PROGRESS REPORT ON THE STUDY OF RADIOACTIVE QUARTZ-PEBBLE CONGLOMERATE OF THE MEDICINE BOW MOUNTAINS AND SIERRA MADRE, SOUTHEASTERN WYOMING

By

Robert S. Houston, Karl E. Karlstrom, and Paul J. Graff

With a chapter on

URANIUM AND THORIUM MINERALS IN PRECAMBRIAN METACONGLOMERATES, MEDICINE BOW MOUNTAINS, SOUTH-CENTRAL WYOMING

By

George A. Desborough and William N. Sharp

Open-file report 79-1131

1979

Contents

Page

Introduction ---------- 1

Geologic background ---------- 1

General geology ---------- 4

Stratigraphy ---------- 4

Archean ---------- 7

Assemblage of Phantom Lake ---------- 7

Lower part ---------- 7

Radioactive rocks of the lower part ---------- 8

Upper part ---------- 10

Preliminary discussion of depositional environment of the radioactive beds and adjacent strata ---------- 15

Assemblage of Deep Lake ---------- 18

Libby Creek Group ---------- 26

Regional structure that may control the distribution of radioactive conglomerate ---------- 27

Metamorphism ---------- 35

Radioactive quartz-pebble conglomerate ---------- 36

Uranium and thorium minerals in Precambrian meta-conglomerates, Medicine Bow Mountains, south-central Wyoming, by George A. Desborough and William N. Sharp ---------- 38

Discussion of mineralogy and possible effects of regional metamorphism ---------- 40

References cited ---------- 41

Illustrations

Page

Figure 1. Index map showing location of Sierra Madre and Medicine Bow Mountains, southeastern Wyoming -------- 2

2. Radioactive quartz-pebble conglomerate layer near base of the upper part of the assemblage of Phantom Lake, One Mile Creek area, Medicine Bow Mountains ---- 11

3. Pillow lava in upper part of the assemblage of Phantom Lake, South Spring Lake area, Sierra Madre 13

4. Paraconglomerate layers in upper part of the assemblage of Phantom Lake -------------------------------- 14

5. Trough crossbeds in quartzite of the upper part of the assemblage of Phantom Lake, South Brush Creek area, Medicine Bow Mountains ------------------------ 16

6. Paraconglomerate of the Campbell Lake Formation, Medicine Bow Mountains ------------------------------- 23

7. Dropstones of Vagner Lake Formation ------------------- 25

8. Tentative interpretation of structure at northwest border of Sierra Madre ------------------------------- 34

Table 1. Tentative correlation of metasedimentary rocks of the Sierra Madre and Medicine Bow Mountains --------------- 6

2. List of localities where radioactive rocks have been ----- 9

3. Formation description, in brief. Name, lithology, paleocurrent data. Information on depositional environment. Possible depositional environment ------- 22

Plate 1. General geology of Precambrian-cored uplifts, southeastern Wyoming in pocket

2. Preliminary geologic map showing metasedimentary rocks of the northwestern Sierra Madre and northeastern Medicine Bow Mountains, Wyoming in pocket

INTRODUCTION

A recent report (Miller, Houston, Karlstrom, Hopkins, and Ficklin, 1977) on geological and geochemical investigations of uranium occurrences in the Arrastre Lake area of the Medicine Bow Mountains of southeastern Wyoming indicates that the quartz-pebble conglomerate of the Precambrian Deep Lake Formation (Houston and others, 1968), where it crops out north and east of Arrastre Lake, may contain economic concentrations of uranium in the subsurface. Studies of similar conglomerates in other parts of the Medicine Bow Mountains and in the Sierra Madre (fig. 1) show that radioactive conglomerates are present in several areas in both ranges. None of these conglomerates contains ore grade material at the surface, but most outcrops are oxidized, and geochemical studies by Miller and others (1977) strongly suggest that uranium has been leached from surface outcrops. Drilling, therefore, may be the only way to prove the presence of uranium ore in this area. This report reviews the results of current geologic mapping in both the Sierra Madre and Medicine Bow Mountains, proposes a tentative stratigraphic succession for both ranges, and indicates areas where radioactive conglomerates have been found. This information may be useful for further exploration.

The work reported here was undertaken in 1975 at the suggestion of the senior author and is a cooperative investigation of the U.S. Geological Survey, Geological Survey of Wyoming, University of Wyoming, Department of Geology, and the U.S. Department of Energy. The work was financed by a grant to the Geological Survey of Wyoming from the U.S. Geological Survey, and by a grant to the U.S. Geological Survey from the U.S. Department of Energy. The project chief was Robert S. Houston of the University of Wyoming, and the principal investigator was Forest K. Root of the Geological Survey of Wyoming. Mapping was done in the Medicine Bow Mountains by Karl E. Karlstrom and in the Sierra Madre by Paul J. Graff, both graduate students of the Geology Department, University of Wyoming. Detailed geologic maps for parts of the Medicine Bow Mountains and for the Sierra Madre should be available in 1978.

GEOLOGIC BACKGROUND

Precambrian miogeosynclinal metasedimentary rocks were first recognized in the Medicine Bow Mountains by Hague (Hague and Emmons, 1877), who gave a relatively good description of these rocks, located in the north-central Medicine Bow Mountains. They were later described in more detail by Van Hise (Van Hise and Leith, 1909) and Blackwelder (1926). Blackwelder (1926) gave the first complete description of these rocks and named various units in the upper part of the succession. Of particular interest is the fact that in a later paper Blackwelder (1935) noted that these miogeosynclinal rocks strongly resembled the Huronian rocks of the Great Lakes region. The first description of miogeosynclinal metasedimentary rocks in the Sierra Madre was by Spencer (1904), who made a superb reconnaissance study of almost the entire area.

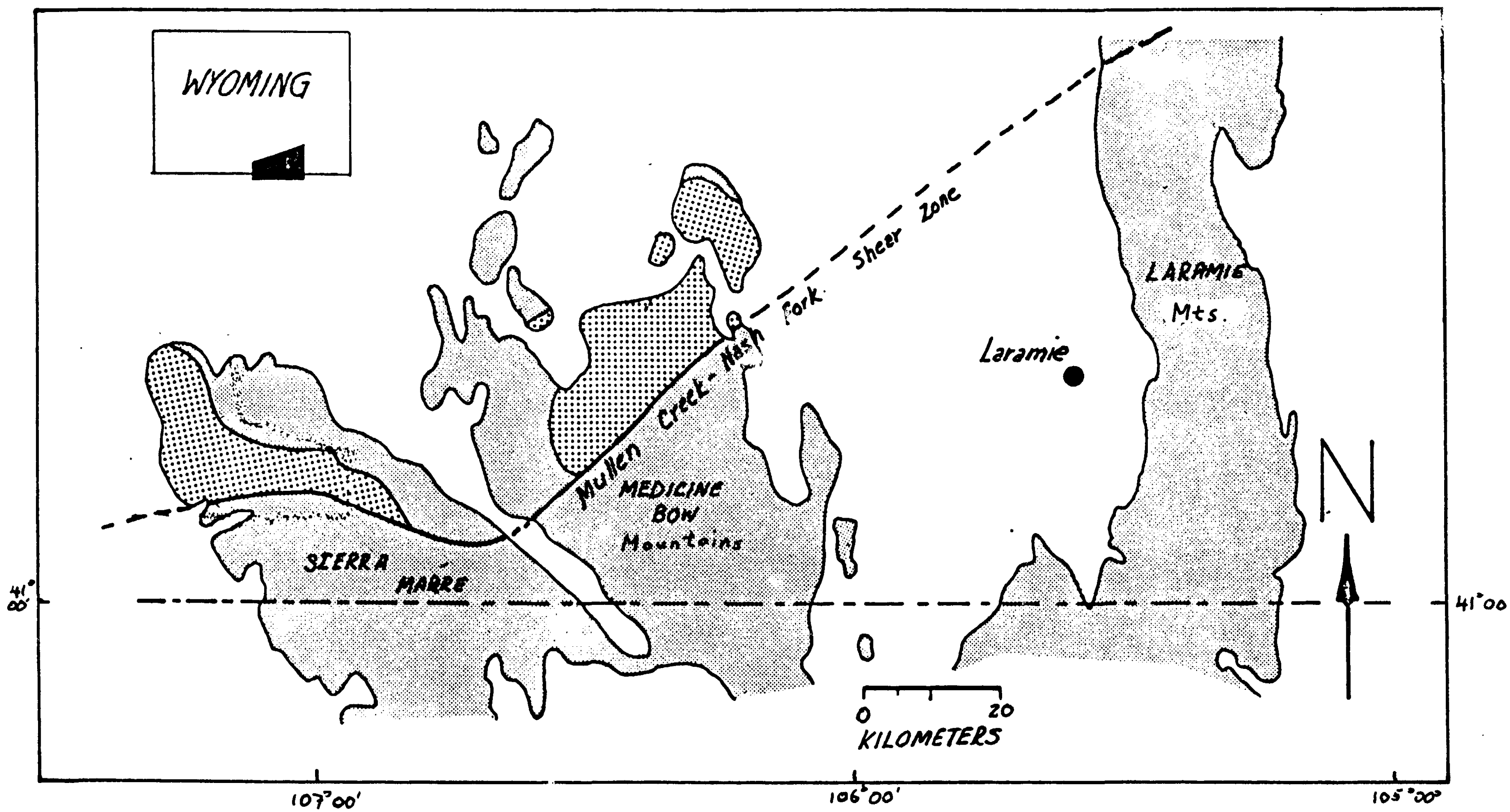

Figure 1.--Index map showing location of metasedimentary rocks in the Sierra Madre and Medicine Bow Mountains, southern Wyoming. Metasedimentary rocks (open stipple).

In 1957, The Geological Survey of Wyoming, then under the direction of H. D. Thomas, sponsored a study of the Precambrian rocks of Wyoming, with emphasis on the Medicine Bow Mountains, an area which was thought to have the most complete geological record of any Precambrian-cored uplift in Wyoming. This study resulted in the publication of a report (Houston and others, 1968) that included a regional geologic map of the Medicine Bow Mountains and described for the first time the entire succession of miogeosynclinal metasedimentary rocks of the northern Medicine Bow Mountains. Like Blackwelder, Houston and others (1968) were impressed by the lithologic resemblance between these rocks and Precambrian miogeosynclinal rocks of the Great Lakes area. This lithologic correlation was supported by geochronologic studies (Hills and others, 1968) that bracketed the age of these metasedimentary rocks of the Medicine Bow Mountains between 2,500 m.y. and 1,800 m.y. At the time the Medicine Bow report was compiled it was known that Precambrian conglomerates of about this age contained economic concentrations of gold and uranium; and several reports had been published (Joubin, 1954; Roscoe, 1957) that described uranium deposits in quartz-pebble conglomerates in the Blind River area of Canada. For this reason, Houston and others (1968, p. 159) suggested that the better sorted conglomerates of the Deep Lake Formation (the rocks in the Medicine Bow Mountains that most closely resembled ore-bearing horizons in Canada) should be examined as a possible source of gold and other heavy minerals. This suggestion received little attention by American geologists, but Canadian geologists familiar with the Huronian (Young, 1970) also suggested the correlation. In the early 1970's Stewart Roscoe of the Canadian Geological Survey, who had done much of the detailed geologic study of the Blind River area in Canada, examined some conglomerates brought to his attention by one of the authors (Houston) and determined that they were slightly radioactive. To the writers' knowledge, Roscoe was the first person to recognize the presence of radioactive conglomerates in the region.

During the 1960's and 1970's, geologic studies of Precambrian rocks in Wyoming were continued at the University of Wyoming, with particular emphasis on the Sierra Madre. A preliminary report on the miogeosynclinal rocks of the Sierra Madre was published as a result of a study jointly sponsored by the U.S. Geological Survey and the Geological Survey of Wyoming (Houston, Schuster, and Ebbett, 1975). This report called attention to the strong resemblance of miogeosynclinal metasedimentary rocks of the Sierra Madre to rocks of the Deep Lake Formation of the Medicine Bow Mountains. At the time of the Sierra Madre report it was widely accepted that uranium-bearing minerals in Precambrian pyritic conglomerates were preserved because of the lower oxygen pressure in the Precambrian atmosphere that existed prior to about 2,000 m.y. (Cloud, 1968; Roscoe, 1973). Houston, Schuster, and Ebbett (1975) again emphasized the lithologic resemblance of the Sierra Madre and Medicine Bow miogeosynclinal rocks to the Canadian Huronian, and they suggested that a more definitive correlation might come from additional isotopic studies (a more closely bracketed age determination) or from proof that the pyritic conglomerates that seem to characterize rocks of early middle Precambrian age (2,500-2,000 m.y.) are present in the Wyoming successions.

The geologic studies, reported herein, were undertaken to better establish the stratigraphic succession in the Sierra Madre and Medicine Bow Mountains, to make more detailed maps of the miogeosynclinal metasedimentary rocks, and to search for radioactive, pyrite-bearing conglomerate.

GENERAL GEOLOGY

The general geology of Precambrian-cored uplifts in southeast Wyoming is shown in plate 1. Miogeosynclinal metasedimentary rocks occur on the north side of a major fault system in both the Sierra Madre and the Medicine Bow Mountains. This great fault system (Houston and McCallum, 1961) is thought to be a middle Precambrian suture (Hills, Houston, and Subbarayudu, 1975), where island arcs then located in Colorado were brought into contact with the Archean craton of Wyoming. The preservation of these miogeosynclinal metasedimentary rocks in southeast Wyoming some 2,000 kilometers from their possible equivalents in Canada may in some fashion be related to the development of this suture. Certainly these rocks are preserved only on the north side of the suture; rocks to the south are entirely eugeosynclinal facies.

In both the Sierra Madre and the Medicine Bow Mountains, miogeosynclinal metasedimentary rocks lie on a basement of Archean gneisses. Contacts between the metasedimentary rocks and basement are probably unconformable, but they are obscured by shearing at the contact and by the presence of sills of mafic igneous rocks.

The middle Precambrian miogeosynclinal metasedimentary rocks were formerly divided into two parts: (1) the Deep Lake Formation of the Medicine Bow Mountains and the metasedimentary rocks of the Sierra Madre that are thought to be its equivalent; and (2) the rocks of the Libby Creek Group (Houston and others, 1968) of the Medicine Bow Mountains, which unconformably overlie the Deep Lake Formation. A discussion of the relationship between these two rock sequences can be found in Houston and others (1968) and Houston, Schuster, and Ebbett (1975). The following discussion emphasizes the Deep Lake Formation and its equivalents because of their potential for uranium and new information on the stratigraphy is introduced.

STRATIGRAPHY

A preliminary discussion of stratigraphy was presented in Houston, Graff, Karlstrom, and Root (1977), where the stratigraphic succession was compared with that of similar rocks in Canada. The rock succession was said to contain cycles that begin with paraconglomerate and end with fairly well-sorted quartzite--a type of rock sequence that seems to characterize sedimentary rocks of early Proterozoic age. These cycles have been verified by further study, but correlations suggested between cycles of the Sierra Madre and Medicine Bow Mountains require revision.

The discovery of extensive beds of radioactive conglomerate in the western Sierra Madre that are similar to those of the Medicine Bow Mountains gives us, for the first time, possible marker beds to assist correlation of rocks of the two areas. By using the radioactive conglomerate beds as marker units, correlation is made between cycles of the Sierra Madre and the Medicine Bow Mountains (table 1).

We suggest four major subdivisions of rocks of the two ranges, as shown in table 1. These rock successions are given informal names for descriptive purposes. Formal names will be proposed only after detailed mapping is completed. The four rock divisions are as follows: Archean gneisses and granitic rocks; a metasedimentary-metavolcanic rock succession referred to informally as the assemblage of Phantom Lake; a succession of metasedimentary rocks that consists of at least three quartzite-dominated metasedimentary cycles and that is referred to informally as the assemblage of Deep Lake; and finally an upper section of metasedimentary rocks, the Libby Creek Group, defined in earlier studies (Houston and others, 1968, p. 22-23). Rocks of the Archean basement, the assemblage of Phantom Lake, and the assemblage of Deep Lake, are present in both the Sierra Madre and the Medicine Bow Mountains, whereas the Libby Creek Group rocks are only in the Medicine Bow Mountains (pl. 2).

Table 1.—Tentative correlation of metasedimentary rocks of the Sierra Madre and Medicine Bow Mountains

	MEDICINE BOW MOUNTAINS		SIERRA MADRE	
LIBBY CREEK GROUP	French Slate[2]	Gray slate		
	Towner Greenstone[2]	Chlorite schist		
	Nash Fork[1]	Graphitic phyllite and metadolomite		
	Sugarloaf Quartzite[2]	Massive quartzite		
	Lookout Schist[2]	Laminated schist with qnartzite layer	Libby Creek Group[1] not present	
	Medicine Peak Quartzite[1]	Quartzite and conglomerate		
		Quartz-pebble conglomerate and quartzite		
		Quartzite		
	Heart Formation[1]	Quartzite		
		Phyllite		
		Quertzite		
	Headquarters Schist[2]	Phyllite		
		Arkoeic quartzite		
		Paraconglomerate		
			shear zone	
ASSEMBLAGE OF DEEP LAKE			Slaughterhouse Gulch	Metadolomite and calcareous phyllite
	Quartzite of Rock Knoll	Conglomerate and quartzite		
		Quartzite and phyllitic quartzite	Quartzite of Copperton	Sheared, massive quartzite
		Quartzite		
	Formation of Wagner Lake	Slate	Formation of Vagner Lake	Quartzite
		Metadolomite		Slate
		Paraconglomerate		Metadolomite
				Paraconglomerate
	Quartzite of Cascade Lake	Pebbly arkosic quartzite	Quartzite of Cascade Lake	Arkosic quartzite
		Pebbly quertzite		Quartzite and pebbly quartzite
	Formation of Campbell Lake	Slate	Formation of Campbell Lake	Quartzite
		Paraconglomerate		Slate
				Paraconglomerate
	Quartzite of Lindsey		Formation of Singer Peak	Quartzite
	Lake	Quartzite		Slate
	Formation of Magnolia Lake	Phyllitic quartzite	Formation of Magnolia Lake	Quartzite
		Quartz-granule conglomerate		Oartzite-granule conglomerate
		Quartz-pebble conglomerate		Quartz-pebble conglomerate
ASSEMBLAGE OF PHANTOM LAKE			WEST	EAST
	UPPER	Phyllite, basalt and conglomerate	Phyllite and slate	Megavolcanic rocks and paraconglomerate
			Phyllitic quartzite	
		Micaceous quartzite	UPPER Slate and Quartzite	Quartzite
		Slate and quartzite	Paraconglomerate	Metavolcanic rocks and paraconglomerate
		Quartz-pebble conglomerate		
			Quartz-pebble conglomerate	Quartzite
	LOWER	Volcanoclastic metagraywacke metaflows, metatuffs, quartzite, quartz-pebble conglomerate and paraconglomerate	LOWER Volcaniclastic metagraywacke, metaflows, metatuffs, quartzite, quartz-pebble conglomerate, and paraconglomerate	

ARCHEAN GRANITE, METASEDIMENTS AND GNEISSES

[1] Houston and others (1968)

[2] Blackwelder and others (1926)

Archean (≥2,500 m.y.)

The Archean basement consists of quartzo-feldspathic gneiss, biotite gneiss and associated syntectonic granite gneiss and granite (Houston, Schuster, and Ebbett, 1975, p. 9-11). Amphibolite, hornblende gneiss, and minor bodies of fine-grained quartzite are interlayered with the felsic gneisses locally, and although some gneisses have textures suggestive of volcanic origin, there are no greenstone belts in this immediate area. The Archean gneisses are cut by large gabbroic intrusions and by dikes of tholeiitic composition. Zones of migmatite and magmatite along with discrete unzoned pegmatite are common in the felsic gneiss. The petrography and mineralogy of the Archean gneiss and pegmatite has not been studied in detail, but minerals containing radioactive elements that might be the source of radioactive elements in the pyritic quartz-pebble conglomerate have not been detected to date (1977). Archean gneisses and syntectonic granite have been dated in the Medicine Bow Mountains by Hills and others (1968) and in the Sierra Madre by Divis (1976). Ages range from about 2,500 m.y. for granite to about 2,700 m.y. for gneiss.

Assemblage of Phantom Lake1/

1/ The name Phantom Lake is from a lake in the north-central Medicine Bow Mountains (sec. 16, T. 16 N., R. 80 W.) where rocks of this assemblage were first described (Houston and others, 1968; Karlstrom, 1977).

Metasedimentary rocks of the assemblages of Phantom Lake include paraconglomerate, quartzite, phyllite, metavolcanic rocks, and marble. Locally these rocks are interlayered with amphibolite, hornblende gneiss and schist, and felsic gneiss, all of possible volcanic origin. So far as has been determined, these rocks lie unconformably on the Archean basement, but most contacts between basal units of the assemblage and the Archean basement are faulted or are occupied by mafic intrusive rock. The basal unit of the assemblage of Phantom Lake is fine-grained feldspathic quartzite; no basal conglomerate has been found.

The most distinctive marker bed in the assemblage of Phantom Lake is a micaceous quartzite containing beds of radioactive quartz-pebble conglomerate. This unit is used to separate the assemblage of Phantom Lake into an upper and lower part.

Lower part of the assemblage of Phantom Lake

Beds of the lower part crop out in the northwest Sierra Madre in T. 15 N., Rs. 87 and 88 W., and are present in the Arlington area of the Medicine Bow Mountains (pl. 2). However, the marker bed has not been fully mapped in the Arlington area, so some of the rocks there that plate 2 assigns to the lower part of the assemblage may actually be younger. The lower part of the assemblage consists of fine-grained feldspathic quartzite interbedded with phyllite (graywacke?); locally, beds of coarse-grained pebbly quartzite, marble, amygdaloidal metabasalt, meta-agglomerate, and metaparaconglomerate are present. Amphibole gneiss, amhibolite, and felsic gneisses are interlayered with the metasedimentary rocks locally; these rocks are considered to be largely metavolcanic rocks. The stratigraphy has not been established for the lower part of the assemblage of Phantom Lake, in part because these rocks have not been mapped in detail, but also because the rocks are probably isoclinally folded, are of relatively high metamorphic rank (amphibolite facies), and retain few primary structures; thus a reliable stratigraphic reconstruction may not be possible.

The age of the lower part of the assemblage is unknown. Some interlayered gneisses resemble rocks dated as Archean in other areas, but no gneisses have been dated from the lower part. Two samples of a staurolite-garnet-muscovite schist from a locality 3 kilometers southwest of Arlington were analyzed by Hills, Gast, Houston, and Swainbank (1968, p. 1771). These two points gave an isochron solution of 1,913 m.y., which is possibly a metamorphic date for these rocks. Certainly two points are inadequate to establish a reliable isochron, but the date of 1,913 m.y. is about 200 million years older than ages determined by whole-rock Rb/Sr methods for schists of the Libby Creek Group. This information, though not conclusive, is compatible with the field evidence, which suggests that the lower part of the assemblage Phantom Lake was deformed and metamorphosed earlier than the metasedimentary rocks that overlie it.

Granite that resembles Archean granite is locally in contact with metasedimentary rocks of the lower assemblage of Phantom Lake near Arlington. In some areas field relationships suggest that these metasedimentary rocks lie unconformably on the granite, but in other areas the granite has gradational or crosscutting contacts with the metasedimentary rocks. There are no reliable age determinations in these granitic rocks. Three samples were analyzed by Hills and others (1978, p. 1763) from gneissic granite near Arlington; these samples formed an isochron with an apparent age of 2,350 m.y. with an error of ±84 m.y. This is too few samples for a reliable isochron, but it does suggest that some rocks of the lower part of the assemblage are earliest Proterozoic or Archean.

Radioactive rocks of the lower part of the assemblage of Phantom Lake.--No strongly radioactive rocks have been found in these strata to date, but rocks having radioactivity 2-3 times background for the area have been found in a number of places. These localities are listed in table 2. Beds of quartz pebble conglomerate and beds of paraconglomerate are the most common rocks with above-background radioactivity, and some micaceous quartzite also shows above-background radioactivity.

Table 2.--List of localities where radioactive rocks have been identified in the Sierra Madre and Medicine Bow Mountains

Type of rock	Pyrite	Radioactivity relative to local background	PPM-U	PPM-Th	Location	Formation or assemblage
					Medicine Bow	
Arkosic quartz-pebble conglomerate	Present	9 samples Range 2-6X	9 samples Range 2.8-8.4	9 samples Range <20-38	NW sec. 10, T.16 N., R. 80 W.	M
Heavy mineral separate from above conglomerate	Present	n.d.	89	n.d.		M
Arkosic quartz-pebble conglomerate	Present	5 samples Range 2-6X	5 samples Range 0.5-11.2	n.d.	SW1/4 NW1/4 sec. 22, T. 17 N., R. 79 W.	M
Coarse-grained arkosic quartz-pebble conglomerate	Present	3X	3.2	n.d.	SW1/4 sec. 10, T. 18 N., R. 79 W.	LP
Pebbly quartzite	n.d.	2.5X	n.d.	n.d.	sec. 30, T. 18 N., R. 79 W.	LP
Paraconglomerate (arkosic matrix]	Present	5-6X	n.d.	n.d.	NW1/4 NW1/4 sec. 23, T. 16 N., R. 81 W.	LP
Paraconglomerate (amphibolite matrix)	Not present	2-3X	n.d.	n.d.	NW1/4 sec. 21, T. 16 N., R. 80 W.	UP
Quartz-pebble conglomerate	Present	22X	*141	*377	S1/2 NW1/4 sec. 6, T. 18 N., R. 78 W.	UP
Quartz-pebble conglomerate	Present	18X	*132	*262	S1/2 NW1/4 sec. 6, T. 18 N., R. 78 W.	UP
Quartz-pebble conglomerate	Present	20X	*109	*916	SE1/4 NW1/4 sec. 5, T. 18 N., R. 78 W.	UP
Feldspathic quartz	n.d,	2X	7	n.d.	SW1/4 sec. 26, T. 19 N., R. 79 W.	LP
Hematitic quartz vein	n.d.	1.5X	7	n.d.	E1/2 sec. 31 T. 18 N., R. 79 W.	LP
Hematitic quartz-vein	n.d.	1.5X	10	n.d.	SW1/4 sec. 32, T. 18 N., R. 79 W.	LP
Quartz vein	-	-	31	n.d.	SE1/4 sec. 10, T. 16 N., R. 80 W.	M
Arkosic quartz pebble conglomerate	n.d.	7X	n.d.	n.d.	C sec. 25, T. 18 N., R. 79 W.	M
Arkosic quartz-pebble conglomerate	n.d.	3X	n.d.	n.d.	N 1/2 sec. 2, T. 17 N., R. 79 W.	
Arkosic quartz-pebble conglomerate	n.d.	5X	n.d.	n.d.	NW1/4 sec. 6, T. 17 N., R. 78 W.	M
Muscovite schist	n.d.	5X	n.d.	n.d.	NW1/4 sec. 35, T. 18 N., R. 79 W.	UP
Sulphide veinlet in granite	Present	20X	n.d.	n.d.	NW1/4 sec. 17, T. 16 N., R. 79 W.	LS
Sheared granite	n.d.	10X	n.d.	n.d.	SW1/4 SE1/4 sec. 8, T. 17 N., R. 79 W.	MP

Upper part of the assemblage of Phantom Lake

Beds of the upper part crop out in two overturned synclines in the northwest Sierra Madre and in an east-striking belt that extends throughout the north-central Sierra Madre (pl. 2). In the Medicine Bow Mountains, rocks of the upper part are in an overturned syncline located southeast of Arlington, in the core of an anticline southeast of Sand Lake, and in the general area east and west of Phantom Lake (pl. 2). The basal unit of the upper part of the assemblage is a coarse-grained, radioactive, micaceous quartzite containing beds of strongly radioactive quartz-pebble conglomerate. This radioactive unit is variable in thickness, but in the One Mile Creek area of the Medicine Bow Mountains (sec. 6, T. 18 N., R. 78 W.) and the Deep Gulch area of the Sierra Madre (sec. 36, T. 16 N., R. 88 W.) the unit is over 100 meters thick (fig. 2).

In the Sierra Madre the radioactive unit grades upward into a unit containing fining-upward sets. These sets contain quartz-pebble conglomerate that grades upward into quartzite with trough cross-bedding. The quartz-pebble conglomerate of these sets is better sorted than that of the radioactive unit, but it has a radioactivity only slightly above background. The unit with fining-upward sets grades upward into finer grained quartzite with less developed or less preserved crossbedding. The total thickness of quartz-rich beds above the radioactive unit is 200 meters. These beds are overlain by a fine-grained biotite-amphibole schist containing thin pebble layers. These schists may represent turbidites. The thickness of the schist unit is unknown because of poor exposure and because the schist is invaded by abundant diabase sills, but its thickness probably exceeds 200 meters. The schist unit is overlain by a bluish-white, fine- to medium-grained quartzite in which planar crossbedding can be recognized locally. This quartzite unit is also cut by diabase sills. It has an approximate thickness of 200 meters. The quartzite is overlain by a fine-grained marble unit marked by thin layers of silica and containing one thick bed of phyllite near the middle of the unit. The marble unit is overlain by medium- to fine-grained quartzite containing numerous diabase sills. This quartzite is approximately 400 meters thick; it is succeeded by biotite-amphibole gneisses and schists that have beds of paraconglomerate. The paraconglomerate contains scattered clasts of granite and quartzite. This gneiss-schist unit is also cut by sills of diabase; its thickness is approximately 550 meters. Exposures in the Sierra Madre are such that it is not possible to establish the stratigraphy of beds overlying the gneiss-schist unit, but these upper metasedimentary rocks are chiefly phyllitic, fine-grained quartzite. The uppermost unit of the upper part of the assemblage in the Dexter Peak area of the Sierra Madre is light-gray phyllite at least 200 meters thick. The total thickness of the upper part is not well established, but its thickness in western and central Sierra Madre is thought to average about 5,000 meters. (A 30 percent reduction in thickness might be reasonable if sills are not considered.)

Figure 2.--Radioactive quartz-pebble conglomerate layer (foreground) near the base of radioactive unit of the upper "Phantom Lake Group" of the One Mile Creek area, northeastern Medicine Bow Mountains. Looking southeast, beds overturned.

From west to east there are distinct facies changes in the upper part of the assemblage in the Sierra Madre. Metavolcanic rocks and paraconglomerate become more abundant in the east and make up over 50 percent of the total section in the vicinity of south Spring Creek Lake (pl. 2). Metavolcanic rocks are metatuffs, metagraywacke (probably volcano-sedimentary rocks), amygdaloidal metabasalt and metabasalt containing pillow structures (fig. 3). The metavolcanics occur as discrete lenticular masses in the succession (pl. 2), or they may have an associated suite of paraconglomerate. For example, south of Bridger Peak in the Sierra Madre, metavolcanic rocks are overlain by paraconglomerate and metagraywacke. The paraconglomerates are lenticular masses that are locally 600 meters thick (fig. 4). These paraconglomerates change in character from base to top of the succession: those at the base contain a higher percentage of volcanic rock fragments than those at the top, and the basal paraconglomerates are also characterized by an amphibolitic matrix. These basal paraconglomerates are interbedded with lithicwacke, composed mostly of volcanic rock clasts. Some granite clasts may be present in all the paraconglomerates, but they become far more abundant in the upper part of the succession, where the matrix of the paraconglomerate is arkosic. The upper paraconglomerate has lithicwacke associated with it that is composed mostly of granite clasts. The changing composition of the clasts in paraconglomerate and associated lithicwacke probably reflects a change in source through time. We must emphasize, however, that paraconglomerate is found throughout the assemblage of Phantom Lake in both upper and lower successions, and it varies greatly in the nature of clasts and matrix[2/].

2/ A more detailed description of the part of the upper assemblage of Phantom Lake in the Sierra Madre is in Graff (1978), where formation names are proposed for parts of the assemblage and composite type sections are established.

The upper part of the assemblage of Phantom Lake in the Medicine Bow Mountains is not as well exposed as in the Sierra Madre, but lithologies in the two areas are very similar. In the Phantom Lake region at the southwest limit of exposure of the upper part, the lower part of the assemblage is not well exposed but includes fine-grained quartzite, phyllites, and paraconglomerate, which crop out west of the confluence of Little Brush Creek and South Brush Creek (sec. 24,T. 16 N., R. 81 W.; pl. 2). The radioactive micaceous quartzite with conglomerate beds that marks the boundary between the lower and upper parts of the assemblage is not exposed but is believed to be present above the paraconglomerate, which is strongly radioactive and better sorted in this area than in most localities of either the Sierra Madre or the Medicine Bow Mountains. Quartzite exposed east of the radioactive paraconglomerate has characteristics very much like those of the quartzite overlying the radioactive marker in the Deep Gulch area of

Figure 3.--Pillow lava of upper "Phantom Lake Group." South Spring Creek Lake area, Sierra Madre. Looking north.

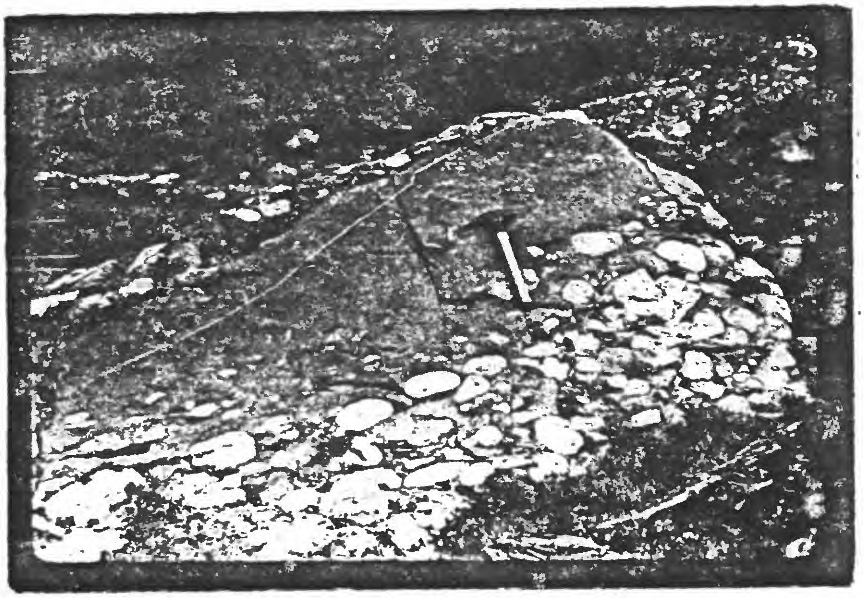

Figure 4.--Paraconglomerate layers in upper "Phantom Lake Group." Locality approximately 1.2 kilometers southwest of Bridger Peak, Sierra Madre. Rounded clasts are white and pink granite. Note suggestions of grading in lower conglomerate. Looking north.

the Sierra Madre (fig. 5), further reinforcing the concept that the marked bed is present in this area. The lowest beds of the upper part of the assemblage are poorly exposed in this south Brush Creek area, but exposures of the higher beds along lower Arrastre Creek are chiefly of fine- to medium-grained quartzite with interbedded sericite schist and fine-grained sericitic quartzite. These quartzites grade upward into a section consisting of metavolcanic rocks and paraconglomerate. Sills and dikes of metadiabase are abundant. The thickness of these upper beds in the Medicine Bows, less sills, is estimated to be about 3,000 meters; thus the total thickness of the upper part of the assemblage of Phantom Lake probably approaches the 5,000 meters recorded in the Sierra Madre.

Rocks of the upper part in the Arlington area of the Medicine Bow Mountains (pl. 2) are better exposed than those in the Phantom Lake area, and the radioactive marker bed is well developed. This area has not been mapped in detail, but the upper part of the assemblage appears to be thinner than elsewhere, perhaps averaging less than 3,000 meters. Quartzite is the most common rock type in the succession south of Arlington, whereas metavolcanic rocks and paraconglomerates are more abundant from Rock Creek to the Medicine Bow River (pl. 2).

The age of the upper part of the assemblage of Phantom Lake is unknown. No rocks in this group have been dated. Lithologically these metasedimentary rocks resemble rocks of early Proterozoic age, and the presence of pyritic-quartz pebble conglomerate suggests an age greater than or equal to 2,200 m.y.

<u>Preliminary discussion of depositional environment of the radioactive beds and adjacent strata in the assemblage of Phantom Lake</u>.--The basal beds of the upper part of the assemblage of Phantom Lake including the radioactive sericitic quartzite with conglomerate beds and the overlying quartzite with fining-upward sets, are fluvial. Much more information must be obtained on primary structure, paleocurrent direction, and petrography before a sedimentological model can be proposed, but these basal beds have features like those described by Minter (1976) for the Vaal Reef gold-uranium placer and associated beds of South Africa; by McGowen and Groat (1971) for the Cambrian(?) distal facies Van Horn Sandstone of West Texas; and by McDowell (1957), Roscoe (1969), and Robertson (1976) for the Blind River uranium-bearing quartz-pebble conglomerates of Canada.

Minter (1976) interprets the Vaal Reef as a braided drainage system deposited unconformably on a gently sloping paleosurface. The Vaal Reef orebody is a light-gray pebbly siliceous quartzite with a bimodal size-frequency distribution (Minter, 1976, p. 165). According to Minter it contains every combination of sand-sized and pebble-sized material ranging from a few inches of siliceous quartzite to consecutive layers of conglomerate, pebbly quartzite, conglomerate, siliceous quartzite, and quartzite developed in channels. The beds that underlie the Vaal Reef are coarse-grained siliceous to argillaceous quartzites with minor,

Figure 5. -Quartzite of the upper "Phantom Lake Group." Locality near South Brush Creek, sec. 24, T. 16 N., R. 81 W., Medicine Bow Mountains. Note trough crossbedding (lower), tabular crossbedding (middle), and horizontal stratification (upper). The eroded contacts between stratification units are phyllitic partings. The tabular crossbedding below the hammer is part of a sandbar which contains reactivation surfaces. This quartzite is considered to be typical of the fluvial units of the upper "Phantom Lake Group." Looking north.

thin shale partings (Minter, 1976, p. 162). The beds that overlie the Vaal Reef are largely argillaceous quartzite. The Vaal Reef is thus a conglomeratic unit, a few centimeters to a meter or more thick, largely confined by coarse-grained quartzite. Minter has made thousands of observations of the Vaal Reef and associated rocks, including many underground observations, and from his comprehensive data bank he has developed a model that describes the genesis of the Vaal Reef placer. It is much too early to attempt this kind of interpretation for the units of the Sierra Madre and Medicine Bow Mountains; however, we will present the information collected to date, and the reader will see a similarity to the Vaal Reef and associated rocks.

In the Arlington or One Mile Creek locality of the Medicine Bow Mountains some limited information is available from surface studies of the radioactive coarse-grained sericite quartzite unit and from study of cores made available by the Exxon Company. Maximum thickness of the radioactive unit measured in subsurface is 130 meters. The unit is essentially sericitic, coarse-grained quartzite with pebble layers. The pebble layers range from beds with the thickness of a single pebble to compound zones approximately 3 meters thick that include pyritic quartz-pebble conglomerate, fine-grained pyritic quartzite, and coarse-grained pyritic quartzite in varying combinations. There are four compound zones ranging from 0.5 to 3 meters in thickness. In addition there are eleven other pyritic quartz-pebble layers less than 0.5 meters thick scattered through the 130-meter section. As noted above, the entire section has radioactivity above background for the area, but the most radioactive units are the conglomerate layers. These conglomerate layers are several orders of magnitude more radioactive in subsurface samples (at depths below 35 meters) than they are on the surface, and they contain abundant pyrite (up to 20 percent from visual estimates), which is almost entirely leached from surface samples.

Clearly both uranium minerals and pyrite have been largely removed from the surface, and environmentally useful information on the occurrence of these minerals must come from the subsurface. Subsurface samples show that the most intense radioactivity is characteristically at the base of conglomerate layers, suggesting that there is a concencentration of uranium and thorium bearing minerals at the base of channels. Study of cores also shows that pyrite is more abundant in conglomerate layers, but it does not appear to be concentrated at the base of the layer. Some pyrite appears rounded in hand specimens but most occurs as euhedral grains, some with vugs. The pyrite may have been redistribed; it has certainly been largely recrystallized.

The pyritic quartz-pebble conglomrate layers are trimodal and consist of a major clay-silt-sized fraction, sand-sized fraction, and pebble-sized fraction. The silt-sized fraction is largely sericite, the sand-sized fraction is largely quartz with subordinate feldspar, and the rounded pebbles consist chiefly of vein quartz, quartzite, altered felsic volcanic(?) rocks, and some altered feldspar(?) of possible pegmatite origin.

The source of the clasts in the radioactive unit is not known. A few paleocurrent measurements have been made on crossbedding sets in quartzite above the radioactive unit, and they indicate a source to the north or north-northeast. These measurements are not statistically valid, and they are not from rocks within the radioactive unit proper. However, field observations of size of clasts within the conglomerate of the radioactive unit indicates that the coarsest fraction is found in the northernmost outcrop; so the available evidence, although not conclusive, suggests a north to north-northeast source.

We suggest that the presence of (1) pyritic quartz-pebble conglomerate units with radioactive minerals concentrated at their base, (2) fining-upward sets containing quartzite with trough crossbedding, (3) "rounded" pyrite, and (4) thick channel-like units similar to those described by Minter (1976, p. 165-166) in the Vaal Reef of South Africa implies a fluvial origin for the conglomerate and its associated pyrite and radioactive minerals. As stated above, the best guess is that these conglomerates were deposited in braided streams, but their exact depositional environment or source is presently unknown.

In the Sierra Madre the radioactive unit is also considered to be fluvial and is succeeded by fine-grained quartzites that grade upward into rocks that were probably argillites; overall, the section (cycle 1) becomes finer upward and might be interpreted as a transgressive sequence of some type. There is no evidence to ascertain whether the upper part of the cycle is marine or nonmarine. The sequence above cycle 1 grades from quartzite to marble, suggesting a second transgressive sequence (cycle 2). The marble may indicate a marine origin for the upper part of this unit. In the western Sierra Madre, beds above these two cycles were probably also deposited in cycles, but they are generally finer grained and contain a larger proportion of rocks that were originally argillite. These characteristics suggest deposition at some distance from source and a possible marine origin for some of these rocks. The origin of the metavolcanic rocks and associated paraconglomerate of the eastern Sierra Madre is uncertain. Features of some metavolcanic rocks (pillows) suggest a marine environment of depositon, but the paraconglomerates may be nonmarine. (See Graff, 1978, for a detailed discussion of these rocks.)

Assemblage of Deep Lake

The assemblage of Deep Lake is defined in the north-central Medicine Bow Mountains, where the rocks of this assemblage are best exposed and where they are least deformed and metamorphosed. A tentative stratigraphic succession has been established by Karlstrom (1977, p. 10), who has subdivided the assemblage of Deep Lake into six units: the formation of Magnolia Lake quartzite of Lindsey Lake, formation of Campbell Lake, quartzite of Cascade Lake, formation of Vagner Lake, and quartzite of Rock Knoll.

In the Sierra Madre, Graff (1978) also recognizes the assemblage of Deep Lake but some lithologies differ enough from those of the Medicine Bow Mountains to require different names, for example: beds in the stratigraphic position of the quartzite of Lindsey Lake are named the formation of Singer Peak; beds in the stratigraphic position of the quartzite of Rock Knoll are named the quartzite of Copperton; and a new unit, the formation of Slaughterhouse Gulch, is added at the top of the succession (table 1).

The formation of Magnolia Lake is the basal rock succession of the assemblage of Deep Lake, and it unconformably overlies rocks of the assemblage of Phantom Lake. It crops out in the Medicine Bow Mountains in the Arrastre Lake area (sec. 10, T. 16 N., R. 80 W.), where it lies on metavolcanic rocks of the assemblage of Phantom Lake, and along the North Fork of Rock Creek, where outcrops extend fron near the head of the North Fork to its confluence with Rock Creek proper (pl. 2). Near the head of the North Fork of Rock Creek the formation of Magnolia Lake lies on metavolcanic rocks of the assemblage of Phantom Lake, and near the confluence of the North Fork of Rock Creek and Rocks Creek it appears to be in fault contact with younger rocks (pl. 2). The formation of Magnolia Lake also crops out along the south side of Deep Creek in the Medicine Bow Mountains, where it lies on paraconglomerates of the assemblage of Phantom Lake. The formation of Magnolia Lake may also extend east of Rock Creek in the Medicine Bow Mountains (pl. 2), where it may lie on quartzite of the assemblage of Phantom Lake. The occurrence east of Rock Creek is speculative because no detailed mapping has been done in this area.

Beds that are believed to be correlatives of the formation of Magnolia Lake have been mapped by Graff (1978) in the Sierra Madre. In the western Sierra Madre they are in a syncline with its axes located near Dexter Peak (sec. 21, T. 15 N., R. 87 W.), and they probably extend beneath Tertiary cover south of this area and appear in another syncline north of Deep Creek (sec. 34, T. 15 N., R. 87 W.). Linear outcrop of the formation of Magnolia Lake continues to an area near the head of Haggerty Creek where it is cut out by a mafic intrusion (pl. 2). In most of this area these Magnolia Lake rocks lie on phyllite of the upper part of the assemblage of Phantom Lake. Beds of the formations of Magnolia Lake are also present in an east-striking belt that extends from a locality east of Haggerty Creek to Bottle Creek (pl. 2); contact relationships with older rocks are uncertain in this area, but here the formation of Magnolia Lake may be thrust over older rocks.

The basal beds of the formation of Magnolia Lake in the Medicine Bow Mountains are referred to as the "Conglomerate Member" by Karlstrom (1977, p. 23-25); these beds are a radioactive, coarse-grained, arkosic quartzite with conglomerate layers and are remarkably similar to the basal unit of the upper assemblage of Phantom Lake. In fact, these units are so similar that the writers are still uncertain which of these radioactive beds has been mapped in the area of the Medicine Bow Mountains east of Rock Creek and in the northwest Sierra Madre. The basal beds of the formation of Magnolia Lake vary somewhat from one locality to another. For example, in the Medicine Bow Mountains east of Arrastre Lake, a lenticular, relatively coarse-grained conglomerate with clasts up to 16 cm diameter is present at the base of the unit. This conglomerate is as much as 3 meters thick in places and is strongly radioactive (7-8 times background). It is green to yellowish-red and contains rounded clasts of quartzite, micaceous quartzite, phyllite, metavolcanic rocks, and granite in a pyritic arkosic matrix. The basal conglomerate is overlain by a more continuous quartz-pebble conglomerate that contains pebble-sized clasts of quartz, quartzite, fine-grained sericitic quartzite, phyllite, and altered rocks of probable volcanic origin in a sericitic, feldspathic-quartzite matrix. In the Arrastre Lake area the "Conglomerate Member" of the formation of Magnolia Lake is not continuous. It pinches out west of Arrastre Lake, where it apparently grades laterally into fine-grained quartzite. The conglomerate that crops out near the head of the North Fork of Rock Creek (sec. 22, T. 17 N., R. 79 W.) consists of arkosic quartzite interbedded with dark-colored, conglomeratic quartzite. The dark-colored conglomeratic layers are more radioactive than the arkosic quartzite. Outcrops of the conglomerate west of Rock Creek (pl. 2) have not been examined in any detail but are radioactive pebbly arkosic quartzite. The conglomerates of the formation of Magnolia Lake are 150 meters thick at Arrastre Lake and 200 meters thick near the head of the North Fork of Rock Creek.

In the western Sierra Madre, rocks thought to be the equivalent of the conglomerates of the formation of Magnolia Lake are pebbly sericitic quartzite with beds of quartz-pebble conglomerate. The quartz-pebble conglomerate is strongly radioactive locally, and, as in the Medicine Bow Mountains, the entire unit shows radioactivity above background for the area. In the Dexter Peak area of the Sierra Madre, vein quartz is the major constituent of the pebble fraction of conglomerate layers; quartzite and altered rocks of possible volcanic origin are also present. The matrix of the conglomerate is a pyritic, sericitic quartzite. The pyrite has been completely altered to goethite, and its former presence is indicated in most samples by vugs with goethite coatings. An interesting feature of the conglomerate at Dexter Peak is the presence of fining-upward sets with conglomerate at the base of each set and trough-crossbedded quartzite at the top suggesting fluvial origin for the unit.

The conglomerate of the formation of Magnolia Lake mapped in the eastern Sierra Madre is a fine-grained quartz-pebble conglomerate that appears to be better sorted than the western "Conglomerate Member." It is also less radioactive.

In the Medicine Bow Mountains the conglomerates of the formation of Magnolia Lake grade upward into quartzite. The quartzites are coarse-grained and well-sorted and consist largely of well-rounded quartz granules that average 1-2 mm in diameter and less common pebbles that are as much as one cm in diameter. The quartzites contain less matrix than the underlying conglomerates (<5 percent) and are relative low in feldspar (<5 percent).

The quartzites have well-developed trough crossbeds with troughs approximately 5 to 15 cm deep. The quartzites have a more consistent thickness than the underlying conglomerates, averaging 425 meters.

The formation of Magnolia Lake is overlain by the quartzite of Lindsey Lake, which crops out in the Medicine Bow Mountains in the axis of a northeast-plunging anticline located west of Dipper Lake (secs. 2 and 11, T. 16 N., R. 80 W.) and in a doubly plunging anticline that extends from Deep Lake (sec. 32, T. 17 N., R. 79 W.) to sec. 24, T. 17 N., R. 79 W. The quartzite of Lindsey Lake is also present in the trough of a syncline that crops out near Mutt and Jeff Lakes (sec. 28, T. 17 N., R. 79 W.) and in the area of Rock Creek (sec. 36, T. 18 N., R. 79 W.) of the Medicine Bow Mountains (pl. 2). In the Dipper Lake area the quartzite of Lindsey Lake is light gray and medium-grained with layers of pebbles concentrated on forset beds of crossbeds and in smaller scours. The overall characteristics of this unit (table 3) suggest a fluvial origin in the Dipper Lake area, whereas Karlstrom (1977, p. 35) suggests a marine origin for a fine-grained facies of the quartzite of Lindsey Lake, located east of Deep Lake (pl. 2, table 3).

In the Sierra Madre the stratigraphic position of the quartz of Lindsey Lake is occupied by a thick sequence of metasedimentary rocks that are mostly phyllite. These rocks are referred to as the foremation of Singer Peak (Graff, 1978) and they crop out in two synclines in the western Sierra Madre and in an east-striking belt that extends from Deep Creek (sec. 3, T. 14 N., R. 87 W.) to Crow Creek (sec. 19, T. 14 N., R. 85 W.). Key properties of the rocks of the formation of Singer Park are in table 3. The formation is thickest in the west, where the upper part contains beds of quartz-pebble conglomerate and quartzite of possible fluvial origin. In the east the upper part of the unit is cut out by a thrust fault (pl. 2).

The quartzite of Lindsey Lake is overlain unconformably by the formation of Campbell Lake which contains distinctive marker beds useful in mapping. The formation of Campbell Lake consists of a paraconglomerate (fig. 6) overlain by a quartz-rich phyllite. The paraconglomerate has an arkosic matrix containing rounded clasts of white granite, phyllite, quartzite, and metabasalt that are as much as 76 cm in diameter. The conglomerate grades into a dark-gray to black phyllite, which becomes quartz-rich at the top. The formation of Campbell Lakes crops out in two localities in the north half of T. 16 N., R. 80 W., and in two localities in the south half of T. 17 N., R. 80 W. (pl. 2). It is also on the west side of the Medicine Bow River (sec. 23, T. 17 N., R. 80 W.) and in three localities north, south, and east of Deep Lake (pl. 2). Although it is exposed over a wide area of the Medicine Bow Mountains, it is not continuous; where it is absent, its absence is thought to be the result of nondeposition. Rocks that are considered correlatives of the formation of Campbell Lake are present at one locality in the Sierra Madre, in the western Sierra Madre, on Deep Creek (pl. 2).

Table 3.--Description of the formations of the assemblage of Deep Lake and the Libby Creek Group[1], Sierra Madre and Medicine Bow Mountains, Wyoming

	MEDICINE BOW MOUNTAINS						SIERRA MADRE					
	Formation	Lithology	Primary features	Source	Depositional environment	Thickness (m)	Formation	Lithology	Primary features	Source direction	Depositional environment	Est. thickness (m)
LIBBY CREEK GROUP[1]	French Slate[2]	Gray slate	Thin quartzite layers	?	Marine	600						
	Towner Greenstone[2]	Chlorite schist	Relict igneous textures	?	?	0-480						
	Nash Fork Formation[1]	Lenticular phyllite Metadolomite	Graphitic layers Stromatolites	?	Marine Shallow marine	1900						
	Sugarloaf Quartzite[2]	Massive quartzite	Cross-beds, ripple marks	?	Marine	0-580						
	Lookout Schist[2]	Laminated schist with quartzite layers	Sole markings Clastic dikes Cross-bedding	?	Marine, turbidites	365	Libby Creek Group[1] not present					
	Medicine Peak Quartzite[1]	Quartzite conglomerate Quartz-pebble conglomerate quartzite Quartzite	Fining upward sequences Massive Tabular cross-beds	ENE	Fluvial and shallow marine Pro-deltaic? Near shore marine	1585						
	Heart Formation[1]	Quartzite Phyllite Quartzite	Massive Laminated Massive, cross-beds	NE	Shallow marine Marine Shallow marine fluvial	650						
	Headquarters Schist[2]	Phyllite Arkosic quartzite Paraconglomerate	Varves? Cross-beds Dropstones	NNE	Glacial or glacio-marine	650						
			Unconformity				Shear zone					
ASSEMBLAGE OF DEEP LAKE	Quartzite of Rock Knoll	Conglomerate quartzite Quartzite; phyllitic quartzite	Channels Slate partings; ripple marks	FSE	Fluvial Shallow marine	380	Formation of Slaughter Gulch	Phyllite, calc-silicate, metadolomite	Not observed	?	Marine	500
							Quartzite of Copperton	Massive sheared quartzite, minor phyllite	Not observed	?	?Shallow marine?	1400
		Quartzite	Planar cross-beds		Shallow marine		High-angle reverse fault					
	Formation of Vagner Lake	Phyllitic quartzite Marble Paroconglomerates	Ripple marks; cross-beds Siliceous and calcareous layers Dropstones	ENE	Glacial or glacio marine	120-400	Formation of Vagner Lake	Phyllite quartzite, marble Paraconglomerates	Rare cross-beds Channels	NE?	Glacio-marine	600
	Unconformity						Unconformity					
	Quartzite of Cascade Lake	Pebbly, arkosic quartzite Pebbly quartzite Quartzite	Black chert pebbles; Tabuler and trough cross-beds Massive	ENE	Fluvial	150-1530	Quartzite of Cascade Lake	Pebbly arkosic quartzite Quartz-arenite Quartz-pebble conglomerate	Trough cross-beds Channels	NE	Fluvial	2100
	Formation of Campbell Lake	Quartz-rich phyllite Paraconglomerates	Faint stratification	NE	Marine? Glacial?	75	Formation of Campbell Lake	Green phyllite, thin quartzite, Paraconglomerates	Rare cross-beds		?Glacio-marine?	200
	Quartzite of Lindsey Lake	Medium-grain quartzite	Trough cross-beds	?	Fluvial; fluvial deltaic	440	Formation of Singer Peak	Thick green phyllite, green Phyllite with thin, interbedded quartzite	Not observed	?	Marine	1100
	Formation of Magnolia Lake	Coarse-grain quartzite Radioactive quartz-pebble conglomerates	Trough cross-beds Poor sorting, planar beds	NNE	Fluvial Fluvial	570	Formation of Magnolia Lake	Arkosic quartzite thin phyllite, Quartz-granule and quartz-pebble conglomerates	Trough cross- Graded beds Channels	NE	Fluvial	400
						Unconformity						

1/ Houston and others (1968)
2/ Blackwelder (1926)

Figure 6.--Paraconglomerate of the "Campbell Lake Formation," Medicine Bow Mountains. Locality near Campbell Lake, sec. 35, T. 17 N., R. 79 W. Clasts in this paraconglomerate vary greatly in size from granule to boulder. Small granite clast can be seen to left of large granite clast; white objects above large clast are pebble-sized clasts.

The formation of Campbell Lake is overlain conformably by the quartzite of Cascade Lake (Karlstrom, 1977, p. 41). Properties of the quartzite of Cascade Lake are in table 3. The quartzite of Cascade Lake crops out over a large area of the north-central Medicine Bow Mountains and probably occurs in a Precambrian block exposed between Cooper Hill and Rock Creek (pl. 2). It also occurs in an east-striking belt in the Sierra Madre, from Big Sandstone Creek to the Encampment River (pl. 2). The unit has a distinctive lithology in both mountains; it is marked by pebble layers ranging from a thickness of one pebble to channels 20 meters thick that contain pebbles of quartz, quartzite, black chert, and pink granite. The black chert is readily identified and serves to distinguish the quartzite of Cascade Lake from other similar units. For the most part, the quartzite of Cascade Lake is a more mature rock type than most quartzites that underlie it. For example, it contains more resistant clasts and it is not feldspathic except at the very top of the unit. As indicated in table 3, the quartz of Cascade Lake is thought to be fluvial.

The quartzite of Cascade Lake is unconformably overlain by the formation of Vagner Lake (Karlstrom, 1977, p. 48-53), which is a threefold unit consisting of a basal paraconglomerate, a middle metalimestone, and an upper phyllite. It crops out in the Medicine Bow Mountains in a northeast-striking belt that extends from Dipper Lake northeast to Trail Creek (pl. 2). It can be recognized in a locality on the west side of Rock Creek (sec. 6, T. 17 N., R. 78 W.) and probably occurs in the block of Precambrian rocks exposed west of Cooper Hill and east of Rock Creek (pl. 2).

In the Medicine Bow Mountains the matrix of the paraconglomerate is arkosic, and clasts, in order of decreasing abundance, are red granite, white granite, quartzite, phyllite, and rare metavolcanic(?) rocks. This paraconglomerate and associated phyllite have features suggestive of glacial origin. As first noted by Blackwelder (1926) and later by Sylvester (1973), these paraconglomerates are poorly sorted, have more angular clasts, and have larger clasts (some boulder sized) than the paraconglomerates described previously. Furthermore, associated phyllites have dropstones (fig. 7) and this fact, along with other evidence (Sylvester, 1973), strongly suggests a glacial or possibly glacio-marine origin for the paraconglomerate and phyllite. The origin of the associated metalimestones is uncertain, but these metalimestones may represent calcium carbonate brines deposited in response to the retreat of dry-based glaciers (Carey and Ahmad, 1961, p. 886).

In the Sierra Madre, units thought to be equivalent to the formation of Vagner Lake crop out in a syncline located where Big Sandstone Creek makes an abrupt right angle turn and flows west (pl. 2) and in an east-striking belt that extends along the southern margin of the Sierra Madre metasedimentary rock mass (pl. 2). In the western Sierra Madre the formation of Vagner Lake is like that of the Medicine Bow Mountains in that it consists of paraconglomerates and associated phyllite layers overlain by metalimestone, which is, in turn, overlain by phyllite. The clasts in paraconglomerates are largely red granite

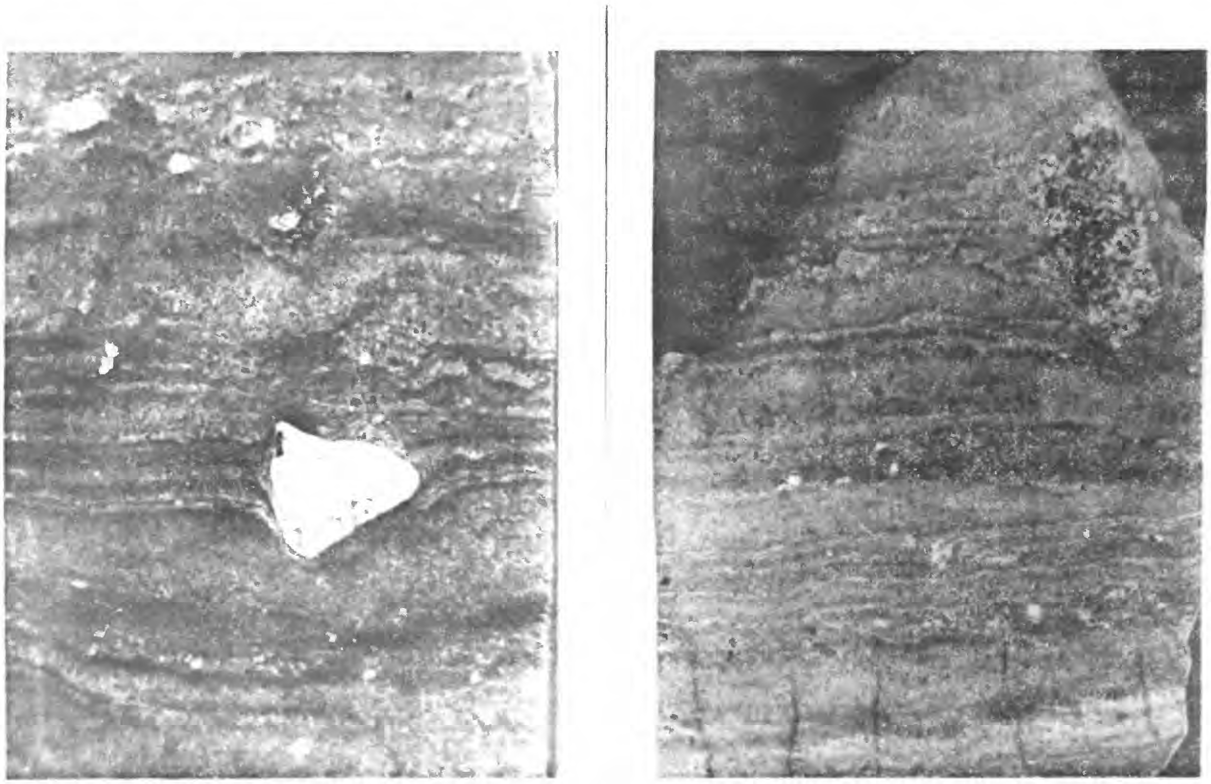

Figure 7.--Dropstones of the "Vagner Formation." Larger elongate clasts in right-hand photograph 45 mm long. Samples collected by G. H. Sylvester from area west of South Twin Lakes, Medicine Bow Mountains.

with subordinate quartzite, and some of the phyllites have isolated clasts resembling dropstones. In the eastern Sierra Madre the meta-limestone is missing, but paraconglomerates and phyllites are like that of the Medicine Bow Mountains. In some localities of the Sierra Madre quartzite layers are found within the unit mapped as the formation of Vagner Lake, a feature that is not typical of the unit in the Medicine Bow Mountains.

The formation of Vagner Lake is conformably overlain by the quartzite of Rock Knoll (Karlstrom, 1977, p. 53). The quartzite of Rock Knoll is chiefly gray and fine to medium grained with thin layers of phyllite (table 3). Near the base of this unit planar crossbedding in sets 0.6 to 1.5 m thick are common; this crossbedded sequence is overlain by quartzite with olive-colored patches. The olive-colored patches are distinctive and may characterize this part of the unit. These olive-colored patches have been interpreted by Blackwelder (1926, p. 627) and Houston and others (1968, p. 17-22) as clay galls and by Karlstrom (1977, p. 53) as erosional remnants of shale partings. Both features are probably present in the lower part of the quartzite of Rock Knoll and they both appear as olive-colored patches in cross-sectional view. The upper part of the quartzite of Rock Knoll has abundant thin (6-10 cm) beds of conglomerate. Clasts are quartz, quartzite, or granite. As suggested by Blackwelder (1926, p. 626-627), this part of the quartzite of Rock Knoll may be fluvial.

In the Sierra Madre the rocks in the stratigraphic position of the quartzite of Rock Knoll are referred to as the quartzite of Copperton (Graff, 1978) and are near the contact with a major shear zone (pl. 2). They are sheared and locally mylonitic. This deformation has largely destroyed primary structure.

In the Medicine Bow Mountains the quartzite of Rock Knoll is overlain unconformably by rocks of the Headquarters Schist (Houston and others, 1968), the basal unit of the Libby Creek Group. However, in the Sierra Madre, equivalents of the quartzite of Rock Knoll are overlain by highly deformed and brecciated graphitic marbles. These graphitic marbles are tentatively considered the uppermost part of the assemblage of Deep Lake (table 3) and have probably been removed from the Medicine Bow area by erosion. They are referred to as the formation of Slaughterhouse Gulch (Graff, 1978). No rocks of the assemblage of Deep Lake have been dated, and their age is therefore unknown. They are probably middle Precambrian in age based on the same criteria used for assemblage of metasedimentary rocks of the upper Phantom Lake.

More detailed descriptions of formations of the assemblage of Deep Lake including type sections are in Karlstrom (1977) and Graff (1978).

Libby Creek Group

The Libby Creek Group has been described by Blackwelder (1926) and by Houston and others (1968). As defined by Houston and others (1968) it includes all rocks above the unit then referred to as the Deep Lake Formation and now referred to as the assemblage of Deep Lake. The formations of the Libby Creek Group (from bottom to top) are the Headquarters Schist (paraconglomerate and laminated phyllite of possible glacial origin), Heart Formation (largely quartzite with primary structure suggestive of shallow-water origin), Medicine Peak Quartzite (thick, massive quartzite probably including fluvial deposits and high-energy marine shoreline deposits), Lookout Schist (interlayered quartzite, phyllite, and schist with structure characteristic of distal turbidities; beds of iron-formation are present at the base of the Lookout Schist), Sugarloaf Quartzite (high silica orthoquartzite of probable marine origin), Nash Fork Formation (stromatolitic dolomite and black graphitic phyllite, both of probable shallow marine origin), Towner Greenstone (mafic igneous rocks of uncertain origin), and French Slate (gray slate with rare thin quartzite layers, both of probable marine origin). These formations are described in some detail in the reports cited above and in papers by Knight (1968) on the Nash Fork Formation and Wilson (1975) on the Lookout Schist, and these formations are currently being studied as part of a wilderness evaluation program. Further details on their lithology will be covered in later reports.

It has been necessary to redefine the Headquarters Schist of the Libby Creek Group because part of this unit as originally defined by Blackwelder (1926, p. 627-631) has been included in the formation of Vagner Lake of the assemblage of Deep Lake of this report (table 1).

Several rocks within the Libby Creek Group have been dated (Hills and others, 1968). The Rb/Sr whole-rock ages determined for these metasedimentary rocks are probably dates of metamorphism, but they set an upper limit on the age of the metasedimentary succession. The most reliable metamorphic date for the Lookout Schist is a Rb/Sr whole-rock age of 1,710±60 m.y. Inasmuch as the Headquarters Schist and/or Heart Formation lies on basement gneiss (sec. 11, T. 14 N., R. 81 W.) dated as older than 2,500 m.y. (Hills and others, 1968, p. 1762-1763) and the metamorphic date is approximately 1,710±60 m.y. these rocks must be younger than about 2,500 m.y. and older than about 1,700 m.y. Clearly we need a much closer age bracketing to evaluate the economic potential of these metasedimentary rocks.

REGIONAL STRUCTURE OF THE MEDICINE BOW MOUNTAINS AND THE SIERRA MADRE THAT MAY CONTROL THE DISTRIBUTION OF RADIOACTIVE CONGLOMERATE

Background information on the structure of the Medicine Bow Mountains is in Houston and others (1968, p. 101-135) and in Houston, Schuster, and Ebbett (1975, p. 6-25) for the Sierra Madre. Karlstrom (1977, p. 70-110) gives detailed information on the structure of the metasedimentary rocks of the Medicine Bow Mountains in the area from the confluence of Little Brush Creek and South Brush Creek to the heads of Trail Creek and the Middle Fork of Rock Creek. Details of Sierra Madre structure are in Graff (1978). This review of the structure of these two ranges will be confined to regional features that may control the distribution of radioactive conglomerates.

In the Medicine Bow Mountains, outcrops of the assemblage of Phantom Lake west of the confluence of Little Brush Creek and South Brush Creek (pl. 2) constitute an east-plunging syncline. The radioactive unit at the base of the upper assemblage of Phantom Lake probably is located in the trough of this syncline. A major northeast-striking fault with southeast side down is extrapolated into this area and is believed to strike roughly parallel to Little Brush Creek. A north-northeast-plunging anticline is exposed east of this fault. Rocks in the core of this anticline are from the upper part of the assemblage of Phantom Lake, and those in the nose of the structure belong to the assemblage of Deep Lake, up to the quartzite of Cascade Lake (pl. 2). The radioactive unit at the base of the formation of Magnolia Lake has been mapped on the east side of this anticline and is missing on the west side. If the radioactive unit represents a braided river system, it may trend north-northeast parallel to paleocurrent directions measured in the associated quartzite. The width of such a paleoriver system is not known, but the radioactive unit should be expected in the subsurface east of the surface outcrop. Another braided river system may occur in the subsurface on the northwest flank of the anticline, but there is no surface evidence for such a system. Inasmuch as rocks of the assemblage of Phantom Lake are in the core of the anticline, the radioactive unit in the upper assemblage of Phantom Lake may be found by drilling. That unit, if present, might be encountered at shallow depth by drilling in the South Brush Creek area. The southeast flank of the anticline is bound by a northeast-striking thrust fault that brings rocks of the Libby Creek Group over this structure. Rocks of the assemblage of Phantom Lake and the assemblage of Deep Lake may be in the subsurface east of this fault, but any interpretation of their distribution would be highly speculative.

To the northeast within the outcrop area of the assemblage of Deep Lake the anticlinal axis changes strike from north-northeast to east (pl. 2). The anticline is limited on the north by a major fault (the Jeff Lake fault), which is downthrown on the south side; and on the south, rocks of the Libby Creek Group are thrust over the older rocks of the anticline (pl. 2).

East of Deep Lake the anticlinal axis changes to a northeast strike once again and this strike continues to Rock Creek (sec. 18, T. 17 N., R. 78 W.), where the structure is disrupted by a series of north-striking faults that parallel Rock Creek. Erosion does not cut deeply enough to expose radioactive conglomerate of either the assemblage of Deep Lake or the assemblage of Phantom Lake. However, on the upthrown side of the Jeff Lake fault, older rocks are exposed in a number of areas in a block bounded by the Medicine Bow River on the west, Rock Creek on the east, Deep Creek on the north, and the Jeff Lake fault on the south. Oucrops within this block are uncommon, but the structure is probably a series of anticlines and synclines disrupted by faults that parallel the fold axes and are upthrown on the north side (pl. 2). This block or domain can be divided into two parts by considering rocks east and west of a north-striking fault that is located west of Corral Lake, the Corral Lake fault (pl. 2). West of the Corral Lake fault the quartzite of Cascade Lake is exposed, and although there are no surface exposures of radioactive conglomerate, if the radioactive conglomerate of the formation of Magnolia Lake exposed east of Arrastre Lake is projected north-northeast (parallel to paleocurrent indicators), it might be found by drilling in the area east of the Medicine Bow River. East of the Corral Lake fault, radioactive conglomerate is exposed at four localities: one is near the head of the North Fork of Rock Creek (sec. 22, T. 17 N., R. 79 W.), where radioactive conglomerate of the formation of Magnolia Lake is exposed on the south limb of an anticline; two more are on the south side of Deep Creek, where radioactive conglomerate of the formation of Magnolia Lake is exposed on the north limb of a syncline; and the fourth is west of Rock Creek, where radioactive conglomerate is exposed on the south limb of the same syncline (pl. 2). These surface exposures show that radioactive conglomerate of the formation of Magnolia Lake should be expected in the subsurface in much of this eastern area; unfortunately there is not sufficient information on paleocurrent directions to establish a reliable trend for a braided river system. Paleocurrent measurements (Karlstrom, 1977, pl. 11) are difficult to obtain in the conglomerate of the formation of Magnolia Lake, and those obtained in the quartzite of the formation of Magnolia Lake were quite variable. A south-southeast trend for a braided river system is suggested, however, from work to date. If this trend is correct there were probably two river systems in the area, one near the headwaters of the North Fork of Rock Creek, and another in the vicinity of Rock Creek. There is no information on radioactive conglomerate of the upper part of the assemblage of Phantom Lake, but it could occur within this area.

East of Rock Creek and north of Deep Creek, mapping is largely reconnaissance, and all formations shown in this area on plate 2 may have to be revised. For example, the radioactive unit mapped on One Mile Creek (sec. 6, T. 18 N., R. 78 W.) is exposed in the trough of a syncline with its northwest limb overturned. It is mapped as the basal radioactive unit of the upper part of the assemblage of Phantom Lake. However, there has been no recent mapping between One Mile Creek and Rock Creek. Therefore, it is possible that the overturned north limb of the syncline extends to an area south of the confluence of Deep Creek and Rock Creek, and the radioactive unit would thus be coincident with others mapped as the basal part of the formation of Magnolia Lake. We prefer the former interpretation, however, because hornblende schist and gneiss layers overlie the radioactive conglomerates on One Mile Creek. These rock types have not been found interbedded with metasedimentary rocks that are stratigraphically above the Formation of Magnolia Lake, but they are present in units of the assemblage of Phantom Lake that overlie the radioactive conglomerate of the Sierra Madre. The radioactive beds exposed on One Mile Creek appear to strike to the southeast and extend under cover of Paleozoic rocks in sec. 5, T. 18 N., R. 78 W., but they are cut out by a large mafic intrusion on the overturned northwest limb of the syncline (pl. 2). We have not mapped the radioactive unit beyond this point.

If the above interpretation is correct, drilling in the axis of the syncline mapped west of Rock Creek and the axis of the same syncline extrapolated east of Rock Creek might encounter two radioactive beds: one at the base of the formation of Magnolia Lake and another at the base of the upper part of the assemblage of Phantom Lake. Inasmuch as we have no reliable information on paleocurrents, no recommendations can be made on exact drill site locations. If a hole were drilled in the axis of the syncline west of Rock Creek, depth to the base of the formation of Magnolia Lake would be approximately 130 meters, but depth to the base of the upper part of the assemblage of Phantom Lake might be 3,000 meters or more.

In general, mapping east of Rock Creek and north of the southern margin of T. 18 N. is outdated and mostly reconnaissance. Further mapping will be required to evaluate the economic potential of this area.

Sierra Madre structure has never been well understood because primary structures, used for top and bottom criteria in metasedimentary rock, have been difficult to find. Crossbedding, channels, and graded bedding have been found in local areas by geologists who have studied the metasedimentary rocks (Short, 1958; Ebbett, 1970; Divis, 1976; Houston and Ebbett, 1977; and Graff, 1978), but they are often missing or destroyed in key areas where they are needed to establish a stratigraphic succession or interpret the structure. Therefore, it is not surprising that a different structural interpretation has been proposed by every geologist who has described the metasedimentary succession.

From the areas along both sides of the Encampment River where the easternmost exposures of metasedimentary rocks are found, west to the limit of outcrop of metasedimentary rocks, in the great majority of beds in the metasedimentary succession the top faces south. There is good evidence for folding, however, in rocks exposed in the western Sierra Madre, notably west of Haggerty Creek and in the entire northwest area of the outcrop of metasedimentary rocks (pl. 2). In this report, we interpret metasedimentary rocks of the central and eastern Sierra Madre (east of Haggerty Creek) not as being isoclinally folded, but instead as being disrupted by east-striking thrust faults, and further we interpret the stratigraphic succession exposed in the western Sierra Madre between Jack Creek and Deep Creek (pl. 2) as a normal succession interrupted only by minor folds.

In sec. 25, T. 15 N., R. 87 W., radioactive conglomerate is present near the base of the metasedimentary succession (pl. 2). This radioactive conglomerate probably lies unconformably on an Archean basement of felsic gneiss and older metasedimentary rocks, but the actual unconformity is not exposed. This radioactive conglomerate is mapped as the basal bed of the upper part of the assemblage of Phantom Lake. West of the head of Deep Creek (pl. 2) is another exposure of radioactive conglomerate that is correlated with the radioactive conglomerate at the base of the formation of Magnolia Lake. This radioactive conglomerate probably also lies unconformably on older rocks, but again the actual unconformity is not exposed. Rocks that are stratigraphically above the formation of Magnolia Lake are the formation of Singer Peak and the formation of Campbell Lake.

The east Fork of Savery Creek (sec. 17, T. 15 N., R. 87 W.) is a convenient line to separate the Sierra Madre into two parts. We will discuss the structure of the metasedimentary rocks south and east of the East Fork of Savery Creek first. South of this fork, a series of southwest-plunging folds is developed in the formation of Magnolia Lake and in overlying beds (pl. 2). These folds die out down section in the metasedimentary rocks of the upper part of the assemblage of Phantom Lake. The folds are best developed in metasedimentary rocks having a high proportion of phyllite and slate, and they may represent detachment of younger metasedimentary rocks from older rocks, with the phyllite or slate layers acting as detachment planes. These folds have not been mapped east of Haggerty Creek; in that area most beds dip south and with few exceptions the top also faces south. There is local evidence of folding in the rocks east of Haggerty Creek, however, such as minor folds with amplitudes of several meters and a few isolated quartzites with primary structure, suggesting the top faces north. Inasmuch as we have not been able the uncommon reversals are considered to be parts of minor folds developed in response to the same stress field that caused the development of thrust faults.

From west to east the exposed metasedimentary succession (probably representing the north limb of a west-plunging synclinorium) is reduced from about 13,000 meters to about 3,000 meters; in fact, it tapers to a featheredge on the east bank of the Encampment River (pl. 2). This reduction is accomplished by thrust faults that move younger rocks over older. These thrust faults dip south, are commonly marked by thick sills of diabase, and clearly have greater displacement to the east than to the west. There may also be a wedge effect, because Archean basement is thought to be in fault contact with quartzites of the upper part of the assemblage of Phantom Lake from South Spring Creek east to the limit of outcrop (pl. 2).

The Archean basement may be thrust over rocks of the upper part of the assemblage of Phantom Lake along fault planes that dip north. There is a major fault within the basement which follows the East Fork of Savery Creek and turns southeast at about sec. 24, T. 15 N., R. 87 W. (pl. 2). This fault brings hornblende gneiss of possible volcanic origin against quartzite in sec. 14, T. 15 N., R. 87 W., and where it turns southeast it brings northeast-striking basement gneiss against northwest-striking basement rocks (pl. 2). This fault continues southeast to South Spring Creek Lake, where it is offset by another fault that strikes northeast (pl. 2). It may be the same fault that brings Archean basement rocks over rocks of the upper part of the assemblage of Phantom Lake in the eastern Sierra Madre.

The distribution of the basal radioactive conglomrate of the upper part of the assemblage of Phantom Lake is controlled largely by structure. Outcrops are such that the conglomerate cannot be traced for a significant distance northwest or southeast of its outcrop area in sec. 25, T. 15 N., R. 87 W. The conglomerate should be cut out by a fault to the northwest, however, and it probably does not extend too far to the southeast, because from South Spring Creek eastward it would most likely be cut out by faults bringing the Archean basement over rocks of the assemblage of Deep Lake (pl. 2).

The radioactive conglomerate at the base of the formation of Magnolia Lake is exposed in the axes of two southeast-plunging synclines and probably extends under cover in an anticlinal axis located in sec. 28, T. 15 N., R. 87 W. The radioactive conglomerate has been traced in a linear outcrop southeast to sec. 2, T. 14 N., R. 87 W. The radioactive conglomerate may pinch out east of this locality or it may be removed by faults. Radioactive conglomerate of the formation of Magnolia Lake reappears in the eastern Sierra Madre between Cow Creek and Bottle Creek (pl. 2). This conglomerate is not like the basal conglomerate in the folds to the west; it is cleaner (contains less sericite), finer grained, and much less radioactive. It resembles conglomerate higher in the formation of Magnolia Lake. Perhaps the lower part of this formation is removed by faults in this area (pl. 2), or the unit may simply thin and change character.

North of the East Fork of Savery Creek, mapping of metasedimentary rocks is reconnaissance level and there are sizeable gaps even in the reconnaissance mapping (pl. 2). This is an extremely interesting area, however, because thick beds of radioactive sericitic quartzite and associated radioactive conglomerate have been found in several areas and may occur at other localities.

Divide Peak (sec. 3, T. 15 N., R. 87 W.) is near the axis of an overturned syncline (pl. 2). The axis of the syncline strikes northeasterly from the East Fork of Savery Creek to Divide Peak and then gradually changes strike to the east and southeast (pl. 2). The northern limb of the syncline is overturned, and here the radioactive unit at the base of the upper part of the assemblage of Phantom Lake lies unconformably on biotite gneiss. This biotite gneiss complex of the lower part of the assemblage contains local layers of quartzite and has many quartz-rich layers that are probably metasediments; it is cut by a pink granite best exposed in sec. 1, T. 15 N., R. 88 W. (pl. 2). The radioactive unit has been mapped over a distance of 2.4 kilometers. Detailed mapping has not been undertaken, but the radioactive unit has not been traced to the northeast beyond sec. 6, T. 15 N., R. 87 W, where it extends under cover to the southwest (pl. 2). Before we can consider the possible distribution of this radioactive unit in other parts of the syncline, exposures of metasedimentary rocks north and northwest of the syncline must be discussed.

The overturned northwest limb of the syncline is thought to be repeated in sec. 36, T. 16 N., R. 88 W. (pl. 2). Here a radioactive unit nearly identical to that exposed on the northwest limb of the syncline is present. This radioactive unit in sec. 36 lies unconformably on biotite gneiss of the lower part of the assemblage of Phantom Lake, which is very similar to that at the base of the radioactive unit in the northwest limb of the syncline. The biotite gneiss of sec. 36 is undoubtedly partly paragneiss; near the contact with the radioactive unit it contains highly deformed but identifiable clasts of granite and various metamorphic rocks. These gneisses of sedimentary origin grade into biotite gneiss, and although no primary structure can be found in the biotite gneiss it has a layered aspect that suggests the unit was derived from sedimentary rocks of volcano-sedimentary rocks. The radioactive unit of sec. 36 can be traced for about 5 kilometers northeast, but in the NE1/4 sec. 30, T. 16 N., R. 87 W., the radioactive unit lies on quartzite. The radioactive unit, therefore, probably lies on successively younger rocks to the east and is therefore clearly unconformable. The structural relationship might be as suggested in figure 8.

Inspection of plate 2 shows that the structure suggested above is disrupted by later faults, and also that key areas are yet to be mapped. The above interpretation is simply a working hypothesis, at present, but it may be significant that the radioactive unit exposed on One Mile Creek in the Medicine Bow Mountains shows a relationship to underlying rocks remarkably similar to that suggested above (pl. 2).

It is now possible to suggested other localities where the radioactive units may be found in the northwest Sierra Madre. The first, simplest, and least attractive hypothesis economically is to suggest that the radioactive units pinch out at about their northeast mapped limit. This does not seem probable because both radioactive units have at least average thickness at their northeast limit. Certainly the two radioactive units might extend under cover for some distance to the southwest, because both units are near maximum thickness at their southwest limit. In other words, we do not expect these radioactive units to terminate abruptly.

The northernmost radioactive unit is probably cut out by a northwest-striking fault extrapolated into this area from a locality where it is well exposed (sec. 17, T. 15 N., R. 86 W.). This fault is upthrown on the northeast and would bring older rocks in contact with the radioactive unit near the point where it is exposed in the NW1/4 sec. 29, T. 16 N., R. 87 W. (fig. 8).

The radioactive unit on the northwest limb of the syncline might be found near the contact with gneiss by careful mapping to the northeast

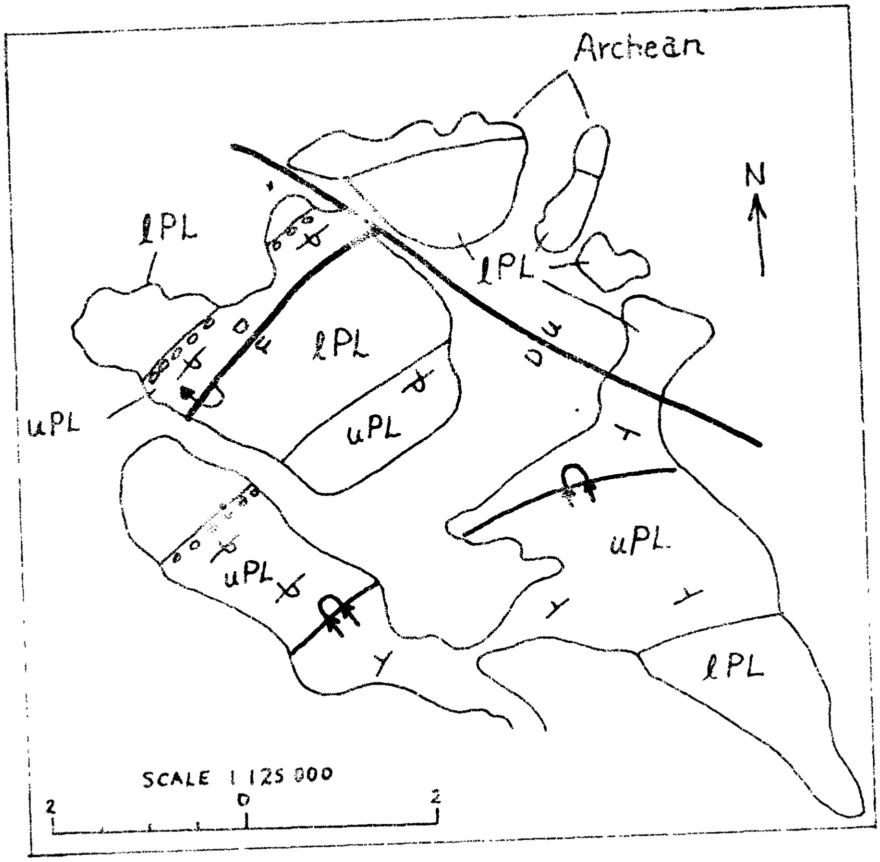

Figure 8.--Tentative interpretation of structure at northwest border of the Sierra Madre. ℓPL = lower "Phantom Lake Group," μPL = upper "Phantom Lake Group," other symbols as shown on plate 1. Fault in northwest is thought to have developed prior to folding and it may by overturned during folding, but its actual dip is unknown.

of the last known exposure. An interesting possibility, however, is that this radioactive unit lies on younger units to the northeast in the same manner that the northernmost radioactive unit does. Under such circumstances it might be expected in a quite different stratigraphic position on both the north and south limb of the syncline.

METAMORPHISM

In the Sierra Madre, metasedimentary and metavolcanic rocks are metamorphosed to high green schist-low almandine amphibolite facies, or, using the terminology of Winkler (1976, p. 64-95), the metasedimentary and metavolcanic rocks lie close to the boundary between low and medium grade. The metamorphic rank is higher (almandine amphibolite) in the northern Sierra Madre, where typical mineral assemblages of pelitic(?) schists are quartz, biotite, and muscovite, $\pm$ garnet, hornblende, plagioclase, chlorite, and microcline. In the northern Sierra Madre, chlorite is present in relatively few schists, and although chlorite composition is not known, the temperature of metamorophism was probably high enough (>550°C) that relatively iron-rich chlorite might react with muscovite to form higher-temperature mineral suites. Divis (1976, p. 26) reports a garnet composition of $Alm_{46}Sp_2Gr_{52}$ in metasedimentary rocks of the northern Sierra Madre. As Divis (1976, p. 26) points out, the low pyrope composition of the garnet as compared with that of garnets in Archean gneiss of the area (Pyr_{23}, $Alm_{39}Sp_{10}And_{28}$ Divis, 1976, p. 16) suggests a lower almandine amphibolite facies for the sedimentary rocks and upper almandine amphibolite facies for the Archean gneiss.

In the southern Sierra Madre a line can be drawn from Dexter Peak in the northwest to Bridger Peak in the center of the metasedimentary succession and then southeast to the limit of outcrop of metasedimentary rocks (pl. 2). South of this line the rank of metamorphism is lower. Pelitic schists of this area contain co-existing muscovite and chlorite, but kyanite is also present in the schist, suggesting that the rocks are upper green schist facies. Unfortunately, key index minerals such as staurolite or cordierite have not been recognized in the Sierra Madre, so it is difficult to fit the temperature and pressure of metamorphism. However, the presence of kyanite and almandine garnet suggest pressures of 5 kbar or more, and mineral suites suggest temperatures of 550°C to 600°C.

Regional studies (Houston and others, 1968) of the metasedimentary rocks of the Medicine Bow Mountains indicated that the metasedimentary rocks of the central Medicine Bow Mountains were less deformed and of lower metamorphic grade than metasedimentary rocks to the northeast or southwest. Phyllites and slates of the central Medicine Bow Mountains contain muscovite, chlorite, and quartz with or without biotite, plagioclase, garnet, and epidote. Muscovite and chlorite commonly co-exist, and this association suggests green schist facies, but the presence of garnet and biotite in the pelitic rocks and kyanite in the matrix of many quartzites suggests upper green schist facies for most of the metasedimentary rocks of the central Medicine Bow Mountains. Mineral assemblages in pelitic rocks of the southwestern Medicine Bow Mountains are more typical of almandine amphibolite facies metamorphism; suites include quartz, muscovite, biotite, and staurolite with or without garnet and kyanite. Chlorite is not a primary mineral in these rocks.

In the northwest Medicine Bow Mountains, mineral assemblages are also more typical of almandine amphibolite facies metamorphism. For example, mineral assemblages in pelitic schists are quartz, muscovite, and biotite with or without staurolite, garnet, epidote, and chlorite. There is a transition from staurolite-bearing muscovite, chlorite, biotite, and quartz schists west of Rock Creek to schist consisting of quartz, biotite, muscovite, staurolite, and garnet, with or without epidote, in the northern Medicine Bow Mountains (north of Carlson Creek) and in all areas east of Rock Creek. These metasedimentary rocks show a transition from low to medium almandine amphibolite facies, and the presence of labradorite in many metamorphosed mafic volcanics (especially east of Rock Creek) suggests that, locally at least, upper almandine amphibolite facies may be attained.

The above mineral suites suggest that a temperature of approximately 500°C and a pressure of approximately 5 kbar may have been attained in the central Medicine Bow area, and that temperature and possibly pressure increased both in the southwest and northeast. Maximum temperature was probably obtained in the northeastern Medicine Bow Mountains, where temperatures of 600°C are reasonable for the metamorphic grade.

RADIOACTIVE QUARTZ-PEBBLE CONGLOMERATE

The distribution, structural control, and general characteristics of radioactive quartz-pebble conglomerate of the Sierra Madre and Medicine Bow Mountains have been discussed above, and that discussion will not be repeated here. Essentially, the uranium- and thorium-bearing minerals in the conglomerates are considered detrital and are thought to be derived from Archean rocks located north and northeast of the present site of deposition of the conglomerate. The uranium- and thorium-bearing minerals are believed to have been deposited in channels of braided rivers that flowed south or southwest. In the Sierra Madre and the Medicine Bow Mountains there are two major horizons that contain radioactive quartz-pebble conglomerate: one at the base of the upper part of the assemblage of Phantom Lake and one at the base of the formation of Magnolia Lake of the assemblage of Deep Lake which is more than 3,000 meters higher in the section. These two horizons are very similar lithologically, and additional mapping must be done before their distribution is fully understood. It is clear, however, that radioactive conglomerate is distributed over large areas in both the Sierra Madre and the Medicine Bow Mountains, and it is also clear that conglomerate layers are thick enough (>3 meters), at least locally, to be mined. Major questions that remain to be answered are as follows:

1. What is the uranium-thorium content of the quartz-pebble conglomerate below the zone of weathering?

2. What is the mineralogy of unoxidized conglomerate?

3. What effect does upper green schist and almandine amphibolite facies metamorphism have on radioactive, pyritic, quartz-pebble conglomerate?

4. What are tonnages of mineable ore?

Obviously, extensive drilling programs and more detailed mapping will be required to answer the last, most critical question, but preliminary studies of surface and subsurface samples give us partial answers to the first three. We will consider these three questions beginning with a discussion of mineralogy by G. A. Desborough and W. N. Sharp.

URANIUM AND THORIUM MINERALS IN PRECAMBRIAN METACONGLOMERATES, MEDICINE BOW MOUNTAINS, SOUTH-CENTRAL WYOMING

By George A. Desborough and William N. Sharp

Uranium and thorium silicates are the major radiogenic minerals that occur in pyritic Precambrian schistose metasedmentary rocks consisting principally of quartz and muscovite with minor K-feldspar and albite. Before medium-grade metamorphism, these rocks were sandstones, siltstones, and conglomerates, as indicated by composition, texture, and vertical textural distribution. A section represented by a 65-meter drill core consists of thin bands, a few centimeters to a few meters thick, of medium-grained (1 mm) quartz mica schist interlayered at irregular intervals with bands of micaceous quartz-pebble metaconglomerate. Pebbles generally range from 2 to 5 mm in diameter, but cobbles as large as 5 cm are present.

Certain intervals of the section are mainly pyritized along layering and foliation. These pyritic bands are commonly present in the pebble metaconglomerate layers forming interlocking discontinuous lenses which generally follow the conspicuous planar structure and bedding of the rock. At places the pyrite bands are offset and finely folded by crosscutting shear cleavage. Sparse microfractures both parallel and perpendicular to the bedding and foliation are healed with pyrite veinlets.

A radioactivity profile of the 65-m section of drill core shows that the radiogenic minerals are associated very closely with the pyrite-rich conglomeratic layers.

The pyrite-rich zones of the pebble metaconglomerate contain 0.1- to 0.2-mm grains rich in uranium and thorium, which have the chemical composition of coffinite and thorite. Associated galena is probably of radiogenic origin. Other minerals include Ni-Co-Fe sulfides, marcasite, chalcopyrite, zircon, garnet, monazite, ilmenorutile, columbite, and apatite, which are unevenly distributed in the muscovite that folds and fills around quartz grains and pebbles. The coffinite and thorite are the principal radioactive minerals, but recrystallized zircon and monazite contain as much as 6 weight percent thorium. Ilmenorutile occurs as spongy round aggregates of subhedral to euhedral crystals supported interstitially by quartz. This morphology is interpreted to indicate recrystallization of some Nb-rich detrital mineral (in addition to columbite previously mentioned). Poorly crystallized round grains of graphite are present in one specimen, and these contain small inclusions of coffinite. Because the graphite contains sulfur, it is presumed to be of organic origin, and thus an association of uranium with hydrocarbons may be implied.

Heavy-mineral concentrates obtained from one pyritic layer contain sparse magnetite, sphene, ilmenite, spessertine, and zircon grains with morphological and chemical characteristics of detrital materials from a granitic rock source. Some zircon, monazite, and ilmenorutile in the same pyrite layer appear to be products of metamorphism.

The principal uranium and thorium minrals are silicates, which do not have morphological characteristics that can be readily attributed to a detrital origin. Grains of these minerals are anhedral but are more like blebs than rounded grains in the sense of having a detrital history. The minor occurrence of uranium and thorium minerals in Ni-Co sulfide crystals indicates cogenetic development, which probably occurred during metamorphism.

The chemical composition of the uranium and thorium silicates varies widely. Some of the grains contain abundant tiny inclusions of galena and/or pyrite, while others are free of inclusions. Coffinite contains about 45-61 weight percent uranium and a few tenths to several weight percent of thorium and lead. Thorite contains 30-45 weight percent of thorium, and a few tenths to several percent of uranium, lead, and yttrium. Some thorite grains decompose during electron-beam analysis, which may indicate a high degree of hydration.

The complex metamorphic history, the suite of low-temperature sulfides (marcasite and Ni-Co-Fe sulfide), the presence of graphite of organic origin, the incipient oxidation of some samples sufficient to generate iron oxides, and the porous character of available samples presently precludes an unequivocal interpretation of the origin and development of the uranium and thorium silicates we have studied.

DISCUSSION OF MINERALOGY AND POSSIBLE EFFECTS OF REGIONAL METAMORPHISM

The samples studied by Desborough and Sharp are from the One Mile Creek localities of the northeastern Medicine Bow Mountains. These samples are from below the zone of weathering, which extends to approximately 30 meters at this locality. Cores show almost complete oxidation of pyrite to this depth, but below 30 meters samples appear fresh and pyrite is abundant in the conglomerate layers. The conglomerate of this locality is in rocks of upper almandine amphibolite facies metamorphism which are perhaps as highly deformed and metamorphosed as any rocks in the Medicine Bow Mountains. This is an area of polymetamorphic history where temperature probably was 600°C during metamorphism and pressure approximately 5 kbar.

We were obviously optimistic when we anticipated that study of the mineralogy might verify a detrital origin for the uranium-thorium-bearing minerals. The preliminary study of Desborough and Sharp demonstrates that the pyrite and probably the uranium-thorium minerals were completely recrystallized during metamorphism, if indeed they were detrital originally. It is clear that samples must be obtained from less metamorphosed localities before the original mineralogy of the conglomerate can be ascertained. Interestingly, field studies of gold-uranium-bearing conglomerate of the Witwatersrand of South Africa led most South African geologists to the conclusion that these deposits were of placer origin, but detailed study, especially of the mineralogy, texture and paragenesis of the deposits led others (Davidson, 1953) to the conclusion that the ores were not of placer origin. Eventually, irrefutable evidence of placer origin was obtained from relatively unmetamorphosed specimens collected underground. We hope that better evidence for origin of these southern Wyoming deposits will come from samples obtained by drilling, and that it will not be necessary to wait for development (which may or may not take place) before we can be certain of their origin.

REFERENCES CITED

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

______1935, Precambrian rocks of Utah and Wyoming: Utah Academy of Sciences, Arts and Letters Proceedings, v. 22, p. 153-157.

Carey, S. W., and Ahmad, N., 1961, Glacial marine sedimentation, in Rassch, G. O. (ed.), Geology of the Arctic: University of Toronto Press, Toronto, Ontario, Canada, p. 865-894.

Cloud, P. E., 1968, Atmospheric and hydrospheric evolution on the primitive earth: Science, v. 160, p. 719-736.

Davidson, C. F., 1953, The gold-uranium ores of the Witwatersrand: Mining Magazine, v. 88, no. 2, p. 73-85.

Divis, A. F., 1976, Geology and geochemistry of Sierra Madre Range, Wyoming: Colorado School of Mines Quarterly, v. 71, n. 3, 127 p.

Ebbett, Ballard, E., 1970, Geologic maps of the Singer Peak, Encampment, Red Mountain and Bridger Peak quadrangles: Geological Survey of Wyoming open-file maps.

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: University Wyoming Ph.D. thesis, 92 p.

Hague, Arnold, and Emmons, S. F., 1877, Descriptive geology: United States Geological Exploration 40th Parallel (King), 2, 890 p

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

Hills, F. A., Houston, R. S., and Subbarayudu, G. V. 1975, Possible Proterozoic plate boundary in southern Wyoming: Geological Society of America Abstracts with Programs, v. 7, no. 5, p. 614.

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.

Houston, R. S., Graff, P. J., Karlstrom, K. E., and Root, F. G., 1977, Preliminary report on radioactive conglomerate of middle Precambrian age in the Sierra Madre and Medicine Bow Mountains of southeastern Wyoming: U.S. Geological Survey Open-File Report 77-574, 31 p.

Houston, R. S., and McCallum, M. E., 1961, Mullen Creek - Nash Fork shear zone, Medicine Bow Mountains, southeastern Wyoming (Abs.): Geological Society of America Special Paper 68, p. 91.

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: Geological Survey of Wyoming Memoir 1, 167 p.

Houston, R. S., Schuster, J. E., and Ebbett, B. E., 1975, Preliminary report on the distribution 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.

Joubin, F. R., 1954, Uranium deposits of the Algoma District, Ontario: Canadian Institute Mining Transactions, v. 57, p. 431-437.

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

Knight, S. H., 1968, Precambrian stromatolites, bioherms and reefs in the lower half of the Nash Formation, Medicine Bow Mountains, Wyoming: Wyoming University Contributions to Geology, v. 7, no. 2, p., 73-116.

Miller, W. R., Houston, R. S., Karlstrom, K. E., Hopkins, D. M., and Ficklin, W. H., 1977, Geological and geochemical investigations of uranium occurrences in the Arrastre Lake area of the Medicine Bow Mountains, Wyoming: U.S. Geological Survey Open-File Report 77-92, 30 p.

Minter, W. E. L., 1976, Detrital gold, uranium, and pyrite concentrations related to sedimentology in the Precambrian Vaal Reef Placer, Witwatersrand, South Africa: Economic Geology, v. 71, p. 157-177.

McDowell, J. P., 1957, The sedimentary petrology of the Mississagie Quartzite in the Blind River area: Ontario Department of Mines Geological Circular No. 6, 31 p.

McGowen, J. H., and Groat, C. G., 1971, Van Horn Sandstone, West Texas: an alluvial fan model for mineral exploration: Texas Bureau of Economic Geology, Report of Investigations 72, 57 p.

Robertson, J. A., 1976, The Blind River uranium deposits: the ores and their setting: Ontario Division of Mines, Miscellaneous Paper 65, 45 p.

Roscoe, S. M., 1957, Stratigraphy Quirke Lake-Elliot Lake sector, Blind River area, Ontario, in The Proterozoic in Canada (ed. J. E. Gill): Royal Society of Canada Special Publication No. 2.

______1969, Huronian rocks and uraniferous conglomerates in the Canadian Shield: Geological Survey Canada, Paper 68-40, 205 p.

______1973, The Huronian Supergroup, a Paleoaphebian succession showing evidence of atmospheric evolution: Geological Association of Canada Special Paper No. 12, p. 31-48.

Short, Ben L., 1958, A geologic and petrographic study of the Ferris-Haggerty Mining area, Carbon County, Wyoming: Wyoming University M.S. thesis., 138 p.

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

Sylvester, G. H., 1973, Depositional environment of diamictites in the Headquarters Formation, Medicine Bow Mountains, southeastern Wyoming: Wyoming University M.S. thesis, 84 p.

Van Hise, Charles, and Leith, C. K., 1909, Precambrian geology of North America: U.S. Geological Survey Monograph 52, 641 p.

Wilson, B. D., 1975, The origin of slaty cleavage and associated structures, Precambrian Lookout Schist, Medicine Bow Mountains, Wyoming: Wyoming University M.S. thesis, 83 p.

Winkler, H. G. F., 1976, Petrogenesis of Metamorphic rocks, 4th ed.: Springer-Verlag, New York, Heidelberg, Berlin, 334 p.

Young, G. M., 1970, An extensive Early Proterozoic glaciation in North America: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 7, p. 85-101.