks of the Vulcan Mountain Metavolcanics, Overland Creek Gneiss, and Phantom Lake Metamorphic Suite are crosscut by granitic plutons of Archean and earliest Proterozoic age in several places in the Sierra Madre and Medicine Bow Mountains. These granitic intrusions have a variety of compositions including quartz-alkali-feldspar granite, alkali-feldspar granite, granite, granodiorite, quartz monzodiorite, and tonalite (tables 14 and 15). Three felsic bodies have been dated: the gray Spring Lake Granodiorite of the central Sierra Madre as about 2,700 Ma, the red-pink orthogneiss of Premo (1983) in the northern and northeastern Sierra Madre as about 2,700 Ma, and the pink Baggot Rocks Granite in the western Medicine Bow Mountains as about 2,450 Ma.

SPRING LAKE GRANODIORITE

Gray, foliated granodiorite, herein named the Spring Lake Granodiorite (unit Wsl, pl. 1), crops out over an area of about 80 km^2 in the north-central and northwestern Sierra Madre where it intrudes Archean quartzo-feldspathic gneiss, the Vulcan Mountain Metavolcanics (fig. 20), and rocks of the Phantom Lake Metamorphic Suite. The type area is in the area between South Spring Creek Lake and the abandoned Jack Creek mine site. Southeast of the Carrico Ranch (pl. 1), a small body of granodiorite believed to be the Spring Lake Granodiorite cuts the Silver Lake Metavolcanics of the Phantom Lake Metamorphic Suite and is, in turn, intruded by mafic igneous rocks (too small to show on plate 1, in S½SW¼ sec. 8, T. 15 N., R. 87 W.). Spring Lake Granodiorite is similar to massive phases of the quartzo-feldspathic gneiss of the Archean basement, and until detailed mapping was done in the north-central Sierra Madre (in the type area), the Spring Lake Granodiorite had been considered part of the quartzo-feldspathic gneiss terrane. It is strongly foliated and is typically conformable in structure to rocks it intrudes. Hence, it is indeed difficult to distinguish from quartzo-feldspathic gneiss of the basement in much of its outcrop area.

A.C. Spencer recognized the intrusive nature of the Spring Lake Granodiorite during his reconnaissance geologic studies of 1902 (Spencer, 1904, p. 37); he showed quartz diorite intruding metavolcanic rocks on his geologic map (Spencer, 1904, pl. 2). Geochemistry and petrography of the Spring Lake Granodiorite are shown in tables 14 and 15. The Spring Lake Granodiorite is more mafic than the red-pink orthogneiss and Baggot Rocks Granite with the exception of an outcrop of red granite in the extreme northwest Sierra Madre (sample 9, table 14). It also is older than Baggot Rocks Granite inasmuch as the best-fit whole-rock rubidium-strontium isochron for samples collected near the Jack Creek mine site suggests an age for the Spring Lake Granodiorite of this area as about 2,700 Ma. C.E. Hedge (written commun., 1983) attempted to date the Spring Lake Granodiorite by the whole-rock rubidium-strontium method. He concluded that this unit is probably 2,700 Ma old but that the samples had been so disturbed by a later event that the age could not be determined to an acceptable degree of accuracy. A uranium-lead zircon date determined by Premo (1983) that verifies Hedge's conclusion is 2,710±12 Ma for the Spring Lake Granodiorite.

RED-PINK ORTHOGNEISS OF PREMO (1983)

Many red to pink bodies of orthogneiss crop out in both the Medicine Bow Mountains and Sierra Madre (unit Wg, shown as granite and granite gneiss on pl. 1). Dated orthogneiss is in the northern and eastern Sierra Madre, but intrusions that are similar in composition and texture are in the Medicine Bow Mountains on Elk Mountain, southwest of Arlington, and along North Brush Creek (T. 16 N., R. 81 W.; Houston and others, 1968).

The orthogneiss is typically concordant in structure with enclosing quartzo-feldspathic gneiss and locally has gradational contacts with the gneiss, with or without an augen gneiss transitional phase. Locally massive phases of the orthogneiss cut the basement quartzo-feldspathic gneiss, showing that the orthogneiss is younger than the basement or has been mobilized preferentially in a later event.

The red-pink orthogneiss has been dated in two localities by Premo (1983). An orthogneiss of tonalitic composition from the northern Sierra Madre (NW¼NW¼, sec. 16, T. 16 N., R. 86 W.) yielded a uranium-lead zircon age of 2,665±28 Ma, and an orthogneiss of tonalitic composition from the northeast Sierra Madre (NE¼SW¼, sec. 14, T. 15 N., R. 85 W.) yielded an age of 2,683±5 Ma.

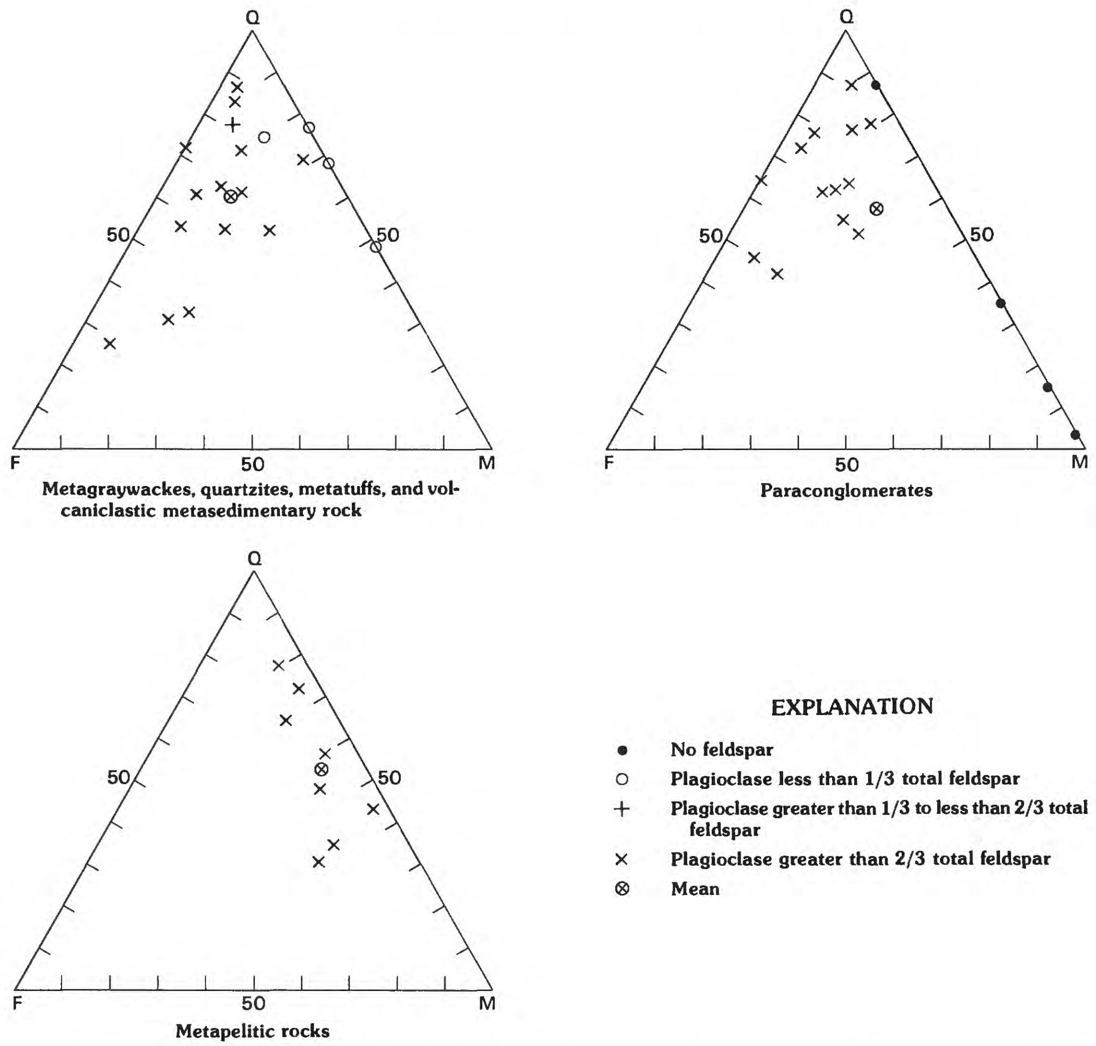


FIGURE 19.—Ternary diagrams showing composition of sand-size fractions of samples from the Silver Lake Metavolcanics, Sierra Madre, Wyoming. Q, quartz; F, feldspar, M, mica plus chlorite.

BAGGOT ROCKS GRANITE

A pink granitic body crops out in the extreme western Medicine Bow Mountains (unit Xbr, T. 15 N., R. 83 W., pl. 1; Houston and others, 1968) that is referred to as the Baggot Rocks Granite (Hills and Houston, 1979), named after the granite exposed at Baggot Rocks (spelled Bagget Rocks on pl. 1), its type locality. The Baggot Rocks Granite is an irregularly shaped phacolithic body in the axis of a north-plunging antiform in quartzo-feldspathic gneiss. It conforms generally in strike to foliation of the quartzo-feldspathic gneiss but is locally crosscutting, especially along the southwest border. It ranges from massive to faintly foliated to strongly sheared, well-foliated granite. Both the granite and quartzo-feldspathic gneiss are cut by mafic dikes that are themselves metamorphosed. Contacts between granite and mafic dikes show the Sederholm effect in which the dikes cut the granite, but the granite intrudes the dikes locally.

Field relationships suggest a complex history for the Baggot Rocks Granite, perhaps involving remobilization. A complex history is also suggested by geochronology. Hills and Houston (1979) reported an age of 2,425±50 Ma determined by the rubidum-strontium whole-rock method. Mineral separates from the Baggot Rocks Granite yielded ages of 1,625±35 Ma and 1,540±70 Ma (Hills and Houston, 1979, table 1). Divis (1977) reported a rubidum-strontium whole-rock age of 2,505±100 Ma for rocks he correlated with the Baggot Rocks Granite and that crop out in the northern Sierra Madre. The granite dated by Divis appears to be the orthogneiss dated by Premo as about 2,700 Ma by the

FIGURE 20.—Spring Lake Granodiorite cutting amphibolitic paraconglomerate in the lower beds of the Vulcan Mountain Metavolcanics, center sec. 5, T. 14 N., R. 86 W., Sierra Madre, Wyoming. Note clast in paraconglomerate in lower right part of photograph. Contacts have been highlighted.

uranium-lead zircon method. We prefer the uranium-lead zircon dates for these rocks, although we admit that there may be granites of different ages in the northern Sierra Madre.

Continued geochronological investigation of the Baggot Rocks Granite suggests that it is Early Proterozoic. W.R. Premo (oral commun., 1984) dated the Baggot Rocks Granite as 2,430±5 Ma by the uranium-lead zircon method, and Bennett and DePaolo (1987) reported an age of 2,400 Ma and a crustal model age (T_{DM}) of 3,400 Ma determined by the samarium-neodymium method. The model crustal-formation age (T_{DM}>2.7 Ga) of Bennett and DePaolo confirms the Archean character of the basement of this area, but the uranium-lead zircon age supports an Early Proterozoic age for the Baggot Rocks Granite. A later Proterozoic thermal history for the Baggot Rocks Granite is suggested by the 1,500–1,600 Ma mineral-separate dates of Hills and Houston (1979), but this thermal event may not have been at a temperature high enough to remobilize the granite as suggested by field evidence.

A single analysis of Baggot Rocks Granite from the type locality is in table 14 (sample 13).

GEOCHRONOLOGY

In T. 14 N., R. 86 W., near North Spring Creek Lake in the Sierra Madre (pl. 1), the Jack Creek Quartzite is intruded by the 2,700-Ma Spring Lake Granodiorite, but the Silver Lake Metavolcanics and Bridger Peak Quartzite are not in contact with dated intrusive rocks. In NW¼ T. 15 N., R. 87 W. and in sec. 1, T. 14 N., R. 86 W., Silver Lake Metavolcanics and the Bridger Peak Quartzite are intruded by felsic igneous rocks that are believed to be equivalent to Spring Lake Granodiorite, but these felsic igneous rocks have not been dated. If our correlations are correct, the Phantom Lake Metamorphic Suite of the Sierra Madre is Late Archean, but this has yet to be verified for the upper(?) part of the succession.

In the Medicine Bow Mountains we correlate the 2,700-Ma red-pink orthogneiss of Premo (1983) (unit Wg, pl. 1) with undated granite gneiss that intrudes both the Overland Creek Gneiss and the Colberg Metavolcanics of the Phantom Lake Metamorphic Suite. If this correlation is correct, both Overland Creek Gneiss and the lower part of the Phantom Lake Metamorphic Suite are Late Archean. We correlate the Overland Creek Gneiss with the Vulcan Mountain Metavolcanics of the Sierra Madre and the Phantom Lake Metamorphic Suite with that of the Sierra Madre. If these correlations are correct, this is additional support for a Late Archean age for the Overland Creek Gneiss and lower part of the Phantom Lake Metamorphic Suite of the Medicine Bow Mountains.

There is little doubt that the basement quartzo-feldspathic gneiss that is intruded by 2,700-Ma igneous rocks is Late Archean or older. The basement gneiss may be as old as middle Precambrian. For example, G.L. Snyder (oral commun., 1984) reported a rubidium-strontium model age of 3.2 Ga for basement gneiss along the east side of the central Laramie Mountains that may correlate with that of this area, and, as noted above, Bennett and DePaolo (1987) determined a model crustal-formation age of 3.4 Ga for the source rocks of the Baggot Rocks Granite.

Intrusive granites of the northern Medicine Bow Mountains are unconformably overlain by radioactive conglomerates of the basal Deep Lake Group in the Onemile Creek area (T. 18 N., R. 78 W.). This unconformity is documented by clasts of granite in the basal conglomerates of the Deep Lake Group and provides evidence for a Proterozoic age of the Deep Lake Group (Karlstrom and others, 1981). Premo (1983) dated detrital zircons from the basal Deep Lake Group of the Sierra Madre as 2,451±12 Ma by the uranium-lead method. This date suggests that

TABLE 14.—*Chemical analyses of samples of Archean granitic intrusive rocks from the Sierra Madre and Medicine Bow Mountains, Wyoming*

[Available modal analyses and rock names are given in table 15. Values are in percent. Samples 1–9 are red-pink orthogneiss; sample 13 is Baggot Rocks Granite; 11 and 12 are Spring Lake Granodiorite. Analysts: Allan Divis (1976, samples 1–6); Steve Boese, University of Wyoming (samples 7–12, 14, 16); samples 13 and 15 from Houston and others (1968). --, not determined]

	Sierra Madre											Medicine Bow Mountains				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Sample No.	AG015	AG067	AG140	AG106	QF152	QF159	SM53	SM54	AFCR1–1	AFCR7–1	AFSC1	SR79–20	--	SR59–30	K261	SR60–55
SiO_2	71.71	72.47	73.65	75.15	71.44	75.88	72.6	75.5	62.7	62.6	69.2	70.7	70.66	73.5	72.3	67.2
Al_2O_3	15.00	15.21	15.37	14.17	15.58	13.88	13.2	11.4	15.5	14.1	12.9	12.6	13.45	13.1	13.6	13.7
Fe_2O_3	.37	.58	.13	.73	2.13	.68	2.85	1.01	4.70	4.38	3.39	4.21	1.88	1.36	.49	4.17
MgO	.05	.15	.18	.10	.50	.01	.73	.15	1.74	3.74	1.55	1.39	.73	.32	.05	2.25
MnO	.001	.001	.014	.013	.030	.007	.03	.03	.08	.08	.05	.05	--	.02	.01	.07
CaO	1.14	1.19	.64	1.13	1.50	1.02	1.57	.43	5.64	2.82	2.26	.81	1.67	1.36	.12	1.84
Na_2O	5.85	5.26	4.05	5.02	3.65	5.12	3.54	4.78	6.11	4.47	3.72	4.26	3.45	5.44	2.72	4.17
K_2O	4.78	4.52	4.87	3.28	3.97	2.63	2.61	3.59	1.40	2.86	3.98	3.32	5.13	2.40	9.22	2.91
TiO_2	.31	.05	.13	.03	.32	.04	.40	.0	.50	.60	.3	.4	.41	.0	.0	.5
P_2O_5	.06	.04	.12	.10	.23	.11	.10	.06	.22	.23	.13	.14	--	.04	.01	.25
CO_2	.15	.18	.11	.04	.14	.08	--	--	--	--	--	--	--	--	--	--
H_2O	.50	.30	.65	.22	.55	.45	--	--	--	--	--	--	1.36	--	--	--
Total	99.92	99.93	99.91	99.98	100.04	99.91	97.63	96.95	98.55	95.88	97.48	97.88	98.74	97.54	98.52	97.06

SAMPLE DESCRIPTIONS

1–6. Divis (1976, p. 49).
7. Red; near Jack Creek, NW¼SE¼ sec. 32, T. 16 N., R. 86 W.
8. Red; near Alameda Creek, NE¼NE¼ sec. 28, T. 16 N.,R. 86 W.
9. Red; north of Carrico Ranch, SE¼SW¼ sec. 1, T. 15 N., R. 88 W.
10. Gray; crosscuts Silver Lake Metavolcanics south of Carrico Ranch, SW¼SE¼ sec. 7, T. 15 N., R. 87 W.
11. Gray; in North Spring Creek Lake cirque, SE¼SW¼ sec. 4, T. 14 N., R. 86 W.
12. Center sec. 24, T. 17 N., R. 82 W.
13. Near Baggot Rocks, T. 15 N., R. 83 W.
14. Near Lincoln Park, center sec. 3, T. 16 N., R. 81 W.
15. Near Arlington, NE¼ sec. 31, T. 19 N., R. 78 W.
16. Near Foote Creek, SE¼ sec. 28, T. 19 N., R. 79 W.

TABLE 15.—*Modal compositions of samples of Archean granitic intrusive rocks from the Sierra Madre, Woming*

[Modes, in percent, from point-counted thin sections. *, samples from Divis (1976). Tr, trace; --, not determined]

Sample No.	Quartz	Plagioclase	Potassium feldspar	Muscovite	Biotite	Epidote	Hornblende	Carbonate	Sericite after plagioclase	Epidote after plagioclase	Apatite	Zircon	Opaque minerals	Sphene	Chlorite	An content of plagioclase	Rock name (Streckeisen, 1976)
Spring Lake Granodiorite (this report)																	
SM56.............	26.7	30.4	11.8	1.2	19.9	6.8	0.6	--	2.5	--	--	--	--	--	--	--	Granodiorite
AFCR7–1.......	15.0	38.8	10.6	3.1	10.6	5.6	10.6	--	5.6	--	--	--	--	--	--	--	Do.
AFSC–1..........	30.6	28.3	16.0	2.3	15.5	1.0	--	1.4	1.8	3.2	--	--	--	--	--	--	Do.
Mean (3)....	24	33	13	2	15	5	4		3	1							Granodiorite
Granite (this report)																	
SM53.............	49.2	37.6	2.8	9.4	--	0.6	--	--	0.6	--	--	--	--	--	--	--	Tonalite
SM99.............	34.3	40.0	15.6	1.2	2.5	3.8	0.6	--	1.9	--	--	--	--	--	--	--	Granodiorite
SM13–341......	27.2	32.4	12.1	8.8	13.9	--	--	1.7	4.1	--	--	--	--	--	--	--	Do.
AFCR1–1.......	19.8	45.7	12.3	--	Tr	4.9	13.0	--	1.2	3.1	--	--	--	--	--	--	Do.
TS144............	24.5	47.9	--	1.2	20.9	5.5	--	--	--	--	--	--	--	--	--	--	Tonalite
OF159*..........	32.3	51.2	16.5	Tr	--	Tr	--	--	--	--	Tr	--	--	--	--	8	Granodiorite
AG015*..........	17.3	55.1	27.6	--	--	Tr	--	--	--	--	--	--	--	--	--	2	Quartz monzodiorite
AG064*..........	23.8	49.5	26.7	Tr	--	Tr	--	--	--	--	--	--	--	--	--	10	Granite
AG067*..........	19.2	52.6	27.4	0.8	--	Tr	--	--	--	--	--	--	--	--	--	8	Quartz monzodiorite
AG104*..........	28.1	44.2	27.7	--	--	--	--	--	--	--	Tr	--	--	--	--	6	Granite
AG106*..........	28.8	50.0	21.2	Tr	--	Tr	--	--	--	--	Tr	--	--	--	--	10	Granoidiorite
AG140*..........	26.3	43.1	29.5	1.1	--	--	--	--	--	--	Tr	--	--	--	--	--	Granite
Mean (13)..	28	46	18	2	3	1	1	1									Granodiorite
Granite (Miller, 1971)[1]																	
Mean (4)....	31.2	26.2	11.2	21.5	Tr	1.2	--	--	--	--	Tr	--	Tr	Tr	Tr	30–32	Granodiorite
Granite (Hughes, 1973)[2]																	
Mean (4)....	29	18	45	5	6	Tr	Tr	--	--	--	Tr	Tr	Tr	--	--	--	Granite
Felsic dikes related to granite (Miller, 1971)[1]																	
Mean (3)....	30.3	26.0	21.7	15.0	Tr	3.3	--	--	--	--	--	Tr	Tr	Tr	Tr	28–31	Granite
Felsic dikes related to granite (Hughes, 1973)[2]																	
Mean (3)....	30	25	24	14	Tr	Tr	--	--	--	--	--	Tr	Tr	--	--	--	Granite

[1]T. 15 N., R. 85 W.
[2]T. 15 N., R. 84 W.

SAMPLE LOCALITIES

SM56: Northwestern Sierra Madre, N½ sec. 1, T. 15 N., R. 88 W.
AFCR7–1: Northwestern Sierra Madre, SE¼ sec. 7, T. 15 N., R. 87 W.
AFSC–1: Near North Spring Creek Lake, S½ sec. 4, T. 14 N., R. 86 W.
SM53: Near Jack Creek, NW¼SE¼ sec. 32, T. 16 N., R. 86 W.
SM99: Northeastern Sierra Madre, N½ sec. 11, T. 15 N., R. 86 W.
SM13–341: From drill hole SM13, sec. 25, T. 16 N., R. 87 W.
AFCR1–1: North of Carrico Ranch, SE¼SW¼ sec. 1, R. 15 N., R. 88 W.
TS144: Northeastern Sierra Madre, NE¼ sec. 31, T. 15 N., R. 85 W.

deposition of the basal Deep Lake Group took place after 2,450 Ma. Premo (1983) dated a metagabbro that intrudes the Cascade Quartzite (a unit in the upper part of the Deep Lake Group) as 2,092±4 Ma by the uranium-lead zircon method. These dates of Premo bracket the deposition of rocks of the Deep Lake Group between about 2,450 and 2,100 million years.

METASEDIMENTARY ROCKS OF EARLY PROTEROZOIC AGE NORTH OF THE CHEYENNE BELT

Rocks of Early Proterozoic age that overlie unconformably or are in fault contact with Late Archean successions are here formally named the "Snowy Pass Supergroup" (pl. 1) for Snowy Range Pass, sec. 20, T. 16 N., R. 79 W., in the Medicine Bow Mountains and the Snowy Pass Group (pl. 1) in the Sierra Madre (this report and Karlstrom and others, 1983). In the Medicine Bow Mountains, these rocks include the Deep Lake Group (pl. 1), which consists largely of fluvial successions, and the Libby Creek Group (pl. 1), which contains largely marine rocks. The Deep Lake Group and Libby Creek Group successions are primarily siliciclastic metasedimentary rocks (quartzite-dominated rock successions). Only one formation, the Towner Greenstone (unit Xt, pl. 1) of the Libby Creek Group, consists of volcanic rocks. The type section of the Snowy Pass Supergroup is well exposed along Wyoming Highway 130, where the French Slate (unit Xf, pl. 1) is in sec. 14, T. 16 N., R. 79 W., and successively older formations are exposed along the highway to the west. The oldest formation exposed along Wyoming Highway 130 is the Medicine Peak Quartzite (unit Xm, pl. 1) in sec. 23, T. 16 N., R. 80 W. The type section of the Snowy Pass that includes formations below the Medicine Peak Quartzite continues by taking the dirt road north to South Twin Lake and Gold Hill, secs. 14, 15, and 16, T. 16 N., R. 80 W. In the Sierra Madre, correlative rocks are referred to as the Snowy Pass Group, because our stratigraphic understanding of these units is less detailed, reflecting the complex structure in the Sierra Madre. The Snowy Pass Group is divided into six formations (pl. 1).

Rocks of the Deep Lake and Libby Creek Groups have been described in detail previously (Houston and others, 1968; Karlstrom and Houston, 1979a, 1979b; Lanthier, 1979; Graff, 1979), so it is not necessary to repeat rock descriptions in this report. However, that terminology is adopted with the changes shown in table 16, made necessary by recent mapping.

DEEP LAKE AND LIBBY CREEK GROUPS OF THE SNOWY PASS SUPERGROUP IN THE MEDICINE BOW MOUNTAINS

The Deep Lake Formation of the Medicine Bow Mountains was raised in stratigraphic rank to Deep Lake Group by Karlstrom and Houston (1979a, 1979b), and it included six formations (table 16). However, we now consider the uppermost unit, the Rock Knoll Formation, to be part of the overlying Libby Creek Group because it is in apparent depositional contact with the overlying Headquarters Formation of the Libby Creek and is now interpreted to be entirely in fault contact with the underlying Vagner Formation of the Deep Lake Group (fig. 21). Evidence for the fault contact between the Rock Knoll and Vagner Formations includes: (1) breccias at the contacts between these formations in Trail Creek (sec. 26, T. 17 N., R. 79 W.) and South Brush Creek (secs. 15 and 22, T. 16 N., R. 80 W.); (2) change in strike of bedding by 45° south of Vagner Lake (sec. 1, T. 16 N., R. 80 W.); (3) change in dip of bedding by 70° northwest of Rock Creek Knoll (secs. 27 and 34, T. 17 N., R. 79 W.); and (4) a topographic scarp between Reservoir and Vagner Lakes (pl. 1) (Lanthier, 1978, p. 26). This fault contact, here called the Reservoir Lake fault, is now considered to be the contact between the Deep Lake and Libby Creek Groups.

The amount and sense of displacement on the Reservoir Lake fault are not known; the fault is subparallel to bedding, and there are no stratigraphic cut-offs that can be matched on opposite sides of the fault. We interpret the fault as a thrust for three reasons. First, it is at a low angle to bedding. Second, inferred extensions of the Reservoir Lake fault to the southwest juxtapose rocks of the Libby Creek Group with Archean gneissic basement, without intervening rocks of the Phantom Lake Suite and Deep Lake Group (pl. 1). This relationship suggests large displacement. Third, in the Reservoir Lake area, the fault separates the Vagner Formation from the Headquarters Formation, both of which contain diamictite units of similar character. Whereas these formations cannot be directly correlated because of the presence of marble in the Vagner but not in the Headquarters, both are believed to have been deposited in a similar glaciomarine setting. Thus, the fault may have caused repetition of different facies of approximately the same stratigraphic zone, implying thrust displacement large enough that sedimentary facies are different in the footwall and hanging wall.

The alternative explanation is that there is very little displacement along the fault in the Reservoir Lake area and that the stratigraphic succession is

TABLE 16.—*Comparison of stratigraphic nomenclature for metasedimentary rocks in the Medicine Bow Mountains, Wyoming*

				This report		Karlstrom and Houston (1979a, 1979b); Lanthier (1979)		Houston and others (1968)	Blackwelder (1926)
EARLY PROTEROZOIC	Snowy Pass Supergroup	Libby Creek Group (2,000+ Ma)	Upper part	French Slate	Libby Creek Group	French Slate	Libby Creek Group	French Slate	French Slate
EARLY PROTEROZOIC	Snowy Pass Supergroup	Libby Creek Group (2,000+ Ma)	Upper part	Towner Greenstone	Libby Creek Group	Towner Greenstone	Libby Creek Group	Towner Greenstone	Towner Greenstone
EARLY PROTEROZOIC	Snowy Pass Supergroup	Libby Creek Group (2,000+ Ma)	Upper part	Nash Fork Formation	Libby Creek Group	Nash Fork Formation	Libby Creek Group	Nash Fork Formation	Ranger Marble Anderson Phyllite Nash Marble Series
EARLY PROTEROZOIC	Snowy Pass Supergroup	Libby Creek Group (2,000+ Ma)		LEWIS LAKES THRUST FAULT	Libby Creek Group		Libby Creek Group		
EARLY PROTEROZOIC	Snowy Pass Supergroup	Libby Creek Group (2,000+ Ma)	Lower part	Sugarloaf Quartzite	Libby Creek Group	Sugarloaf Quartzite	Libby Creek Group	Sugarloaf Quartzite	Sugarloaf Metaquartzite
EARLY PROTEROZOIC	Snowy Pass Supergroup	Libby Creek Group (2,000+ Ma)	Lower part	Lookout Schist	Libby Creek Group	Lookout Schist	Libby Creek Group	Lookout Schist	Lookout Schist
EARLY PROTEROZOIC	Snowy Pass Supergroup	Libby Creek Group (2,000+ Ma)	Lower part	Medicine Peak Quartzite	Libby Creek Group	Medicine Peak Quartzite	Libby Creek Group	Medicine Peak Quartzite	Medicine Peak Metaquartzite
EARLY PROTEROZOIC	Snowy Pass Supergroup	Libby Creek Group (2,000+ Ma)	Lower part	Heart Formation	Libby Creek Group	Heart Formation	Libby Creek Group	Heart Formation	Heart Metagraywacke
EARLY PROTEROZOIC	Snowy Pass Supergroup	Libby Creek Group (2,000+ Ma)	Lower part	Headquarters Formation	Libby Creek Group	Headquarters Formation	Libby Creek Group	Headquarters Schist (included units now mapped as Vagner)	Headquarters Schist (included units now mapped as Vagner)
EARLY PROTEROZOIC	Snowy Pass Supergroup	Libby Creek Group (2,000+ Ma)	Lower part	UNCONFORMITY		UNCONFORMITY	Libby Creek Group		
EARLY PROTEROZOIC	Snowy Pass Supergroup	Libby Creek Group (2,000+ Ma)	Lower part	Rock Knoll Formation	Deep Lake Group	Rock Knoll Formation	Libby Creek Group		
EARLY PROTEROZOIC	Snowy Pass Supergroup			RESERVOIR LAKE THRUST FAULT	Deep Lake Group		Libby Creek Group		
EARLY PROTEROZOIC	Snowy Pass Supergroup	Deep Lake Group		Vagner Formation	Deep Lake Group	Vagner Formation	Libby Creek Group		
EARLY PROTEROZOIC	Snowy Pass Supergroup	Deep Lake Group		UNCONFORMITY	Deep Lake Group			UNCONFORMITY	
EARLY PROTEROZOIC	Snowy Pass Supergroup	Deep Lake Group		Cascade Quartzite	Deep Lake Group	Cascade Quartzite	Deep Lake Formation	Marble	Deep Lake Metaquartzite
EARLY PROTEROZOIC	Snowy Pass Supergroup	Deep Lake Group		UNCONFORMITY	Deep Lake Group		Deep Lake Formation		
EARLY PROTEROZOIC	Snowy Pass Supergroup	Deep Lake Group		Campbell Lake Formation	Deep Lake Group	Campbell Lake Formation	Deep Lake Formation		
EARLY PROTEROZOIC	Snowy Pass Supergroup	Deep Lake Group		UNCONFORMITY	Deep Lake Group		Deep Lake Formation		
EARLY PROTEROZOIC	Snowy Pass Supergroup	Deep Lake Group		Lindsey Quartzite	Deep Lake Group	Lindsey Quartzite	Deep Lake Formation		
EARLY PROTEROZOIC	Snowy Pass Supergroup	Deep Lake Group		Magnolia Formation	Deep Lake Group	Magnolia Formation	Deep Lake Formation	Quartzite	
				UNCONFORMITY		UNCONFORMITY	Deep Lake Formation		
LATE ARCHEAN	Snowy Pass Supergroup	Phantom Lake Metamorphic Suite		Conical Peak Quartzite	Phantom Lake Metamorphic Suite		Deep Lake Formation		
LATE ARCHEAN	Snowy Pass Supergroup	Phantom Lake Metamorphic Suite		Colberg Metavolcanics	Phantom Lake Metamorphic Suite	Upper part	Deep Lake Formation	Metaconglomerate	
LATE ARCHEAN	Snowy Pass Supergroup	Phantom Lake Metamorphic Suite		Bow Quartzite	Phantom Lake Metamorphic Suite		Deep Lake Formation		
LATE ARCHEAN	Snowy Pass Supergroup	Phantom Lake Metamorphic Suite		Rock Mountain Conglomerate	Phantom Lake Metamorphic Suite		Deep Lake Formation		
LATE ARCHEAN	Snowy Pass Supergroup	Phantom Lake Metamorphic Suite		UNCONFORMITY(?)	Phantom Lake Metamorphic Suite	UNCONFORMITY	Deep Lake Formation		
LATE ARCHEAN	Snowy Pass Supergroup	Phantom Lake Metamorphic Suite		Stud Creek Metavolcaniclastics	Phantom Lake Metamorphic Suite	Lower part	Deep Lake Formation	Metavolcanic rocks	
LATE ARCHEAN				UNCONFORMITY(?)	Phantom Lake Metamorphic Suite				
LATE ARCHEAN				Overland Creek Gneiss	Phantom Lake Metamorphic Suite				

essentially uninterrupted in this area (Houston and others, 1968). This interpretation suggests that the Reservoir Lake fault is not continuous with the faults to the southwest, mentioned above. This lack of continuity remains a possibility but creates problems in explaining the juxtaposition of the Libby Creek Group with Archean basement. Houston and others (1968) proposed a possible unconformity at this contact but, as they pointed out, no sedimentary evidence is here or elsewhere in the Medicine Bow Mountains for such an unconformity, no basal conglomerates, and no concentration of granitic detritus in the lower part of the Libby Creek Group. Thus, at present, we prefer the thrust-fault interpretation.

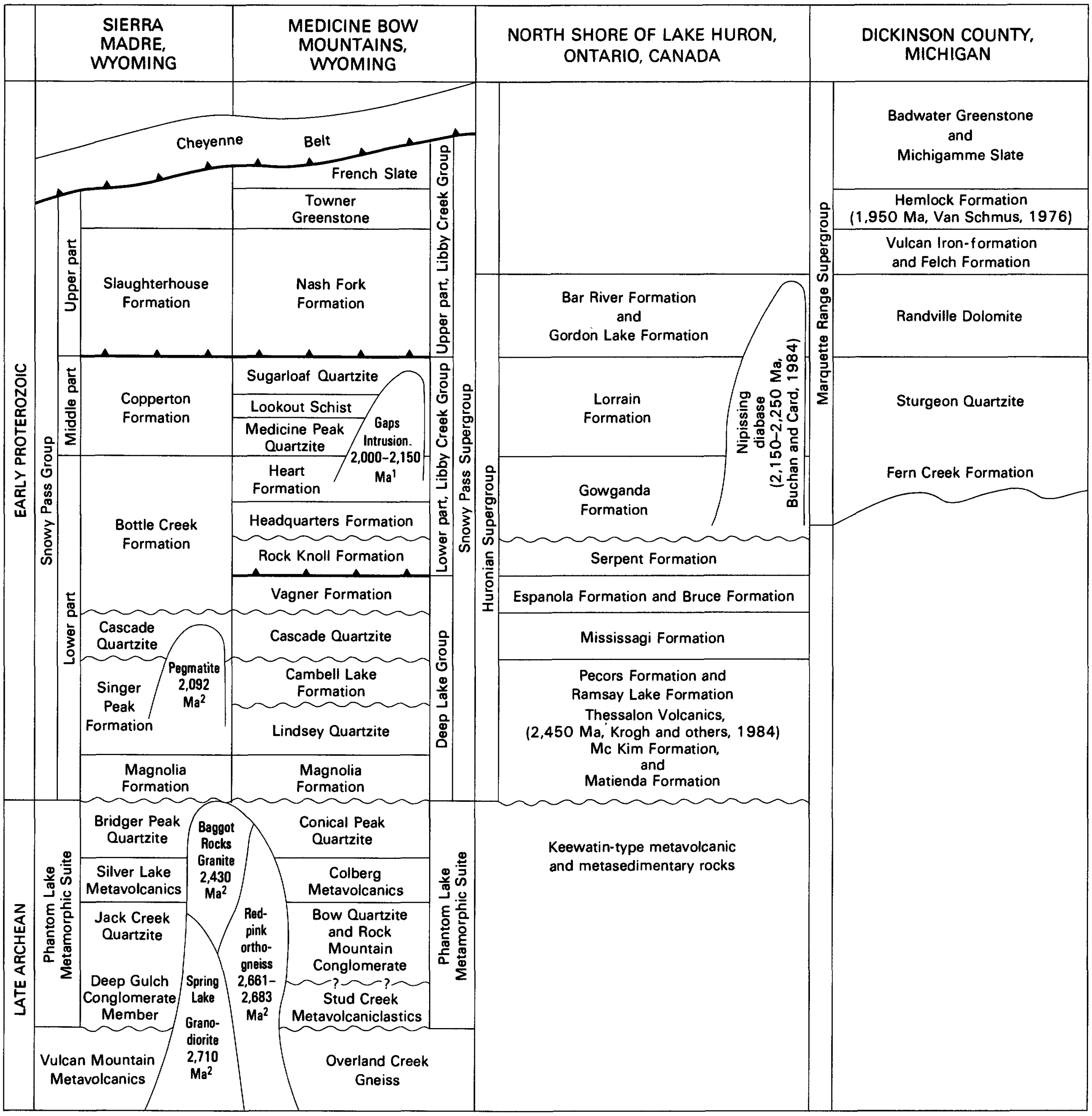
Uncertainties in the nature of the Deep Lake-Libby Creek contact pose some uncertainties in assigning relative ages to the two successions. All previous workers have interpreted the Libby Creek Group to be younger than the Deep Lake Group based on stratigraphic evidence (Blackwelder, 1926; Houston and others, 1968). We still believe this interpretation to be true, in spite of our proposed thrust fault. If the Vagner and Headquarters Formations are indeed diverse facies of a single stratigraphic zone repeated by thrusting, then the stratigraphic-sequence argument is still valid. Furthermore, even if these two glacial units cannot be considered to be broadly time-equivalent units, there are indications that the Libby Creek Group is younger than the Deep Lake Group. Houston, Karlstrom, and Graff (1979) and Houston and Karlstrom (1980) suggested a correlation between the Deep Lake and Libby Creek Groups of the Medicine Bow Mountains and the Huronian Supergroup of southern Ontario (fig. 21). The most compelling units for correlation, in ascending order, are: (1) pyritic and radioactive quartz-pebble conglomerates (Magnolia Formation of Wyoming and Matienda Formation of Ontario); (2) glacial diamictites (Campbell Lake, Vagner, and Headquarters Formations of Wyoming, and Ramsay Lake, Bruce, and Gowganda Formations of Ontario); (3) hematite-bearing, aluminum-rich quartzites (Medicine Peak Quartzite of Wyoming and Lorrain Formation of Ontario) (fig. 21). These correlations suggest that the Libby Creek Group is younger than the Deep Lake Group. Also, the presence of hematite-bearing rather than pyrite-bearing quartzites in the Libby Creek Group is evidence that the Libby Creek Group is younger than the Deep Lake Group, if Roscoe (1973) is correct about the significance of these minerals as indicators of an increase in the oxygen content of Earth's atmosphere in the Early Proterozoic.

The Libby Creek Group of the Medicine Bow Mountains is now divided into lower and upper parts (pl. 1, table 16). This distinction is made for several reasons. First, the lithologies in these two successions are quite different. Whereas the lower succession is predominantly siliciclastic, the upper part of the Libby Creek Group contains dolomite, volcanogenic rocks, and black slate. This major change in lithology indicates different conditions for sedimentation for the two successions. Second, new map interpretations place a major fault, the Lewis Lake fault, between the Sugarloaf Quartzite and the Nash Fork Formation. Evidence for this fault includes: (1) the disappearance of the Sugarloaf Quartzite in secs. 9, 10, and 17, T. 16 N., R. 79 W.; (2) an abrupt thinning of the Medicine Peak Quartzite in sec. 2, T. 16 N., R. 79 W.; and (3) various breccia zones along the contact (Lanthier, 1978, p. 26). We interpret the fault to be a rotated thrust fault, which implies that the upper part of the Libby Creek Group is allochthonous or parautochthonous with respect to the lower part and may have been deposited in very different tectonic and sedimentary environments. Third, although the exact age relationship between the two successions is not yet clear, there is one indication that the upper part of the Libby Creek Group may be appreciably younger than the lower part. The Gaps Intrusion (unit Xgt, pl. 1) cuts the lower part but not the upper, and regional correlations with other metasedimentary successions in North America suggest that the upper part of the group may correlate with the 1,900- to 2,100-Ma Marquette Range Supergroup of Michigan, whereas the lower part may correlate with the 2,150±-Ma Huronian Supergroup of Ontario (Houston and Karlstrom, 1980) (fig. 21).

A stratigraphic column for metasedimentary rocks of the Snowy Pass Supergroup of the Medicine Bow Mountains is shown in figure 3. Maximum thickness of the Deep Lake and Libby Creek Groups is about 10,555 m, and total thickness of Archean and Proterozoic successions is between 13,000 and 16,000 m.

SNOWY PASS GROUP IN THE SIERRA MADRE

The stratigraphy of the Proterozoic rocks of the Sierra Madre was described by Divis (1976) and Graff (1979), and except for the newly named Bottle Creek Formation, the detailed lithologic descriptions are not repeated here. However, recent mapping has necessitated several terminology changes: (1) some of the rocks assigned to the Vagner Formation in the Sierra Madre by Graff (1979) are reassigned in this report to the Bottle Creek Formation; (2) the Copperton Quartzite is called the Copperton Formation from Karlstrom and others (1983); (3) the Singer Peak Formation includes both the Singer Peak Formation and rocks



[1] C.E. Hedge (written communication, 1982)
[2] Premo (1983)

FIGURE 21.—Comparative stratigraphy of metasedimentary rocks of the Sierra Madre; Medicine Bow Mountains; north shore of Lake Huron, Ontario, Canada; and Dickinson County, Michigan.

assigned to the Campbell Lake Formation by Graff (1979); and (4) the entire Proterozoic succession is referred to as the Snowy Pass Group—lower, middle, and upper parts—for reasons discussed below (figs. 9, 21).

SINGER PEAK FORMATION

The Singer Peak Formation of this report (unit Xsp, pl. 1) includes the Singer Peak Formation and Camp bell Lake Formation of Graff (1978, 1979). The Campbell Lake Formation of Graff overlies the Singer Peak of Graff in the western Sierra Madre in a limited outcrop area and cannot be positively identified through most of the Sierra Madre. Because of its limited outcrop area and discontinuous nature, the rocks assigned to the Campbell Lake in the Sierra Madre by Graff are defined as part of the Singer Peak of this report. The Singer Peak Formation of this report is named for Singer Peak in SW¼ sec. 11, T. 14 N., R. 87 W., of the Sierra Madre. The type area for the lower part of the Singer Peak is in the western Sierra Madre in SE¼ sec. 4, NE¼ sec. 9, T. 14 N., R. 87 W., and that of the upper part of the Singer Peak is also in the western Sierra Madre in E½ sec. 8, T. 14 N., R. 87 W.

The Singer Peak Formation is thicker in the western Sierra Madre, where it is about 831 m thick. The exact thickness is uncertain because the unit is folded and is not fully exposed. The unit thins to the east to less than 500 m in sec. 20, T. 14 N., R. 85 W. East of sec. 20, T. 14 N., R. 85 W., the Singer Peak Formation is missing, and a thick gabbroic sill occupies the stratigraphic position of the Singer Peak. The Singer Peak may simply thin to the east, but we suspect it was removed by a fault that brings the Cascade Quartzite against the Magnolia Formation of the Deep Lake Group.

The lower part of the Singer Peak Formation (formally assigned to the Singer Peak Formation by Graff, 1979), from base to top, consists of thick silver-colored phyllites with red garnet, lesser amounts of medium-grained buff to orange quartzites, thick green phyllites, and thin blue phyllites. The quartzite layers are thin and sparsely scattered through the green phyllite. The green phyllite also contains lenses of graywacke that thicken toward the upper part of the green phyllite. No primary structures were noted in this lower part with the exception of bedding in quartzite. The upper part of the Singer Peak Formation (formally assigned to the Campbell Lake Formation by Graff, 1979) is discontinuous and consists of poorly sorted paraconglomerate containing angular granite clasts, thin quartzites, and thin green phyllite. This part is best exposed in E½ sec. 8, T. 14 N., R. 87 W. Quartzite of the upper part is thinly bedded, fine- to medium-grained micaceous rock having rare crossbeds and channels. Paraconglomerates, possibly of glacial origin, contain poorly sorted, angular clasts of granite in a dark-green to black phyllitic matrix. Matrix-supported clasts range from 30 cm to a few millimeters in longest dimension and may be widely scattered within the rock. Foliation of matrix material is bent around clasts locally, suggestive of dropstone textures.

The Singer Peak Formation interfingers with the Magnolia Formation in the Dexter Peak area (sec. 21, T. 15 N., R. 87 W.), but contacts are not exposed elsewhere. The contact between the Singer Peak and the Cascade Quartzite is poorly exposed but is probably an unconformity (pl. 1).

The Singer Peak Formation of this report is correlated with the Lindsey Quartzite and Campbell Lake Formation of the Medicine Bow Mountains (fig. 21). In the Medicine Bow Mountains, the Lindsey Quartzite is interpreted as fluvial and the Campbell Lake Formation as of possible glacial origin (Karlstrom and others, 1983). The Singer Peak Formation of the Sierra Madre may be an offshore facies of the Medicine Bow Mountains formations.

VAGNER FORMATION AND COPPERTON QUARTZITE OF GRAFF (1979)

Graff (1978, 1979) correlated his Vagner Formation of the Sierra Madre, a heterogeneous assemblage of quartzite, marble, phyllite, and diamictite, with the Vagner Formation of the Medicine Bow Mountains; the Copperton Quartzite was correlated with the overlying Rock Knoll Formation; and the Slaughterhouse Formation above the Copperton was correlated with the Headquarters Formation of the Medicine Bow Mountains. Thus, Graff suggested that the Slaughterhouse was the only unit in the Sierra Madre correlatable with the Libby Creek Group of the Medicine Bow Mountains. However, recent mapping in the western Sierra Madre demonstrates that the Copperton Quartzite of Graff is a threefold unit consisting of a lower kyanitic quartzite (that we correlate with the Medicine Peak Quartzite of the Medicine Bow Mountains), a middle laminated phyllite (that we correlate with the Lookout Schist of the Medicine Bow Mountains), and an upper orthoquartzitic quartzite (that we correlate with the Sugarloaf Quartzite of the Medicine Bow Mountains). We therefore have changed the formal name of the Copperton Quartzite to Copperton Formation (unit Xcp, pl. 1), and we redescribe the lithology as discussed below.

The Vagner Formation of Graff (1979) occupies the stratigraphic position of the Vagner Formation, Rock Knoll Formation, Headquarters Formation, and Heart Formation of the Medicine Bow Mountains. We believe that Graff was correct in correlating rocks of his Vagner with those of the Medicine Bow Mountains, but we believe that Graff's Vagner includes equivalents of the Headquarters Formation and Rock Knoll Formation of the Medicine Bow Mountains. We have therefore reassigned in this report Graff's Vagner Formation of the Medicine Bows to the newly named Bottle Creek Formation of the Sierra Madre.

Because rocks of the Bottle Creek Formation straddle the boundary between the Deep Lake and Libby Creek Groups of the Medicine Bow Mountains, we no longer use the terms "Deep Lake" and "Libby Creek Groups" in the Sierra Madre. Instead, we refer to the entire lower part of the Proterozoic succession as the Snowy Pass Group (fig. 21).

BOTTLE CREEK FORMATION

The Bottle Creek Formation as defined in this report is named for Bottle Creek in sec. 24, T. 14 N., R. 85 W. and sec. 19, T. 14 N., R. 84 W. of the eastern Sierra Madre. The type section of the Bottle Creek is in secs. 22, 23, 26, and 27, T. 14 N., R. 87 W., of the western Sierra Madre. We doubt that there is a complete section of the Bottle Creek anywhere in the Sierra Madre, because parts of the section have been removed by faults. The Bottle Creek is exposed in the center of a syncline in the area of the type section; we believe that the lower and middle parts of the Bottle Creek are exposed here. In this area the base of the Bottle Creek is a diamictite unit that is overlain successively by metalimestone, quartzite, a diamictite unit, and quartzite. The upper quartzite is in the center of the syncline where any younger beds were probably removed by erosion. The diamictite units of the Bottle Creek consist of paraconglomerate in a matrix of green or tan phyllite interbedded with medium- to coarse-grained, pale-green, schistose, feldspathic quartzite. Dispersed angular to round clasts (as much as 60 cm in diameter) of red granite, gray granite, quartzite, and green phyllite are in the paraconglomerates. In less deformed areas individual clasts can be removed from the conglomerate matrix, and some have a flatiron shape suggestive of glacial origin. Bedding and (or) foliation is generally warped around clasts because of deformation, but in a few areas textures suggestive of dropstones have been recognized. The quartzites are slabby and buff with interbeds of phyllite. The carbonates are fine grained, yellow, red, and green metalimestone. The thickness of individual units within the Bottle Creek varies greatly but averages in the type section are: lower diamictite unit 80+ m; metalimestone, 30 m; quartzite, 150 m; diamictite unit, 50 m; and upper quartzite, 50+ m.

The Bottle Creek Formation was removed by a fault in sec. 29, T. 14 N., R. 86 W., reappears in sec. 30, T. 14 N., R. 85 W., and continues to sec. 30, T. 14 N., R. 84 W., where it was also removed by a fault. The easternmost outcrop of the Bottle Creek is a 3.1-km-long faulted sliver in secs. 27 and 28, T. 14 N., R. 84 W. We believe that only the lower part of the Bottle Creek is exposed east of the type section where the formation thins to about 250–300 m. Some of the best exposures of the Bottle Creek Formation are in the eastern Sierra Madre along the Hog Park Road south of the area where the road crosses Bottle Creek and north of the area where the road crosses the north fork of the Encampment River. Here it consists of interfingering phyllites, paraconglomerates, calc-silicate schists, and quartzites. Outcrops west of the Hog Park Road show textures and structures suggestive of glacial origin.

The contact between the Bottle Creek and underlying Cascade Quartzite is poorly exposed but is probably an unconformity. The upper contact in the Sierra Madre is a fault that brings the Copperton Formation or Slaughterhouse Formation against the Bottle Creek (pl. 1).

We correlate the lower diamictite unit and metalimestone of the Bottle Creek with the Vagner Formation of the Medicine Bow Mountains; both formations have a lower diamictite unit and an upper limestone, a stratigraphic sequence found nowhere else in either range. We suggest that the middle quartzite and upper diamictite unit of the Bottle Creek may correlate with the Rock Knoll Formation and Headquarters Formation of the Medicine Bow Mountains. All of the units of the Bottle Creek are thinner than possible correlatives in the Medicine Bow Mountains, but lithologies are very similar except that beds of the Sierra Madre are thinner and contain more phyllite. We interpret the Bottle Creek as an offshore facies of the Medicine Bow succession, and we consider it glaciomarine.

The correlation between probable glaciomarine units in the Sierra Madre and Medicine Bow Mountains is convincing and helps to verify the overall correlatives that have been suggested for the two ranges (fig. 21).

COPPERTON FORMATION

Recent mapping in the western Sierra Madre shows that the Copperton Quartzite of Graff (1978, 1979) is a threefold unit consisting of a lower quartzite, a middle laminated phyllite, and an upper quartzite. The middle laminated phyllite is well exposed in sec. 31, T. 14 N., R. 86 W., (unit Xcp, pl. 1) where it crops out north and south of the graded road from Encampment to Baggs, Wyo. (Wyoming Highway 70). The middle laminated phyllite is variable in lithology, but the most common rock type is a laminated phyllite consisting of alternating quartz and mica-rich layers. This laminated phyllite grades upsection into a rock succession consisting of alternating beds of schist and quartzite. The quartzite beds are 30 to 50 cm thick and show small-scale planar crossbedding. In the lower or northern outcrops, the laminated phyllite contains magnetite-rich quartzite. All these lithologic characteristics are found in the Lookout Schist (unit Xl, pl. 1) of the lower part of the Libby Creek Group in the Medicine Bow Mountains. In fact, the middle laminated phyllite of the Copperton Quartzite and Lookout Schist are nearly identical lithologically. We have correlated the middle laminated phyllite of the Copperton Quartzite with the Lookout Schist of the Medicine Bow Mountains (fig. 21). If this correlation is correct, it is reasonable to assume that the lower quartzite of the Copperton is equivalent to the Medicine Peak Quartzite of the Medicine Bow Mountains and that the upper quartzite of the Copperton is equivalent to the Sugarloaf Quartzite of the Medicine Bow Mountains. Both lower and upper quartzites of the Copperton Quartzite are strongly deformed, and we do not believe that either of the quartzites represents a complete section. However, the lower quartzite contains kyanite and in this respect resembles the Medicine Peak Quartzite, and the upper quartzite is an orthoquartzite, similar to the Sugarloaf Quartzite. We therefore suggest that the Copperton Quartzite includes rock units equivalent to the Medicine Peak Quartzite, Lookout Schist, and Sugarloaf Quartzite of the Libby Creek Group in the Medicine Bow Mountains and we have changed its formal name to Copperton Formation (unit Xcp, pl. 1) after the former village of Copperton in NE¼ sec. 36, T. 14 N., R. 87 W.

The type section of the Copperton Formation is in the western Sierra Madre along a line that crosses Wyoming Highway 70, from SW¼ sec. 31 to S½ sec. 29, T. 14 N., R. 86 W. This section is incomplete because both lower and upper parts of the section have been removed by major thrust faults. The maximum exposed thickness in the type section is about 1,070 m.

The basal quartzite beds of the Copperton (Medicine Peak Quartzite equivalent) are predominantly coarse-grained, highly sheared, kyanite-bearing quartzite that is essentially a quartz arenite. Thin sections of the basal quartzite show complete recrystallization of quartz in a granoblastic-polygonal texture. In sheared and mylonitized parts of the quartzite, stringers as long as 30 cm of ribbon quartz can be seen in outcrop. These stringers and other tectonic features are oriented east-west parallel to the Cheyenne belt in this area. Primary structures are rare in the basal quartzite because of the intense deformation. The basal quartzite is about 640 m thick. As noted above, the middle laminated phyllite of the Copperton (Lookout Schist equivalent) is composed primarily of alternating quartz and mica-rich layers and is about 285 m thick. The upper quartzite (Sugarloaf equivalent) of the Copperton is a massive white quartzite consisting almost entirely of quartz. The partial section of this quartzite is only 145 m thick.

The Copperton Formation extends from the western Sierra Madre east to sec. 27, T. 14 N., R. 86 W., where it was removed by a thrust fault. It reappears in sec. 28, T. 14 N., R. 85 W., where it is also bound by thrust faults on the north and south. The Copperton is tectonically thinned to the east until it is entirely removed by faulting in sec. 35, T. 14 N., R. 84 W.

SLAUGHTERHOUSE FORMATION

Divis (1976) formally named a sequence of massive and siliceous marble with interbedded phyllite and calcitic schist the "Slaughterhouse Marble" for Slaughterhouse Gulch (NE½, sec. 27, T. 14 N., R. 85 W.). He correlated the Slaughterhouse with the Nash Fork Formation of the upper part of the Libby Creek Group in the Medicine Bow Mountains. Graff (1978, 1979) adopted Divis' terminology but changed the name to "Slaughterhouse Formation," which is the terminology adopted here. Graff (1978, 1979) correlated his Slaughterhouse Formation with the Headquarters Schist of the lower part of the Libby Creek Group of the Medicine Bow Mountains as noted above. Although we adopt Graff's terminology, we do not agree with his correlation; instead we consider the Slaughterhouse Formation an equivalent of the Nash Fork Formation, as did Divis.

A.F. Divis (unpub. data, 1976) designated outcrops in and adjacent to Slaughterhouse Gulch as his type locality and indicated that deformation in this area has largely obliterated stratigraphic subdivisions. However, he pointed out that his Slaughterhouse Marble was largely fine- to medium-grained calcite and interlayered calcite, dolomite, and quartz. Divis also noted that chlorite-calcite and biotite-calcite schists were interlayered with the marble. The intense deformation and resulting recrystallization and stretching has so disrupted the section in the Slaughterhouse Gulch area that we designate a different type area for the formation where deformation is less intense and primary features can be recognized.

The new type locality designated in the report is in sec. 26 and W½ sec. 25, T. 14 N., R. 86 W. (pl. 1), north of the Rambler guard station and south of the point where Smith Creek crosses Wyoming Highway 70. The basal Slaughterhouse in this area is composed of fine-grained, interbedded yellow, red, and green metalimestone that contains layers of buff metadolomite,

TABLE 17.—*Modal compositions of samples of the Gaps Intrusion, Medicine Bow Mountains and Sierra Madre, Wyoming*

[Modes, in percent, from point-counted thin sections. Sierra Madre data from Schuster (1972). Tr, trace; --, not determined]

Sample No.	Quartz	Plagioclase	Muscovite	Biotite	Epidote	Carbonate	Opaque minerals	Chlorite	An content of plagioclase
				Medicine Bow Mountains					
HL3	11.9	80.7	0.4	--	--	--	7.1	--	--
GG	23.9	67.8	5.3	--	--	--	3.0	--	9
60–85	24.7	53.2	16.1	--	--	--	6.0	--	--
60–85(B)	23.3	46.5	21.4	--	0.6	--	8.2	--	--
SR77–20	5.1	40.2	--	40.2	Tr	2.6	12.0	--	--
SR77–29	23.5	66.9	4.4	--	2.2	2.9	--	--	10
SR77–42	29.3	56.9	10.6	--	--	--	3.2	--	8
SR77–48	5.6	49.1	2.8	--	--	10.2	2.3	--	13
				Sierra Madre					
AFCP–1	20	60	10	--	--	--	8	2	13
AHA272	5.0	80.6	--	0.2	--	--	8.4	5.8	34
AHA275	2.8	68.7	--	1.4	--	--	8.5	18.6	33
AHA300	9.2	42.2	--	--	--	--	8.2	40.4	28
AHA302	2.6	46.5	--	--	--	0.1	9.3	41.5	32
Mean (13)	14	61	5	3	Tr	1	6	8	

quartzite, and dark-green phyllites. Metalimestone grades upsection into a dark-gray, graphitic phyllite, which is probably a metasiltstone; the gray phyllite is overlain by fine-grained chloritic calc-schist. A complete Slaughterhouse section is not exposed here or in any other area of the Sierra Madre because the Slaughterhouse is bracketed on both sides by major thrust faults. In the type section the basal metalimestones are about 400 m thick and the upper phyllite and schist are about 100 m thick, but we emphasize that this is a minimum thickness, and, in fact, the type locality has less of an outcrop area than the Slaughterhouse of Slaughterhouse Gulch where the thickness may be 1,200 m. West of the type section, the Slaughterhouse was removed by thrust faults, and east of the type section it is in discontinuous bodies that are in contact with the Cheyenne belt in the south and thrust faults in the north. Although slivers of the Slaughterhouse can be found to the eastern limit of the metasedimentary succession, the rocks are intensely deformed and recrystallized in most outcrops.

We interpret the Slaughterhouse as a facies of the Nash Fork Formation of the Medicine Bow Mountains. The Nash Fork Formation has abundant and distinctive stromatolites that are interpreted as having been deposited on a carbonate platform in relatively shallow water, whereas the Slaughterhouse is thought to have been deposited on the basin-slope of the platform comparable to similar facies described by Hoffman (1976) in the Great Slave Supergroup of Canada.

BEARING OF THE GAPS INTRUSION ON THE AGE OF THE DEEP LAKE AND LIBBY CREEK GROUPS

In the central Medicine Bow Mountains the only felsic intrusive rock that cuts the Early Proterozoic succession is a small intrusive body previously referred to as the Gaps Granite (Houston and others, 1968). It is in S½ sec. 8, T. 16 N., R. 79 W., and N½ sec. 17, T. 15 N., R. 80 W. (here designated the type locality), north of Lewis Lake and south of a topographic break locally referred to as "The Gaps." We here refer to this intrusion and similar intrusions elsewhere in the Medicine Bow Mountains and Sierra Madre as "Gaps Intrusion" (unit Xgt, pl. 1). We prefer this term to "Gaps Granite" because the intrusions lack potassium feldspar (table 17) and are too low in silica to be a granite (table 18). The Gaps Intrusion cuts the Lookout Schist and Sugarloaf Quartzite, which are the upper formations of the lower part of the Libby Creek Group. The Gaps Intrusion in the west-central Medicine Bow Mountains (sec. 17, T. 15 N., R. 80 W.) cuts the Sugarloaf Quartzite. Both felsic bodies are in contact with and may be differentiates of gabbroic sills.

In the Sierra Madre felsic intrusions cut the Cascade Quartzite in sec. 31, T. 14 N., R. 86 W., and in sec. 20, T. 14 N., R. 84 W. (too small to show on pl. 1). In the latter locality the felsic intrusions are within and are believed to be differentiates of a large gabbroic intrusion. These felsic intrusive rocks that cut rocks in about the same stratigraphic position as the felsic intrusions in the Medicine Bow Mountains are inferred to be broadly equivalent and are assigned to the Gaps.

TABLE 18.—*Chemical analyses of samples of the Gaps Intrusion, Medicine Bow Mountains and Sierra Madre, Wyoming*

[Values are in percent. Analysts: Steve Boese (1–3) and Eric Schuster (1972; 4–7). --, not determined]

	Medicine Bow Mountains		Sierra Madre				
Sample No.	1 SR77–20	2 SR77–48	3 AFCP1	4 AHA272	5 AHA275	6 AHA300	7 AHA302
SiO_2	48.5	54.9	64.3	57.71	52.58	58.00	66.39
Al_2O_3	12.0	12.7	10.9	15.27	15.81	13.23	10.26
Fe_2O_3	17.1	3.58	14.84	12.86	16.04	13.20	9.45
MgO	3.65	2.22	.53	3	5	5	3
CaO	2.93	6.49	.84	.27	.35	.08	3.83
Na_2O	4.71	7.92	5.44	5.49	4.81	1.83	1.06
K_2O	2.77	.21	.63	.96	1.01	1.24	2.03
TiO_2	4.2	1.3	1.3	2.18	2.38	.97	.64
MnO	.09	.25	.02	.03	.04	.07	.11
P_2O_5	.82	--	.25	--	--	--	--
Total	96.77	90.00	99.05	97.8	98.0	93.7	96.8

SAMPLE LOCALITIES

1. Along Wyoming Highway 130, NE¼SW¼ sec. 25, T. 16 N., R. 80 W.
2. SE¼SW¼ sec. 8, T. 16 N., R. 79 W.
3. Near Copperton, SE¼NW¼ sec. 31, T. 14 N., R. 86 W.

4–5. SE¼NE¼ sec. 26, T. 14 N., R. 86 W.

6–7. NE¼SE¼ sec. 30, T. 14 N., R. 85 W.

Felsic intrusive bodies assigned to the Gaps Intrusion in both the Sierra Madre and Medicine Bow Mountains consist primarily of plagioclase (table 17) with lesser and variable amounts of quartz, muscovite, and opaque minerals. Accessory minerals are biotite, epidote, carbonate, and chlorite. Although the composition of these felsic rocks is quite variable (table 17), most are leucocratic, sodic quartz diorite with oligoclase or albite and no potassium feldspar. The unusual mineralogy of these so-called "quartz diorites," that is, high muscovite (or biotite), very sodic plagioclase, high opaque minerals, and local chloritization and carbonatization, raises problems in interpreting their petrologic and tectonic significance. The mineralogy could reflect primary igneous features of these rocks (as spilitization of gabbroic magmas). However, there are several indications that the present mineralogy and geochemistry reflect metamorphic alterations of original quartz dioritic, dioritic, or gabbroic rocks. The intrusions in the Medicine Bow Mountains are along major fault zones and are themselves highly sheared and fractured, which would facilitate extensive alteration of feldspars during the regional greenschist-facies metamorphism. Also, micas in the intrusion at the Gaps define a well-developed foliation that is parallel to foliation in the surrounding Lookout Schist (Karlstrom and others, 1981); these micas probably were of metamorphic origin. Furthermore, sulfides and uraninite mineralization (as much as 1,000 ppm U) occurred along fractures in the intrusion at the Gaps, suggesting rather extensive movement of fluids during deformation.

Although more petrologic work is obviously needed on the Gaps Intrusion, one clue to the original character of these felsic bodies is their spatial association, in outcrop, with gabbroic and dioritic dikes that also cut the Libby Creek Group. This association suggests that the Gaps Intrusion may be genetically related to, and a felsic differentiate of, at least some of the mafic dikes. However, we have found no transitional contacts or mutually crosscutting relationships that would prove a genetic relationship between the mafic and felsic intrusions.

Chemical analyses of the Gaps Intrusion (table 18) and the associated mafic dikes (table 19) also appear to support the interpretation that the Gaps Intrusion is genetically related to the mafic dikes. The intrusion is richer in silica, sodium, and titanium, and poorer in magnesium, manganese, and calcium. However, in spite of those differences, an AFM plot of both felsic and mafic bodies (fig. 22) shows that the quartz diorite follows the same iron-enrichment trend as the mafic dikes. This differentiation trend lies close to the line separating tholeiitic from calc-alkalic rocks (Irvine and Barager, 1971).

The Gaps Intrusion, in spite of its limited outcrop area, is an important unit because, if it were accurately dated, it would place an upper limit on the age of the lower part of the Libby Creek Group and hence most of

TABLE 19.—*Chemical analyses of samples from gabbroic and dioritic dikes cutting rocks of the Libby Creek Group, Medicine Bow Mountains, Wyoming*

[Values are in percent. Analyst: Steve Boese, University of Wyoming, 1979. Where no FeO value is given, total Fe is reported as Fe_2O_3. --, not determined]

	1	2	3	4	5	6	7
SiO_2	48.91	49.00	51.00	52.20	50.20	46.00	49.50
Al_2O_3	14.51	14.70	17.60	17.30	13.00	14.90	12.90
Fe_2O_3	4.39	10.56	10.04	10.88	11.71	12.60	13.33
FeO	8.81	--	--	--	--	--	--
MgO	5.12	7.77	3.41	4.00	7.06	6.78	6.86
CaO	7.76	10.27	8.45	4.87	8.18	10.08	9.71
Na_2O	2.74	2.13	3.21	3.65	3.35	2.29	1.59
K_2O	1.61	.83	1.31	2.29	.47	.22	.34
TiO_2	1.95	.90	.90	1.00	1.30	1.00	1.00
P_2O_5	.16	.09	.08	.12	.10	.09	.09
MnO	.14	.17	.13	.16	.15	.17	.10
H_2O+	2.73	--	--	--	--	--	--
H_2O-	.55	--	--	--	--	--	--
CO_2	.47	--	--	--	--	--	--
Total	99.85	96.42	96.13	96.47	95.52	94.13	95.52

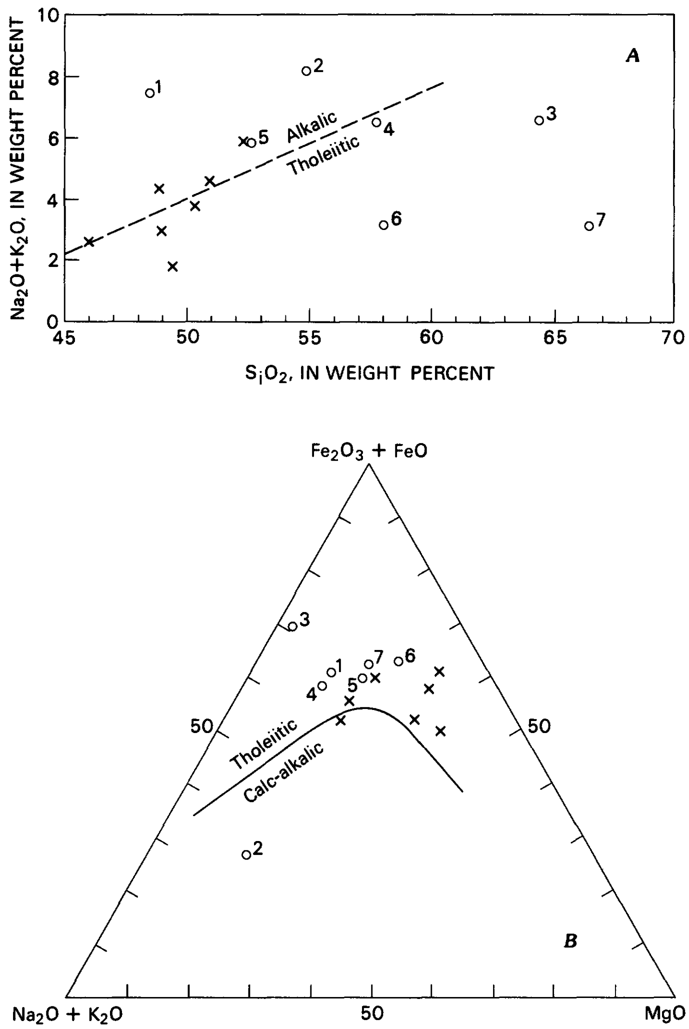
SAMPLE DESCRIPTIONS

1. Houston and others (1968, p. 51), sample 1: Dike cutting the Medicine Peak Quartzite, NW¼ sec. 26, T. 16 N., R. 80 W.
2. SR77–32: Dike cutting the Sugarloaf Quartzite, 400 ft east and 3,900 ft north of the southwest corner sec. 19, T. 16 N., R. 79 W.
3. R77–28: Dike cutting the Sugarloaf Quartzite, 380 ft east and 3,200 ft north of the southwest corner sec. 19, T. 16 N., R. 79 W.
4. SR77–36: Dike cutting the Nash Fork Formation, 4,600 ft east and 1,090 ft north of the southwest corner sec. 18, T. 16 N., R. 79 W.
5. SR77–23: Dike cutting the Sugarloaf Quartzite, 3,935 ft east and 2,415 ft north of the southwest corner sec. 23, T. 16 N., R. 79 W.
6. SW1: Large sill cutting the Nash Fork Formation, 3,670 ft east and 1,700 ft north of the southwest corner sec. 19, T. 15 N., R. 80 W.
7. SW3: Sill cutting the Medicine Peak Quartzite, 4,115 ft east and 2,240 ft north of the southwest corner sec. 26, T. 15 N., R. 81 W.

the Snowy Pass Supergroup. However, attempts to date the Gaps Intrusion at the Gaps locality have yielded equivocal results. Hills and Houston (1979) reported a date of 1,755±215 Ma with an initial $^{87}Sr/^{86}Sr$ ratio of 0.723. The $^{87}Rb/^{86}Sr$ ratio is anomalously high, and the origin of the excess radiogenic strontium is uncertain (Hills and Houston, 1979). More recent attempts at dating the intrusion suggest an age of 1,900–2,150 Ma (Carl Hedge, written commun., 1983). Hedge collected rock from the Gaps area and found two localities where the pervasive shearing and alteration were less pronounced. Large samples collected from these localities failed to yield zircons, but both samples had favorable rubidium-strontium ratios. A two-point isochron gives an age of 1,905 Ma and an initial $^{87}Sr/^{86}Sr$ of 0.715. Hedge considers this to be the minimum age for the Gaps Intrusion.

If the intrusion is a differentiate of the mafic dikes, as we have suggested, the initial $^{87}Sr/^{86}Sr$ of the rocks would have been lower. Using low initial ratios, such as one would expect of a differentiate of a gabbro, Hedge determined ages of 2,100–2,150 Ma for the least sheared sample and 2,000 Ma for the other sample. He concluded that if the quartz diorite is indeed a differentiate of a gabbroic rock, the 2,100- to 2,150-Ma age is most likely, and the apparently young ages and high initial ratios of Hills and Houston (1979) and of the two-point isochron may reflect samples disturbed by shearing and alteration.

The 1,900- to 2,150-Ma age for the Gaps Intrusion at the type locality near Lewis Lake is critically important to our understanding of the Early Proterozoic succession. In earlier papers we suggested that the rocks of the Deep Lake Group and the lower part of the Libby Creek Group might correlate with or be about the same age as the Huronian Supergroup of the north shore of Lake Huron (Houston, Karlstrom, and Graff, 1979) (fig. 21), because of lithologic similarities and the fact that uranium-bearing quartz-pebble conglomerate, which is believed to be time bound, is present in both successions. The Huronian Supergroup is older than about 2,100 Ma, and uranium-bearing quartz-pebble conglomerates are believed to be confined to rocks older than about 2,000 Ma (Houston and Karlstrom, 1980), but until the age of the Gaps Intrusion was determined, our best bracket for the age of the Deep Lake Group and lower part of the Libby Creek Group was 1,700–2,700 Ma (Hills and others, 1968). We can now be more confident of the correlation with the Huronian Supergroup, and, in addition, the



EXPLANATION

- o Gaps Intrusion—See table 18
- × Mafic dikes

FIGURE 22.—Geochemistry of the Gaps Intrusion and mafic dikes cutting the Libby Creek Group. *A*, Alkali-silica plot (alkalic-tholeiitic boundary from MacDonald, 1968). *B*, Alkali-iron-magnesium plot (tholeiitic-calc-alkalic boundary from Irvine and Baragar, 1971).

uranium-bearing quartz-pebble conglomerate of the Deep Lake Group can be said to fit the time-bound model and thus have a higher probability of ultimate economic potential.

REFERENCES CITED

Bennett, V.C., and DePaolo, D.J., 1987, Proterozoic crustal history of the western United States as determined by neodymium isotopic mapping: Geological Society of America Bulletin, v. 99, p. 674–685.

Blackwelder, Eliot, 1926, Precambrian geology of the Medicine Bow Mountains: Geological Society of America Bulletin, v. 37, p. 615–658.

Buchan, K.L., and Card, K.D., 1984, Preliminary comparison of petrographic and paleomagnetic characteristics of Nipissing Diabase intrusions in northeastern Ontario, *in* Current research, pt. A: Geological Survey of Canada Paper 85–1A, p. 131–140.

Bull, W.B., 1972, Recognition of alluvial-fan deposits in the stratigraphic record, *in* Rigby, J.K., and Hamblin, W.K., eds., Recognition of ancient sedimentary environments: Economic Paleontologists and Mineralogists Special Paper 16, p. 63–83.

Childers, M.O., 1957, The geology of the French Creek area, Albany and Carbon Counties, Wyoming: Laramie, Wyo., University of Wyoming M.S. thesis, 58 p.

Cox, K.G., Bell, J.D., and Pankhurst, R.J., 1979, The interpretation of igneous rocks: London, George Allen and Unwin, 450 p.

DePaolo, D.J., 1981, Neodymium isotopes in the Colorado Front Range and crust-mantle evolution in the Proterozoic: Nature, v. 291, p. 193–196.

Divis, A.F., 1976, Geology and geochemistry of Sierra Madre Range, Wyoming: Colorado School of Mines Quarterly, v. 71, no. 3, 127 p.

——— 1977, Isotopic studies on a Precambrian geochronologic boundary, Sierra Madre Mountains, Wyoming: Geological Society of America Bulletin, v. 88, p. 96–100.

Ebbett, B.E., Jr., 1970, Geology of the metasedimentary rocks of the Sierra Madre, Wyoming: Geological Survey of Wyoming open-file map, scale 1:125,000.

Folk, R.L., 1968, Petrology of sedimentary rocks: Austin, Tex., University of Texas, 170 p.

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: Laramie, Wyo., University of Wyoming Ph. D. thesis, 85 p.

——— 1979, A review of the stratigraphy and uranium potential of Early Proterozoic (Precambrian X) metasediments in the Sierra Madre, Wyoming: University of Wyoming Contributions to Geology, v. 17, no. 2, p. 1047–1069.

Gwinner, Don, 1979, Structural setting of uranium-bearing quartz-pebble conglomerate of Precambrian age, northwest Sierra Madre, Carbon County, Wyoming: Laramie, Wyo., University of Wyoming M.S. thesis, 29 p.

Hills, F.A., Gast, P.W., Houston, R.S., and Swainbank, I., 1968, Precambrian geochronology of the Medicine Bow Mountains of southeastern Wyoming: Geological Society of America Bulletin, v. 79, p. 1757–1784.

Hills, F.A., and Houston, R.S., 1979, Early Proterozoic tectonics of the central Rocky Mountains, North America, *in* Boyd, D.W., and others, eds., Wyoming uranium issue II: University of Wyoming Contributions to Geology, v. 17, no. 2, p. 89–109.

Hoffman, P.F., 1976, Shallow and deepwater stromatolites in Lower Proterozoic platform-to-basin facies change, Great Slave Lake, Canada: American Association of Petroleum Geologists Bulletin, v. 58, p. 856–867.

Houston, R.S., and Ebbett, B.E., 1977, Geologic map of the Sierra Madre and western Medicine Bow Mountains, southeastern Wyoming: U.S. Geological Survey Miscellaneous Field Studies Map MF–827, scale 1:125,000.

Houston, R.S., and Karlstrom, K.E., 1980, Uranium-bearing quartz-pebble conglomerates—Exploration model and United States resource potential: U.S. Department of Energy Open-File Report GJBX–1(80), 510 p. Available from U.S. Geological Survey Books and Open-File Reports Section, Federal Center, Box 25425, Denver, CO 80225.

Houston, R.S., Karlstrom, K.E., and Graff, P.K., 1979, Progress report on the study of radioactive quartz-pebble conglomerate of the Medicine Bow and Sierra Madre, southeastern Wyoming: U.S. Geological Survey Open-File Report 79–1131, 41 p.

Houston, R.S., Karlstrom, K.E., Hills, F.A., and Smithson, S.B., 1979, The Cheyenne Belt—A major Precambrian crustal boundary in the western United States: Geological Society of America Abstracts with Programs, v. 11, p. 446.

Houston, R.S., and others, 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: Wyoming Geological Survey Memoir 1, 167 p.

Houston, R.S., Schuster, J.E., and Ebbett, B.E., 1975, Preliminary report on the distributions of copper and platinum group metals in mafic igneous rocks of the Sierra Madre, Wyoming: U.S. Geological Survey Open-File Report 75–85, 129 p.

Hughes, M.A., 1973, A study of the Precambrian rocks of the Cow Creek area, Sierra Madre Mountains, Carbon County, Wyoming: Laramie, Wyo., University of Wyoming M.S. thesis, 43 p.

Irvine, T.N., and Baragar, W.R.A., 1971, A guide to the classification of the common volcanic rocks: Canadian Journal of Earth Sciences, v. 8, p. 523–548.

Karlstrom, K.E., 1977, Geology of the Proterozoic Deep Lake Group, central Medicine Bow Mountains, Wyoming: Laramie, Wyoming, University of Wyoming M.S. thesis, 116 p.

Karlstrom, K.E., Flurkey, A.J., and Houston, R.S., 1983, Stratigraphy and depositional setting of the Proterozoic Snowy Pass Group, southeastern Wyoming—Record of an Early Proterozoic Atlantic-type cratonic margin: Geological Society of America Bulletin, v. 94, p. 1257–1274.

Karlstrom, K.E., and Houston, R.S., 1979a, Stratigraphy and uranium potential of the Phantom Lake Metamorphic Suite and Deep Lake Group, Medicine Bow Mountains, Wyoming: Wyoming Geological Survey Report of Investigations RI–13, 45 p.

——— 1979b, Stratigraphy of the Phantom Lake Metamorphic Suite and Deep Lake Group and a review of the Precambrian tectonic history of the Medicine Bow Mountains: University of Wyoming Contributions to Geology, v. 17, no. 2, p. 111–133.

Karlstrom, K.E., Houston, R.S., Flurkey, A.J., Coolidge, C.M., Kratochvil, A.L., and Sever, C.K., 1981, A summary of the geology and uranium potential of Precambrian conglomerates in southeastern Wyoming: U.S. Department of Energy Report GJBX–139(81), v. 1, 537 p. Available from U.S. Geological Survey Books and Open-File Reports Section, Federal Center, Box 25425, Denver, CO 80225.

King, J.S., 1963, Petrology and structure of the Precambrian and post-Mississippian rocks of the northeastern Medicine Bow Mountains, Carbon County, Wyoming: Laramie, Wyo., University of Wyoming Ph. D. thesis, 125 p.

Kratochvil, A.L., 1981, Geology of the uraniferous Deep Gulch Conglomerate (Late Archean), northwestern Sierra Madre, Wyoming: Laramie, Wyo., University of Wyoming M.S. thesis, 113 p.

Krogh, T.E., Davis, D.W., and Corfu, F., 1984, Precise U-Pb zircon and baddeleyite ages for the Sudbury area, *in* Pye, E.G., and others, eds., The geology and ore deposits of the Sudbury Structure: Ontario Geological Survey Special Volume 1, p. 431–446.

Lanthier, L.R., 1978, Stratigraphy and structure of the lower part of the Precambrian Libby Creek Group, central Medicine Bow Mountains, Wyoming: Laramie, Wyo., University of Wyoming M.S. thesis, 30 p.

——— 1979, Stratigraphy and structure of the lower part of the Precambrian Libby Creek Group, central Medicine Bow Mountains, Wyoming: University of Wyoming Contributions to Geology, v. 17, p. 135–147.

MacDonald, G.A., 1968, Composition and origin of Hawaiian lavas: Geological Society of America Memoir 116, p. 477–522.

McCallum, M.W., 1964, Petrology and structure of the Precambrian and post-Mississippian rocks of the east-central portions of the Medicine Bow Mountains, Albany and Carbon Counties, Wyoming: Laramie, Wyo., University of Wyoming Ph.D. thesis, 164 p.

Miller, W.R., 1971, Geology of the Indian Rocks area, Carbon County, Wyoming: Laramie, Wyo., University of Wyoming M.S. thesis, 40 p.

Miyashiro, A., 1973, Metamorphism and metamorphic belts: London, George Allen and Unwin, Ltd., 492 p.

Premo, W.R., 1983, U-Pb zircon geochronology of some Precambrian rocks in the Sierra Madre Range, Wyoming: Lawrence, Kans., University of Kansas M.S. thesis, 106 p.

Ramsey, J.G., 1961, The effects of folding upon the orientation of sedimentary structures: Journal of Geology, v. 69, p. 84–100.

Roscoe, S.M., 1973, The Huronian Supergroup, a Paleoaphebian succession showing evidence of atmospheric evolution, *in* Young, G.M., ed., Huronian stratigraphy and sedimentation: Geological Association of Canada Special Paper 12, p. 31–48.

Rust, B.R., 1978, The interpretation of ancient alluvial successions in the light of modern investigations, *in* Davidson-Arnott, R., and others, eds., Research in fluvial geomorphology: Guelph Symposium on Geomorphology, Proceedings, no. 5, p. 67–105.

Schuster, J.E., 1972, Distribution of copper and the platinum group in mafic rocks of the Sierra Madre, Carbon County, Wyoming: Laramie, Wyo., University of Wyoming M.S. thesis, 109 p.

Short, B.L., 1958, A geologic and petrographic study of the Ferris-Haggarty mining area, Carbon County, Wyoming: Laramie, Wyo., University of Wyoming M.S. thesis, 130 p.

Spencer, A.C., 1904, The copper deposits of the Encampment district, Wyoming: U.S. Geological Survey Professional Paper 25, 107 p.

Streckeisen, A., 1976, To each plutonic rock its proper name: Earth Science Reviews, v. 12, p. 1–33.

Van Schmus, W.R., 1976, Early and Middle Proterozoic history of the Great Lakes area, North America: Royal Society of London Philosophical Transactions, v. A280, p. 605–628.

Weid, O.J., 1960, Geology of the Encampment area, Carbon County, Wyoming: Laramie, Wyo., University of Wyoming M.S. thesis, 52 p.

Wescott, W.A., and Ethridge, F.G., 1980, Fan-delta sedimentology and tectonic setting—Yallahs Fan Delta, southeast Jamaica: American Association of Petroleum Geologists Bulletin, v. 64, p. 374–399.

☆U.S. GOVERNMENT PRINTING OFFICE: 1992-673-049/46058