THE GEOLOGICAL SURVEY OF WYOMING
Daniel N. Miller, Jr., State Geologist

REPORT OF INVESTIGATIONS No. 13

STRATIGRAPHY AND URANIUM POTENTIAL OF EARLY PROTEROZOIC METASEDIMENTARY ROCKS IN THE MEDICINE BOW MOUNTAINS, WYOMING

by

Karl E. Karlstrom and Robert S. Houston

LARAMIE, WYOMING
1979

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CONTENTS

ILLUSTRATIONS

TABLES


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ABSTRACT

The Medicine Bow Mountains of southeastern Wyoming contain an eight mile (13 km) thick section of Early Proterozoic (2500-1700 m.y. b.p.) metasedimentary rocks which is subdivided into three successions: the Phantom Lake Metamorphic Suite (oldest), Deep Lake Group, and Libby Creek Group.

The Phantom Lake Metamorphic Suite (greater than 3 km thick) is poorly understood because of amphibolite facies metamorphism and isoclinal folding. However, it is provisionally subdivided into a lower part containing dominantly metavolcanic rocks and an upper part containing dominantly micaceous quartzite. The lower and upper parts appear to be separated by an unconformity which is overlain by a radioactive, sericitic and pyritic, quartz-pebble conglomerate.

The Deep Lake Group (3.3 km) unconformably overlies the Phantom Lake Suite and is here subdivided into six formations, for which formal names are proposed. (1) The Magnolia Formation (570 m) contains a radioactive, arkosic, quartz-pebble conglomerate which grades upsection into a trough cross-bedded, coarse-grained quartzite, (2) The Lindsey Quartzite (440 m) is a fine-grained, trough cross-bedded quartzite. (3) The Campbell Lake Formation (75 m) is a thin paraconglomerate-phyllite sequence which serves as a stratigraphic marker. (4) The Cascade Quartzite (1500 m) is a pebble quartzite which contains distinctive black chert pebbles.
(5) The Vagner Formation (350 m) unconformably overlies the Cascade Quartzite and contains paraconglomerate, marble, and phyllite.
(6) The Rock Knoll Formation (380 m) contains quartzite, minor phyllite, and quartzite-pebble conglomerate.

The formations of the Deep Lake Group were deposited during three sedimentary cycles. Representing the first cycle is a fining-upwards fluvial sequence consisting of the Magnolia Formation and the Lindsey Quartzite. In the second cycle (subaerial glacial?), deposition of paraconglomerates and marine deposition of shales of the Campbell Lake Formation was followed by fluvial deposition of the Cascade Quartzite. The third cycle began with glacial or glacio-marine deposition of paraconglomerates of the Vagner Formation and continued with deposition of marine limestones and shales of the Vagner Formation and shallow marine and fluvial deposition of the Rock Knoll Formation. These cycles may represent regional tectonic and climatic fluctuations which could be used to correlate Early Proterozoic metasedimentary sequences in North America. Cyclical deposition ended prior to deposition of the thick shallow-water marine quartzites of the Libby Creek Group.

Paleocurrent study indicates that most of the Deep Lake Group and parts of the upper Phantom Lake Suite were derived from a source area to the northeast which contained Archean metasedimentary and granitic rocks. The strongly unimodal, low-variance distribution of paleocurrent measurements suggests that sediment was transported in rivers that flowed down a southwest paleoslope.

The upper Phantom Lake Suite and the Deep Lake Group are of economic interest because they contain radioactive, pyritic, quartz-pebble conglomerates. The most promising units are the basal conglomerate of the upper Phantom Lake Suite, which appears

to unconformably overlie metavolcanics of the lower Phantom Lake Suite, and the Magnolia Formation, which unconformably overlies the upper Phantom Lake Suite. Outcrops of the former have yielded assays of up to 141 ppm U and 916 ppm Th, with no appreciable gold. Outcrops of the Magnolia Formation have yielded up to 8.4 ppm U and 38 ppm Th. These are certainly not economic concentrations of uranium. Nevertheless, several factors indicate that these units deserve further study. First, the lithologies of the radioactive and nonradioactive units are remarkably similar to those found in known uranium fossil-placers. Second, the paleogeography was favorable for placer accumulation if the conglomerates are fluvial sediments in an epicontinental clastic succession which was deposited during several transgressive-regressive cycles, as we interpret them to be. Third, the age of the conglomerates may be similar to the age of other known uranium placers — i.e., more than 2000 m.y. b.p. And fourth, geological and geochemical studies indicate that both uranium and pyrite have been strongly leached from outcrops and that subsurface rocks contain more uranium than surface rocks do.

INTRODUCTION

Purpose of the Study

The Medicine Bow Mountains of southeastern Wyoming contain an 8 mile (13 km) thick succession of metasedimentary rocks deposited near the southeastern margin of the Wyoming Archean craton during the Early Proterozoic (2500-1700 m.y. ago). The upper half of this succession, named the Libby Creek Group by Houston and others (1968), has been fairly extensively studied (Blackwelder, 1926; McCallum, 1964; Houston and others, 1968; Sylvester, 1973; Wilson, 1975; and Lanthier, 1978) and will not be discussed in this report. The lower half of the succession, however, has received little attention until recently (1975-1978).

In this paper, we discuss the results of our recent work on the stratigraphy and uranium potential of the lower half of the metasedimentary succession. We divide it into two parts — the Phantom Lake Metamorphic Suite and the Deep Lake Group — and we propose these names for formal usage.

Rocks of the Phantom Lake Suite and Deep Lake Group are of particular interest for two reasons. First, these rocks are very similar in lithology and tectonic setting to rocks of the Proterozoic Huronian Supergroup of southern Ontario, which contain stratiform uranium deposits of tremendous economic importance. This lithologic similarity prompted Houston in 1975 to initiate a stratigraphic study in the central Medicine Bow Mountains to help evaluate the uranium potential of the metasedimentary rocks (Houston and others, 1978). Second, the metasedimentary rocks of the Medicine Bow Mountains are some of the least deformed Early Proterozoic metasedimentary rocks in the western United States, and knowledge of their sedimentary and tectonic history is important in understanding the tectonic conditions that existed on the edge of the Wyoming Archean craton during the Proterozoic.

The first part of this report describes the proposed stratigraphic subdivision of metasedimentary rocks in the north-central Medicine Bow Mountains. These rocks, formerly called the Deep Lake Formation (by Houston and others, 1968), are here divided into the Phantom Lake Metamorphic Suite (older) and the Deep Lake Group (younger). The Phantom Lake Suite is highly deformed and metamorphosed to amphibolite facies, and its stratigraphy is, as yet, poorly understood. As a consequence, we use the term "metamorphic suite" rather than "group" for these rocks in accordance with the recommendations of Sohl (1977). We subdivide the Deep Lake Group into six formations and we propose formal names for these formations. Sedimentary characteristics, paleocurrent data, and our interpretations of the depositional environments of the metasediments are discussed because this information is critical in evaluating the potential for stratiform uranium occurrences in these rocks.

The second part of this report compares the rocks of the Phantom Lake Suite and Deep Lake Group with rocks of known Precambrian fossil-placer uranium deposits (e.g., Huronian Supergroup, Witwatersrand System) and evaluates the uranium potential of the Medicine Bow Mountains in terms of a "fossil-placer model." The second part also contains a summary of the locations and lithologies of radioactive units

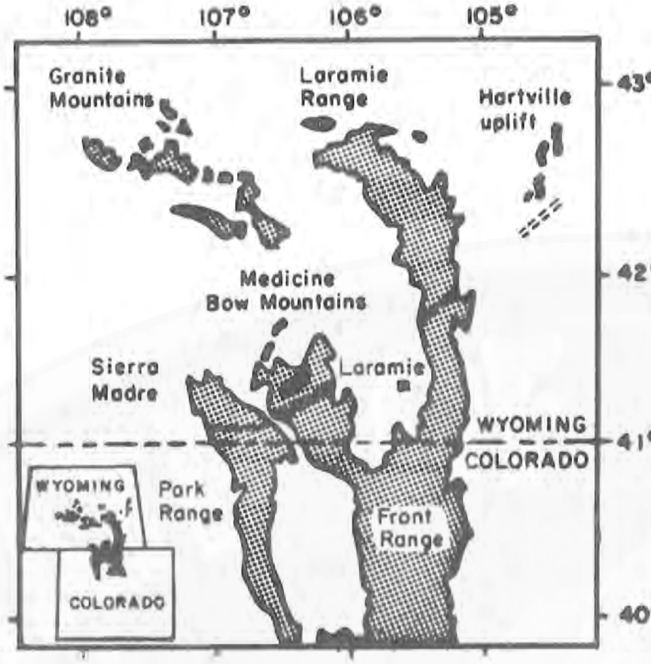


Figure 1. *Index map of southeastern Wyoming and northern Colorado. Black area in the Medicine Bow Mountains is the location of the study area. Stippled areas are Laramide uplifts exposing Precambrian rocks. Dashed lines are known or inferred shear zones.*

in the Medicine Bow Mountains and some recommendations for future exploration.

The study area encompasses about 160 sq. miles (260 sq. km) in the north-central Medicine Bow Mountains and is shown in Figure 1. This area was chosen for detailed stratigraphic study because the rocks are less deformed and metamorphosed than similar rocks that crop out in the northeastern part of the mountains. Thus, they contain more primary sedimentary features on which to base stratigraphic, sedimentological, and structural interpretations.

Geologic Setting

The Medicine Bow Mountains are a compound uplift of Laramide age in which Archean and Proterozoic rocks are exposed. In general, the uplift is a north-plunging, asymmetrical anticline which has been thrust to the east. Paleozoic, Mesozoic, and Early Tertiary sedimentary rocks crop out on the flanks of the uplift and in a major syncline in the northern Medicine Bow Mountains. These sedimentary rocks were deformed during the Laramide Orogeny and are complexly folded and faulted. Sedimentary rocks of Middle and Late Tertiary age lie unconformably on all older rocks and are found in isolated patches throughout the Medicine Bows. Pleistocene glacial deposits are common in the central part of the mountains, where they radiate in all directions from a former ice cap located near the crest of the range. Details of the geology and structure of the Medicine Bow Mountains have been described by Houston and others (1968).

As shown in Figure 2, the Precambrian rocks in the core of the range are divided into two geologic provinces by the northeast-trending Mullen Creek - Nash Fork shear zone (Houston and others, 1968). This shear zone is a major crustal discontinuity which separates Archean rocks (older than 2500 m.y.) to the north from Middle Proterozoic rocks (younger than 1800 m.y.) to the south. The shear zone is up to 6.8 miles (11 km) wide and contains highly sheared cataclastic rocks. Several workers have suggested that this zone represents a Proterozoic plate suture (Hills and others, 1975; Hills and Armstrong, 1974; Hills and Houston, in preparation).

The Archean rocks north of the Mullen Creek - Nash Fork shear zone are predominantly granitic gneisses and intrusive granites (Houston and others, 1968) which yield dates older than 2500 m.y. (Hills and others, 1968; Divis, 1977). These granitic

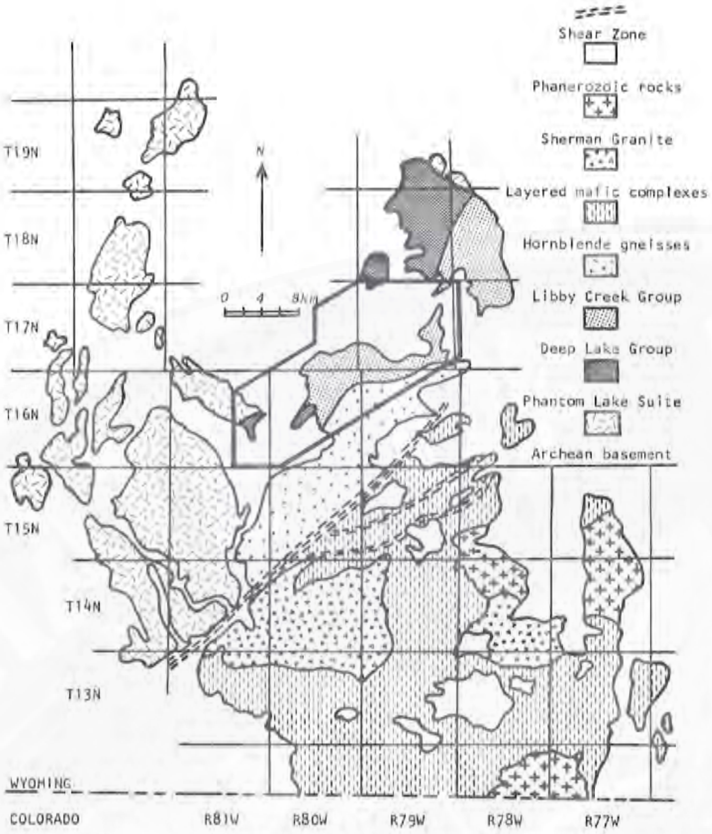


Figure 2. *Generalized geology of the Medicine Bow Mountains, location of study area outlined. Adapted from Hills and others (1968).*

rocks form part of the Archean granite-greenstone terrane which includes Archean rocks exposed in other Laramied uplifts in Wyoming and parts of adjacent states (Houston and Hills, in preparation; Condie, 1976). This Archean terane was termed the Wyoming Province by Engel (1963), who considered it to be the southwestern extension of the Superior Province of the Canadian Shield.

Three sequences of low-grade metasedimentary rocks nonconformably overlie Archean granitic rocks in the Medicine Bow Mountains north of the shear zone. The lowest sequence, the Phantom Lake Metamorphic Suite, contains dominantly quartzite and metavolcanic rocks and is greater than 10,000 feet (3.0 km) thick. The middle sequence, the Deep Lake Group, contains dominantly quartzites and conglomerates and is about 11,000 feet (3.3 km) thick. The highest sequence, the Libby Creek Group, contains quartzites, carbonates, and pelitic rocks and is about 21,000 feet (6.5 km) thick. The metasedimentary rocks were deposited mainly in shallow marine and continental environments near the edge of the Wyoming Province. The great thickness of the metasedimentary rocks indicates that they were deposited during a long period of tectonic stability, possibly during a worldwide period of cratonic stabilization which followed the end of the Archean (Sutton, 1973; Anhaeusser and others, 1969). If this is true, the metasediments may be older than 2200 m.y. (Houston and others, 1975), which is the minimum age of other basal Proterozoic platform sequences such as the Huronian Supergroup in southern Ontario and the Witwatersrand system in South Africa (Robertson, 1974). Unfortunately, radiometric dating that was done in the Medicine Bow Mountains by Hills and others (1968) established only that the metasedimentary rocks were deposited between 2500 and 1700 m.y. ago.

South of the Mullen Creek - Nash Fork shear zone are Middle Proterozoic rocks which are shown in Figure 2 as a complex of hornblende gneisses. These gneisses extend into the Colorado Front Ranges and probably represent volcanogenic island arc sediments (Houston and others, 1968) which were accreted to the Archean craton about 1700 m.y. ago (Hills and others, 1975; Hills and Houston, in preparation). The hornblende gneisses have been intruded by layered mafic complexes and by the 1.35-billion-year old Sherman Granite (Houston and others, 1968).

There are similarities between the Precambrian rocks of the Medicine Bow Mountains and those of other Laramide uplifts of the Wyoming Province. For example, the Sierra Madre contain a major shear zone (Figure 1) which Houston and others (1975) and Graff (1978) interpret as the western extension of the Mullen Creek - Nash Fork shear zone. The shear zone separates Archean rocks and Early Proterozoic metasediments to the north from younger volcanogenic rocks to the south. Also, the metasediments in the Sierra Madre are considered by Houston and others (1977) to be deeper water equivalents of the Phantom Lake Suite and Deep Lake Group. Geologic relationships in the Laramie Range and Hartville uplift also have similarities to those in the Medicine Bow Mountains. As shown in Figure 1, major shear zones have been proposed in both areas (Hills and Armstrong, 1974; Hills and Houston, in preparation) and metasedimentary rocks crop out north of the proposed shear zones (Houston and Hills, in preparation).

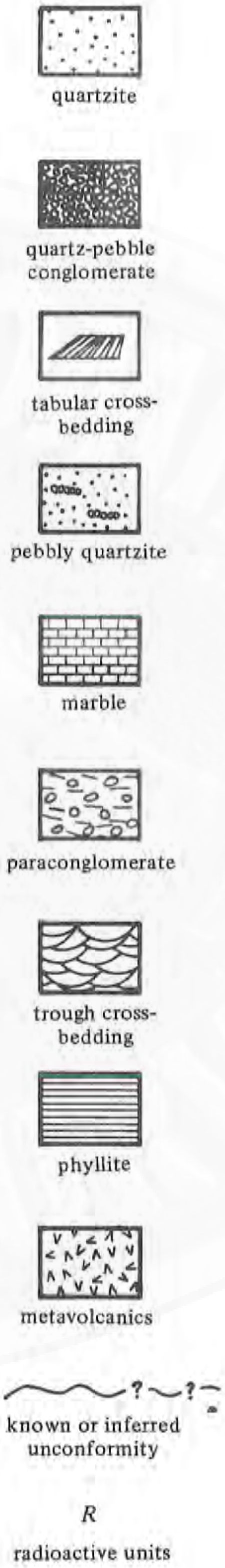
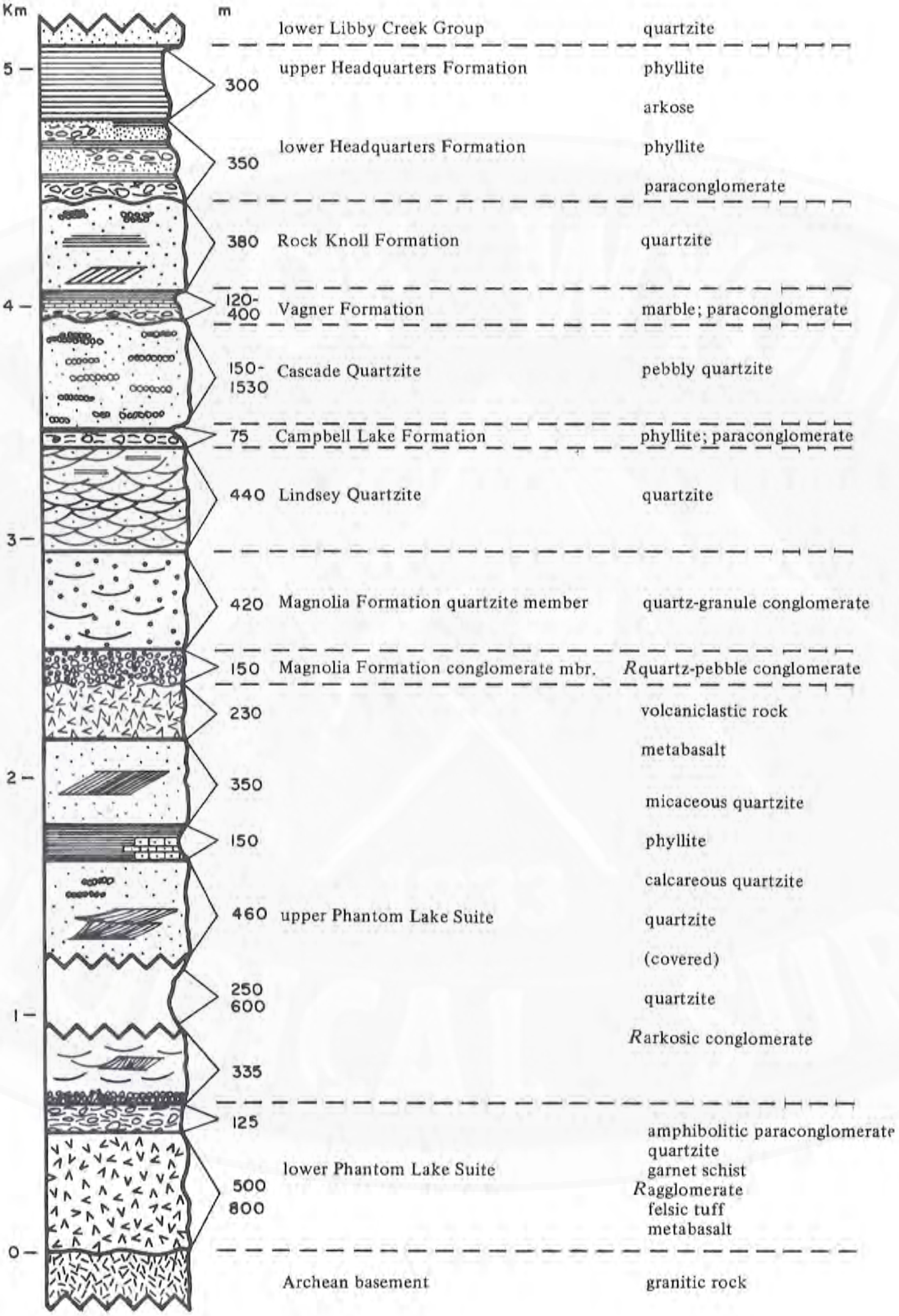


Figure 3. *Stratigraphic column of the Phantom Lake Metamorphic Suite and Deep Lake Group.*


Km
m
lower Libby Creek Group
quartzite
5 —
300
upper Headquarters Formation
phyllite
arkose
350
lower Headquarters Formation
phyllite
paraconglomerate
380
Rock Knoll Formation
quartzite
4 —
120-400
Vagner Formation
marble; paraconglomerate
150-1530
Cascade Quartzite
pebbly quartzite
75
Campbell Lake Formation
phyllite; paraconglomerate
440
Lindsey Quartzite
quartzite
3 —
420
Magnolia Formation quartzite member
quartz-granule conglomerate
150
Magnolia Formation conglomerate mbr.
Rquartz-pebble conglomerate
230
volcaniclastic rock
metabasalt
2 —
350
micaceous quartzite
150
phyllite
calcareous quartzite
460
upper Phantom Lake Suite
quartzite
(covered)
250
600
quartzite
1 —
Rarkosic conglomerate
335
125
amphibolitic paraconglomerate
quartzite
lower Phantom Lake Suite
garnet schist
500
800
Ragglomerate
felsic tuff
metabasalt
0 —
Archean basement
granitic rock

STRATIGRAPHY AND SEDIMENTATION

Terminology and Methods

Several changes in stratigraphic nomenclature are proposed in this report. The Deep Lake Formation of Houston and others (1968) is divided into the Phantom Lake Metamorphic Suite (lower) and the Deep Lake Group (upper). The Phantom Lake Suite is informally subdivided into a lower part containing dominantly metavolcanic rocks and an upper part containing dominantly micaceous quartzite. Additional detailed mapping in the northern Medicine Bow Mountains will be needed before the Phantom Lake Suite can be formally subdivided into formations. The Deep Lake Group is subdivided into six formations, and formal names are proposed (see Figure 3, p. 6-7). Terminoloby for the Libby Creek Group is retained from Houston and others (1968), except that the name Headquarters Formation (Sylvester, 1973) is preferred to Headquarters Schist (Houston and others, 1968) because of the varied lithologies in this formation. Also, some of the units previously mapped as Headquarters are now considered to be part of the Deep Lake Group.

Criteria used to distinguish the quartzite units of the Phantom Lake Suite and Deep Lake Group in the field were: (1) lithologic characteristics of the sediment, especially grain size and mineralogy, (2) types of sedimentary structures, and (3) structural relationships of quartzites to more easily recognized non-quartzite units. Limited petrographic information was used to supplement data from field mapping. Terminology for the lithologic classification of sedimentary units and for grain size descriptions in this paper is adapted from Folk (1968). Terminology for sedimentary structures is that used by Harms and others (1975).

Sedimentary structures such as cross-bedding, ripple marks, and graded bedding were mapped to determine stratigraphic tops and to study the directions of the paleocurrents that deposited the sediment of the Phantom Lake Suite and Deep Lake Group. Plate II shows that paleocurrent information is abundant in some units and missing in others, and, despite limitations, gives valid information on paleocurrent directions for many of the formations of the Deep Lake Group and for some units of the Phantom Lake Metamorphic Suite.

All paleocurrent measurements were reoriented to correct for postdepositional deformation of the metasediments. This was accomplished using a method outlined by Ramsey (1961) which involves rotations on a stereonet to correct for the dips of beds and the plunges of folds. Values of the trend and plunge of local fold axes for these rotations were taken from a structural analysis of folding presented by Karlstrom (1977).

Stratigraphic Units

Archean basement rocks

As shown in Figure 2, the oldest rocks in the Medicine Bow Mountains are granitic rocks which crop out on the west and northwest flanks. These rocks nonconformably underlie metasediments of the Phantom Lake Suite in the western and northern parts of the Medicine Bow Mountains (Houston and others, 1968, Plate I). The 2500 m.y. dates on these granites (Hills and others, 1968) give a maximum age for deposition of the metasedimentary rocks of the Phantom Lake Suite.

Phantom Lake Metamorphic Suite

The Phantom Lake Suite contains the oldest metasedimentary rocks in the Medicine Bow Mountains. Outcrops of this suite are discontinuous, and correlation between widely separated outcrops is difficult. As a result, the Phantom Lake Suite is broadly defined to include the thick sequence of metavolcanic rocks and quartzites which underlies the Magnolia Formation.

In the present study area, the Phantom Lake Suite is best exposed in three localities: in the western part of the study area; south of Phantom Lake in T.16N., R.79W.; and along the North Fork of Rock Creek in T.17N., R.79W. Stratigraphic sections measured from these three areas and from Plate I of Houston and others (1968) were combined using structural data to create the composite stratigraphic section for the Phantom Lake Suite shown in Figure 3.

As shown in Figure 3, the Phantom Lake Suite can be divided into two sequences. The lower Phantom Lake Suite crops out in the northeastern part of the Medicine Bow Mountains, mainly north of the study area. This sequence includes metabasalt (with some pillow basalt), mafic agglomerate, felsic tuff, felsic agglomerate, garnet schist, paraconglomerate, and quartzite, and attains an aggregate thickness of greater than 2600 feet (800 m) (King, 1963; Houston and others, 1968). The stratigraphy of these units is, as yet, poorly understood. In the western part of the study area, most of the lower Phantom Lake Suite has been eroded away following movement along a fault which parallels the Archean granite — Phantom Lake Suite contact.

Figure 4. *Arkosic quartzite of the lower part of the upper Phantom Lake Suite. Outcrop has a slabby appearance due to phyllitic partings between cross-bed sets. Sedimentary structures include trough cross-bedding (in shadow beneath ledge) and large-scale tabular cross-beds (parallel to hammer) which are part of a solitary sand bar. The bar contains reactivation surfaces. Outcrop is located in sec. 24, T.16N., R.81W.*

The upper Phantom Lake Suite is exposed in the western part of the study area, along the North Fork of Rock Creek, and in outcrops north of the present study area. Preliminary stratigraphic study suggests that the upper Phantom Lake Suite contains radioactive quartz-pebble conglomerate (oldest), arkosic quartzite (Figure 4), pebbly quartzite, pyritic black phyllite, micaceous quartzite, and metavolcanic rocks (youngest). The metavolcanic rocks crop out near Arrastre Lake and consist of interbedded massive metabasalts, amygdaloidal metabasalts, volcaniclastic paraconglomerates, and garnet schists. They are informally named the Arrastre Volcanics and were described as a separate formation by Karlstrom (1977).

The thickness of the Phantom Lake Suite is only approximately known because of poor exposure. However, if the stratigraphic section shown in Figure 3 is correct, the western area contains about 6600 feet (2000 m) of Phantom Lake rock. This does not include the metavolcanic rocks of the lower Phantom Lake Suite that presumably have been faulted out of the section. In the northern area, where the metavolcanic rocks are present, the complete Phantom Lake Suite may be about 10,000 feet (3000 m) thick.

The best developed sedimentary structures in the Phantom Lake Suite are in the upper sequence, and are tabular cross-beds that occur in sets ranging from 4 inches (10 cm) to several feet thick (Figure 5). As shown in Figure 18, the mean inclination of these cross-beds is 19 degrees. Smaller scale trough cross-bedding is also present in many outcrops of the Phantom Lake Suite (Figure 4), and a few ripple marks are preserved in outcrops located along the North Fork of Rock Creek.

Paleocurrent indicators can be found in all of the areas of outcrop of the upper Phantom Lake Suite. Individual measurements and statistical parameters are shown in Plate II, and a rose diagram for the entire suite is shown in Figure 6.

Most measurements indicate that the sediments were derived from a source area to the northeast. A notable exception is the far west area of Plate II where sediments were derived from the north. This suggests that the exposed Archean granite could have been the source of the sediment in the western area

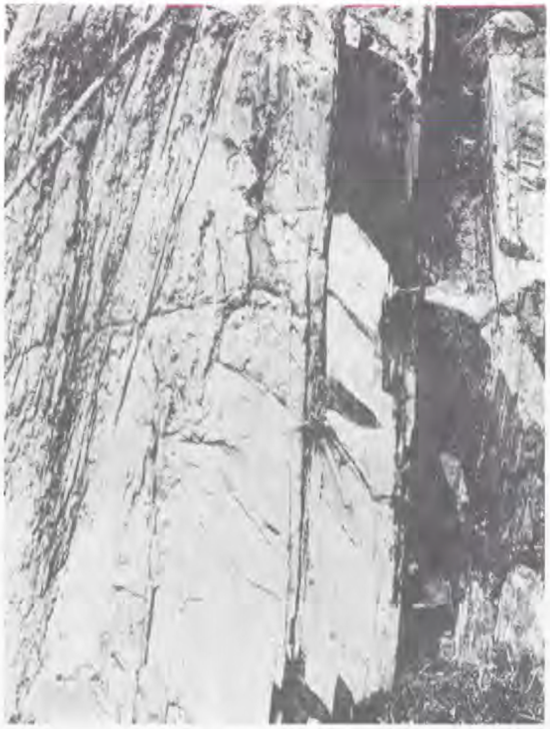


Figure 5. *Large-scale, low angle, tabular cross-bedding in the Phantom Lake Suite. The hammer in the center of the photograph is stuck into a phyllitic parting in the quartzite. Outcrop is located in the SE¼ sec. 15, T.17N., R.79W.*

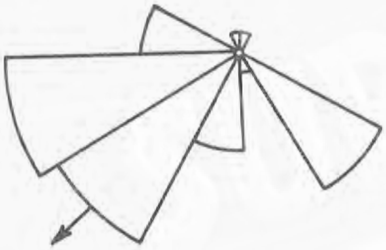


Figure 6. *Rose diagram and vector mean ($\overline{x}$) for n paleocurrents in the upper Phantom Lake Suite. The southeast-directed mode probably represents foreset beds measured on sand bars oriented transverse to the current direction, n = 45, $\overline{x}$ = 226°, unit vector = 0.1 inch.*

of the Phantom Lake Suite. However, no granitic clasts were observed in the paraconglomerate, and the clasts that were observed indicate that the source area contained volcanic and sedimentary rocks.

Rocks of the Phantom Lake Suite represent a variety of depositional environments. The metavolcanic rocks in the lower Phantom Lake Suite probably represent volcanic flows and volcanogenic sediments that were deposited in subaerial environments. The conglomerate and quartzites in the lower part of the upper Phantom Lake Suite probably represent fluvial deposits. This interpretation is supported by the presence of radioactive arkosic conglomerate and trough cross-bedding. In contrast, the fine- and medium-grained quartzites higher in the upper Phantom Lake Suite are probably shallow marine deposits. This interpretation is supported by the fine-grained character of the quartzites and the abundance of muscovite which may represent detrital clay in the original sediment. The presence of clay is indicative of an immature sandstone (Blatt and others, 1972) and suggests that deposition took place in relatively quiet water, presumably in a low-energy, nearshore environment. The presence of pyritic phyllite and calcareous quartzites in the upper Phantom Lake Suite is also interpreted as evidence for shallow marine deposition. The environment of deposition of the volcanics in the upper Phantom Lake Suite is not known, but the absence of pillow structures in the basalts suggests that the flows are probably continental deposits.

In summary, the Phantom Lake Suite is subdivided into a lower sequence composed dominantly of subaerial volcanogenic sediments and flows which crop out mainly to the north of the present study area, and an upper sequence composed of fluvial conglomerates overlain by shallow marine quartzites and metavolcanic rocks. A radioactive paraconglomerate crops out in the western part of the study area, and this unit appears to lie near the boundary between the upper and lower parts. In addition, reconnaissance mapping in the northern Medicine Bow Mountains suggests that radioactive quartz-pebble conglomerates near the town of Arlington may also be near the base of the upper Phantom Lake Suite. The presence of these radioactive units indicates that the upper Phantom Lake Suite is a good target for uranium exploration. Future detailed field stratigraphic study should be devoted to correlating the outcrops of the Phantom Lake Suite in the northern Medicine Bows with widely separated outcrops of the Phantom Lake Suite in the present study area.

Deep Lake Group

Magnolia Formation

The Magnolia Formation, the oldest formation in the Deep Lake Group, is composed of two mappable members. The lower member is an arkosic radioactive conglomerate which directly overlies metabasalt of the upper Phantom Lake Suite. The upper member is a coarse-grained quartzite.

The type section for the radioactive conglomerate member is located in the center of sec. 10, T.16N., R.80W., in the east limb and near the core of the major anticline. The conglomerate contains poorly sorted clasts of micaceous quartzite, phyllite, and metavolcanic rocks in a pyritic, arkosic matrix. The clasts occur in lenses up to 3 feet or more thick that are intercalated with beds of medium-grained arkose. The pyrite in the matrix is largely oxidized, and the resulting hematite stain locally gives the rocks a red-brown color on weathered surfaces. The radioactive conglomerate member of the Magnolia Formation is significantly coarser grained in the type section than in many of its other outcrops. The coarse facies of the conglomerate, such as is seen in the type section, is limited in lateral extent, and appears to occur in distinct channels. The thickness of the radioactive conglomerate member is at least 490 feet (150 m) in the type section.

Another important area of outcrop of the radioactive conglomerate member occurs along the North Fork of Rock Creek, in sec. 22, T.17N., R.79W. These outcrops contain arkosic quartzites interbedded with dark colored, conglomeratic quartzites, and are similar in lithology and grain size to the outcrops in the type section. The darker layers contain rock fragments and quartzite clasts, and are more radioactive than the lighter layers.

The upper units of the radioactive conglomerate grade up-section into the quartzite member of the Magnolia Formation: this member is a very coarse-grained quartzite with rounded and well-sorted granules of quartz. The type locality for the quartzite member is located just east of Stamp Mill Lake, in sec. 16, T.16N., R.80W. The average size of quartz granules in the quartzite member is .04 to .08 inches (1-2 mm), and they range up to 0.4 inch (1 cm). The quartzites contain less than 5 percent feldspar and less than 5 percent mica, and are texturally and mineralogically mature. The quartzite member has a fairly consistent thickness of approximately 1400 feet (425 m) around the nose of the major anticline (Plate I).

Sedimentary structures are poorly developed in the radioactive conglomerate member, although a few trough cross-beds can be seen in the type locality and in outcrops along the North Fork of Rock Creek. In the quartzite member, however, sedimentary structures are better developed. These structures are predominantly trough cross-beds with troughs 2 to 6 inches (5-15 cm) deep. The mean inclination of the cross-bedding to true bedding is 26 degrees, and there are modes at 18 degrees and 28 degrees (Figure 18).

The few paleocurrent measurements that were made in the radioactive conglomerate member (Plate II) give widely scattered current directions that are not statistically meaningful. Paleocurrent measurements in the quartzite member were more readily obtained and show that this unit was derived from a source to the north (Figure 7). The distribution shown in Figure 7 is strongly unimodal and has a small variance (Plate II). This type of paleocurrent distribution is considered by Allen (1967) to be typical of fluvial systems.

Figure 7. *Rose diagram and vector mean ($\overline{x}$) for n paleocurrents in the quartzite member of the Magnolia Formation. n = 40, $\overline{x}$ = 191°, unit vector = 0.1 inch.*

There are several clues to the provenance and depositional environment of the sediments of the Magnolia Formation. The radioactive conglomerate is characterized by poorly-sorted quartz pebbles and rock fragments in an arkosic matrix. The rock fragments are mainly quartzite and phyllite which are similar to micaceous quartzite and phyllite units in the underlying Phantom Lake Suite. No metavolcanic rock fragments were observed. Thus, the radioactive conglomerates appear to have been derived from a not-too-distant source, transported a short distance, and deposited unconformably on the metabasalts of the upper Phantom Lake Suite. The coarse grain sizes, poor sorting, distinct horizons (or channels) of clasts, and trough cross-bedding all suggest deposition by fluvial currents in a fairly high-energy flow regime. The pebbles and rock fragments can be interpreted as stream-gravels that were deposited in migrating channels of a river system, and the few trough cross-beds may have formed by migrating dunes. The prevalence of horizontal stratification, rarity of trough cross-bedding, and coarse grain sizes suggest high current flow velocities (Harms and others, 1975).

Deposition of the quartzite member of the Magnolia Formation represents a gradual change in the paleogeography which resulted in the deposition of increasingly mature sediment up-section. Characteristics of the quartzite member which suggest that it was also deposited in a fluvial system are: (1) abundant trough cross-bedding and (2) the low variance, unimodal distribution of paleocurrent directions. The textural and mineralogical maturity of the quartzite member compared with that of the underlying radioactive conglomerate, and the corresponding change from dominantly horizontal stratification to abundant trough cross-stratification, indicate that the quartzite member was deposited in a lower energy flow regime than that of the radioactive conglomerate, presumably in a lower gradient fluvial system.

The fluvial character, the high radioactivity, and the presence of pyrite are all indications that the radioactive conglomerate member is a good target for exploration for fossil placer uranium.

Lindsey Quartzite

The type locality of the Lindsey Quartzite is in the western part of sec. 2, T.16N., R.80W. There, the Lindsey Quartzite contains uniform white to light gray, medium-grained quartzites with lenses and layers of quartz pebbles. The pebbles are generally concentrated along foreset beds or in small scours, and range in size up to 0.4 inch (1 cm); the average size is several mm. Intercalated with the quartzites are a few less resistant, very-fine-grained phyllitic quartzites and phyllite partings (Figure 8). Higher in the section, immediately beneath the Campbell Lake Formation, the Lindsey Quartzite is a coarser grained, pyritic, quartz granule conglomerate. The thickness of the Lindsey Quartzite is approximately 1350 feet (410 m).

Sedimentary structures are well preserved in the Lindsey Quartzite. The most common sedimentary structure is trough cross-bedding with trough depths ranging from one inch to several inches (Figure 9). The abundance of these trough cross-beds is one of the diagnostic features of the Lindsey Quartzite. The inclinations of the trough cross-beds to bedding have similar values to those of the Magnolia Formation. Ripple marks are also occasionally seen in the Lindsey Quartzite.

Figure 8. *Phyllitic partings leave green patches on exposed bedding surfaces. This feature is characteristic of the Lindsey Quartzite in the eastern part of the study area. Outcrop is located in the S½ sec. 27, T.17N., R.79W.*

Figure 9. *Well developed trough cross-bedding is diagnostic of the Lindsey Quartzite. Outcrop is located in sec. 33, T.17N., R.79W.*

Paleocurrent indicators are abundant in the Lindsey Quartzite. The distribution of current directions for the entire formation (Figure 10) shows a unimodal pattern indicating deposition by southwest directed currents. This represents a change from the south-directed currents that deposited the sediment of the Magnolia Formation. The unimodal distribution of paleocurrent directions suggests deposition by a dominantly fluvial system (Allen, 1967).

In summary, the Lindsey Quartzite has several features which suggest that it was deposited in a fluvial or fluvial-deltaic depositional environment. The pebble layers occur in troughs and scours and probably were deposited in migrating channel systems. The very-fine-grained quartzites and phyllites may represent overbank deposits, and the abundant trough cross-beds may represent migrating dunes in the river system. The unimodal paleocurrent distribution also suggests fluvial deposition. As shown in Figure 3, the fine- and medium-grained sediments of the Lindsey Quartzite are a continuation of the fining-upward trend which begins in the Magnolia Formation. This fining-upward trend is interpreted to be the result of a systematic decrease

Figure 10. *Rose diagram and vector mean ($\overline{x}$) of n paleocurrents in the Lindsey Quartzite. n = 94, $\overline{x}$ = 216°, unit vector = 0.1 inch.*

in gradient of a predominantly fluvial system. The coarse-grained quartzites of the upper Lindsey Quartzite represent a change back toward higher-energy depositional currents.

Campbell Lake Formation

The Campbell Lake Formation is a distinctive unit which consists of a lower paraconglomerate and an upper quartz-rich phyllite. Its distinctive lithologies make it a good stratigraphic marker.

The Campbell Lake Formation is exposed in scattered outcrops throughout the study area. The best of these outcrops are: (1) about 1.1 miles (1.8 km) southwest of Campbell Lake, (2) immediately east of Campbell Lake, and (3) about one mile southwest of Quealy Lake. These three areas of outcrop outline the major northeast-plunging anticline in the Arrastre Lake area.

The type section of the Campbell Lake Formation crops out 1.1 miles (1.8 km) southwest of Campbell Lake, in sec. 4, T.16N., R.80W. The lowest unit in the type section is a poorly sorted paraconglomerate with rounded to subangular clasts in an arkosic matrix. The matrix makes up about 80 percent of the rock and is predominantly quartz with 20-40 percent feldspar (potassium feldspar and plagioclase), 10-40 percent mica (muscovite and biotite plus chlorite), and two to five percent rock fragments. The rock fragments are white granite, phyllite, and quartzite, and range from less than one inch to 30 inches (several mm - 76 cm) in diameter (Figure 11). The shape of the clasts ranges from rounded to subangular. The paraconglomerate is overlain by a black to dark gray, foliated, quartz-rich phyllite. The phyllite is overlain, in turn, by a fine-grained, gray, phyllitic quartzite that is locally cross-bedded.

Figure 11. *The large granitic boulder in the paraconglomerate unit of the Campbell Lake Formation is about 30 inches (76 cm) long. Clasts in the paraconglomerate are poorly sorted and are made up of white granite, phyllite, quartzite, and metabasalt. They range in shape from rounded to subangular. Outcrop is from the type section of the Campbell Lake Formation, sec. 4, T.16N., R.80W.*

In the eastern part of the study area, the paraconglomerate is more quartz rich than in the type section, and contains clasts of quartzite and amygdaloidal metabasalt. The metabasalt clasts suggest that rocks of the Phantom Lake Suite were exposed in the source area during deposition of the Campbell Lake Formation.

The total thickness of the Campbell Lake Formation in the type section is 210 feet (65 m). The bottom 39 feet (12 m) of this is paraconglomerate, the next 112 feet (34 m) is phyllite, and the top 59 feet (18 m) is phyllitic quartzite. The thickness of the formation in other outcrops is about the same as the thickness in the type section. However, there are places where the Campbell Lake Formation is absent and rocks of the Lindsey Formation are in contact with rocks of the Cascade Quartzite (e.g., immediately west of Deep Lake; see Plate I). This is probably the result of nondeposition of the paraconglomerate, and suggests that there may be an unconformity at the top of the Lindsey Quartzite. However, the contact appears to be gradational in the type section, so the presence of an unconformity is questionable.

The most important sedimentary feature in the Campbell Lake Formation is the paraconglomerate itself. This paraconglomerate is mainly a poorly sorted polymictic debris flow deposit, but it also contains oligomictic pebble conglomerate. The paraconglomerate is either unstratified or poorly stratified (Figure 12) and appears to grade into adjacent quartzite or phyllite units at both contacts.

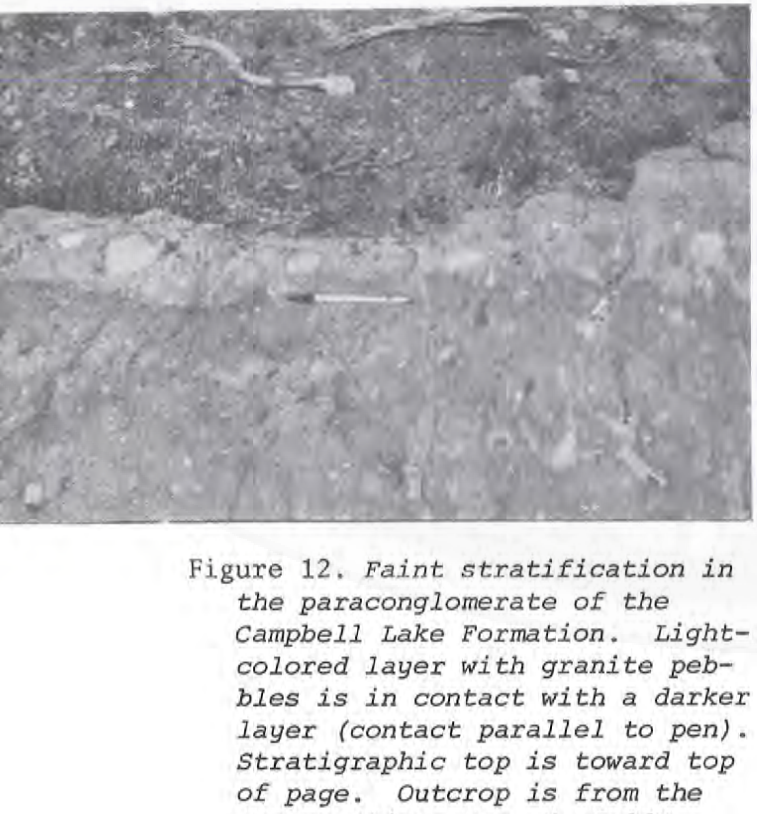


Figure 12. *Faint stratification in the paraconglomerate of the Campbell Lake Formation. Light-colored layer with granite pebbles is in contact with a darker layer (contact parallel to pen). Stratigraphic top is toward top of page. Outcrop is from the type section, sec. 4, T.16N., R.80W.*

Another important sedimentary feature of the Campbell Lake Formation is its vertical sequences: paraconglomerate-phyllite-phyllitic quartzite. This sequence of lithologies is typical of the cycles identified in the Headquarters Formation of the Libby Creek Group (Sylvester, 1973, Plate 6) and in other deposits of presumed glacial origin (e.g., the paraconglomerate units of the Huronian Supergroup; Roscoe, 1973). Unfortunately, there is no unequivocal evidence that the Campbell Lake Formation represents a similar glacial cycle because no dropstones, striated clasts, or other characteristics of glacial deposits were observed.

Regardless of the environment of deposition of the Campbell Lake Formation, the wide areal extent of the unit and its distinctive sequence of lithologies indicate that the sediments were deposited in response to an important regional change in paleogeography. If a glacial origin for the formation is accepted, then the paleogeographic change was caused by the onset of glacial conditions. If a mudflow or turbidite origin is preferred, the paleogeographic change resulted from tectonic movements.

Cascade Quartzite

The Cascade Quartzite is a thick formation containing quartzites and pebbly quartzites, which crops out throughout the north-central Medicine Bow Mountains. It is a very resistant formation, and its outcrops are well developed and fairly extensive. The most complete exposure is located in the western part of the study area, sec. 4, T.16N., R.80W., and this exposure is defined as the type section.

Figure 13. *Pebbles of quartz and black chert on exposed bedding surface in the Cascade Quartzite. These pebbles are well rounded and well sorted, and range up to 2 inches (5 cm) in diameter. Pebbles occur in thin channels (as in photograph) or along foreset beds. The black chert pebbles are diagnostic of this formation. Outcrop is located in the center of sec. 29, T.17N., R.79W.*

The lowest unit in the type section rests on phyllitic quartzites of the Campbell Lake Formation and consists of light-colored, medium-grained quartzarenite that locally contains trough cross-beds with troughs 6 to 12 inches (15-30 cm) deep. This unit grades up-section into pyritic pebbly quartzarenite and subarkose that contain well-rounded and well-sorted quartz pebbles up to 1.2 inches (30 mm) in diameter. These pebbles occur in distinct channels, several inches thick, that form resistant layers and are often exposed on bedding surfaces (Figure 13). The pyrite occurs in the matrix as sparse rounded or euhedral grains less than .04 inches (1 mm) in diameter. The quartzarenite is a pyritic pebbly quartzite that contains pebbles of black chert and quartz. These pebbly quartzites are easily identified throughout the central Medicine Bow Mountains because of the distinctive black chert pebbles. The highest unit in the type section is a pink feldspathic pebbly quartzite which contains pebbles of quartz, chert, and granitic rock in an arkosic to subarkosic matrix containing orthoclase, microcline, and minor plagioclase.

The thickness of the Cascade Quartzite in the type section is 4750 feet (1450 m). The bottom 436 feet (133 m) is medium-grained quartzite, the next 2400 feet (732 m) is pebbly quartzarenite (with and without black chert), and the top 1920 feet (585 m) is pebble arkose. The thickness of the Cascade Quartzite on the south limb of the major fold system (Plate I) is significantly less than the thickness of the type section, because an unconformity at the base of the overlying Vagner Formation cuts down into the Cascade Quartzite. In fact, in the Sheep Lake area, sec. 33, T.17N., R.79W., the Cascade Quartzite is only about 500 feet (150 m) thick.

Sedimentary structures are well developed in the Cascade Quartzite. The most prevalent of these structures, aside from horizontal bedding, is tabular cross-bedding in which the bounding surfaces of the cross-bed sets are planar and parallel (Figure 14). Within these cross-bed sets, pebbles and coarse sand grains are concentrated on the foreset beds so that the sets locally show graded bedding (Figure 15). Trough cross-bedding is another commonly observed sedimentary structure. The mean inclination of foreset beds to planar bedding in the Cascade Quartzite is 24 degrees with modes at 18 and 30 degrees (Figure 18). This bimodal distribution of inclination values is very similar to the distribution observed for the Magnolia Formation and

Figure 14. *Large scale, tabular cross-bedding and horizontal bedding. Hammer handle is parallel to foreset bedding. Above hammer is a bed with horizontal stratification. Above this is another set of low-angle, tabular cross-beds. Outcrop is located in NW¼ NE¼ sec. 6, T.16N., R.79W.*

Figure 15. *Graded bedding in a tabular cross-bed set. Pebbles (about 0.5 cm in diameter) are concentrated along foreset beds. Two pyrite casts with halos of hematite stain can be seen in the upper part of the cross-bed set. Outcrop is located in W½NE¼ sec. 5, T.16N., R.79W.*

the Lindsey Quartzite. In the Cascade Quartzite, these modes probably represent the two different types of cross-bedding commonly observed.

Paleocurrent information for the Cascade Quartzite (see Plate II) is abundant because of good exposures and well-developed cross-bedding. The distribution of paleocurrent directions for the entire formation (Figure 16) is strongly unimodal and shows that the dominant currents were moving west-southwest. The variance of the paleocurrent distribution in the Cascade Quartzite is about half that of the Lindsey Quartzite (Plate II), and this small variance is evidence for fluvial deposition of the Cascade Quartzite (Potter and Pettijohn, 1963).

Important indicators of the depositional environment of the Cascade Quartzite are: (1) channels of well-sorted, well-rounded pebbles, (2) the presence of both tabular and trough cross-bedding, and (3) the strongly unimodal distribution of paleocurrent directions. All of these can be interpreted as features developed in a fluvial environment. For example, the pebbles can be interpreted to be stream gravels deposited in channels and along the foresets of migrating bed forms. The tabular cross-bedding can be interpreted as structures formed on braid bars (Blatt and others, 1972) and the trough cross-beds may represent migrating dunes in the river system. Other good evidence for a fluvial environment of deposition is the small variance, unimodal paleocurrent distribution. This type of distribution is found in braided river environments (McDonald and Banerjee, 1971; Williams and Rust, 1969) and in ancient deltaic deposits, but is not typical of shallow marine deposits (Selley, 1970).

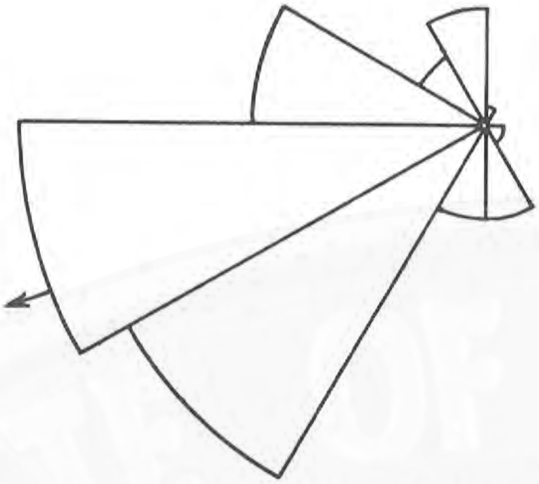


Figure 16. *Rose diagram and vector mean ($\overline{x}$) of n paleocurrent measurements in the Cascade Quartzite. $n = 80$, $\overline{x} = 248°$ unit vector = 0.1 inch.*

In summary, the Cascade Quartzite is interpreted to be a fluvial deposit that represents a period of stabilization of the continent following the paleographic change recorded in the rocks of the Campbell Lake Formation. This period of stability coincided with gradual uplift of the craton following the glacial or tectonic episode during which the paraconglomerate of the Campbell Lake Formation was deposited. The rise of the craton evidently exposed chert beds in the source area (to the northeast) during deposition of the middle part of the Cascade Quartzite, and granitic rocks during deposition of the upper unit. During subsequent uplift of the craton, the area changed from a site of fluvial deposition to an area of erosion, and parts of the Cascade Quartzite were stripped off prior to deposition of the Vagner Formation.

Vagner Formation

The Vagner Formation crops out along the south limb of the major east-northeast-trending anticline in the study area and contains paraconglomerate, marble, and phyllite. The paraconglomerate is very similar to paraconglomerates in the Campbell Lake and Headquarters formations; the marble is a distinctive unit consisting of alternating calcite-rich layers and quartz-rich layers (Figure 17); and the upper unit contains quartz-rich phyllite and laminated, fine-grained quartzite. The best outcrops of the formation occur: west of Rock Creek Knoll, sec. 35, T.17N., R.79W.; near Trail Creek, sec. 6, T.16N., R.79W.; and between Dipper and Vagner Lakes, T.16N., R.80W. None of those outcrops is representative of the entire formation, and no type section is defined in this report.

Stratigraphic relationships in the upper Deep Lake Group are complex, and various interpretations for rocks of the Vagner Formation are possible. Rocks that are shown as Vagner Formation in Plate I were originally mapped by Houston and others (1968, plate I) as partly

Figure 17. *Marble of the Vagner Formation contains alternating layers of calcite-rich and quartz-rich rock.*

Deep Lake Formation and partly Headquarters Formation. Sylvester (1973) followed Houston's interpretation by assigning the paraconglomerate-marble sequence in the area between Dipper and Reservoir lakes (see Plate I) to the Headquarters Formation. However, neither of these authors had stratigraphic information for the Deep Lake Group. The present study is a first attempt to reconcile stratigraphic problems in both the Deep Lake Group and the Headquarters Formation of the Libby Creek Group.

Sylvester (1973) interprets the paraconglomerate unit between Dipper and Reservoir lakes to be a basal diamictite in the Headquarters Formation and suggests that the marble lies unconformably on the paraconglomerate. By this interpretation, the marble in the Dipper Lake - Reservoir Lake area has no counterpart elsewhere in the Medicine Bow Mountains. In this report, the paraconglomerate and the marble are interpreted as part of the Deep Lake Group and correlated with similar rocks along Trail Creek (see Plate I). This correlation relies on the identification of black chert-bearing pebbly quartzites of the Cascade Quartzite beneath the paraconglomerates in both areas, and it leads to the interpretation that the sequence paraconglomerate-marble-phyllite is a unique assemblage in the central Medicine Bow Mountains. This interpretation requires a major unconformity at the base of the paraconglomerate to explain the thinning of the Cascade Quartzite beneath the Vagner Formation of the south limb of the major anticline.

Sedimentary structures are poorly developed in rocks of the Vagner Formation. However, cross-beds and ripple marks occur locally in the quartzite units. Measurement of these structures (see Plate II) indicates that the dominant currents active during deposition of the sediments of the Vagner Formation were directed toward the west.

Interpretation of the depositional environment of the Vagner Formation involves the question of glacial versus tectonic origin of the paraconglomerates. This problem has not been resolved for the rocks of the Vagner Formation, and either mechanism may have been responsible for deposition of the paraconglomerate. Sylvester (1973) argues for a glacio-marine environment of deposition for the paraconglomerate (which he considered Headquarters Formation) on the basis of dropstones, poor sorting, angular clasts, and faintly stratified paraconglomerates. By the glacio-marine hypothesis, the marble can be interpreted as having formed from calcium carbonate brines that were deposited in response to the retreat of dry-base glaciers (Carey and Ahmad, 1961). This interpretation explains the limited lateral extent and variable thickness of the marbles in the Vagner Formation. Continued retreat of the glaciers could, then, account for the deposition of the overlying phyllites.

In terms of the regional paleogeography, the paraconglomerate of the Vagner Formation represents a major change from the dominantly fluvial system that deposited the sediments of the Cascade Quartzite. If this change resulted from the onset of glacial conditions, then the paraconglomerates represent glacio-marine or continental glacial deposits, and the deposition of the overlying limestone and phyllite may represent glacial retreat and consequent transgression of the seas during the late stages of deposition of the Vagner Formation.

Rock Knoll Formation

The Rock Knoll Formation is the youngest formation of the Deep Lake Group. This formation crops out in the eastern and western parts of the study area. In the central area, the formation has apparently been removed by faulting and erosion (see Plate I).

The type section of the Rock Knoll Formation is located on the southeast face of Rock Creek Knoll, sec. 35, T.17N., R.79W., where quartzites directly underlie the basal paraconglomerate of the Headquarters Formation. These quartzites are mainly gray, fine- and medium-grained sediments that are interbedded with phyllitic units up to one foot (30 cm) thick and conglomerate layers up to several feet thick. The conglomerate layers contain clasts of quartz, quartzite, and granite. Layers containing quartzite pebbles are diagnostic of the Rock Knoll Formation. Another diagnostic feature of this formation is the occurrence of olive-colored patches on bedding surfaces.

Blackwelder (1926) presented a measured section which he considered to be typical of the Deep Lake metaquartzite. This section was measured along the south side of Rock Creek Knoll and is shown in simplified form in Figure 3 as the type section of the Rock Knoll Formation. The total thickness of Blackwelder's section is 994 feet (303 m), and the maximum known thickness of the Rock Knoll Formation is 1250 feet (380 m).

The sedimentary structures in Rock Knoll Formation include ripple marks and tabular cross-bedding. These structures and the dominantly fine-grained character of most of the quartzites in the Rock Knoll Formation indicate that deposition took place in a relatively low-energy flow regime, probably in a shallow marine environment. Some of the upper conglomerates are probably fluvial deposits (Blackwelder, 1926).

Plate II shows that the dominant currents that deposited the Rock Knoll Formation were moving to the west-northwest. This current direction is quite different from the southwest current directions characteristic of most of the Deep Lake Group.

The change in grain size from the phyllites in the Vagner Formation to the quartzites and conglomerates in the Rock Knoll Formation indicates a change from deep water marine deposition to shallow marine and then fluvial deposition. Therefore, the Vagner and Rock Knoll formations comprise a sedimentary cycle which probably resulted from marine transgression followed by marine regression.

Libby Creek Group

Headquarters Formation

A detailed discussion of the Headquarters Formation is not within the scope of this report, and the reader is referred to Blackwelder (1926), Houston and others (1968), Sylvester (1973), and Lanthier (1978) for discussion of these rocks. However, certain changes in the stratigraphic divisions of the Headquarters Formation are necessitated by the present stratigraphic subdivision of the Deep Lake Group. The most important change involves the paraconglomerate-marble sequence that crops out between Dipper Lake and Reservoir Lake. In the present study, this sequence is considered to be a part of the upper Deep Lake Group. In addition, Sylvester's (1973) subdivision of other units in the Headquarters Formation was not followed because it was not possible to substantiate significant lateral continuity of paraconglomerate, arkose, and phyllite units as was shown by Sylvester (1973). Instead, the Headquarters Formation is divided into two broad members that are easily distinguished in the field. As shown in Figure 3, the lower member is composed of up to 1120 feet (340 m) of interbedded, lenticular units of paraconglomerate, phyllite, and arkose. This member includes Sylvester's lower three members. The sediments of this member were probably deposited in a glacio-marine environment. The upper member contains about 980 feet (300 m) of varved (?) chlorite-biotite phyllite and was probably deposited in a large lake or in a marine environment.

Rocks of the Headquarters Formation record a major change in the regional paleogeography. The paraconglomerate-phyllite-arkose sequences in the lower Headquarters Formation were interpreted by Blackwelder (1926) and Sylvester (1973) to be glacial or glacio-marine deposits. In these sequences, the basal paraconglomerate is interpreted to represent glacial advance, phyllites to represent deeper water sedimentation caused by ice melt and consequent marine transgression, and arkoses to represent shallow-water sediments deposited in outwash fans during subsequent marine regression. Varved (?) phyllites in the upper Headquarters Formation also resemble glacial deposits. The Headquarters Formation is similar to units in the upper Deep Lake Group in that both sequences appear to have been deposited in response to regional sedimentary (or tectonic) cycles. In contrast, those formations of the Libby Creek Group which overlie the Headquarters Formation were deposited in a more stable marine miogeosynclinal setting (Lanthier, 1978).

Mafic Igneous Rocks

The metasedimentary rocks of the Phantom Lake Suite and Deep Lake Group are cut by a series of large gabbroic intrusive bodies (see Plate I). These intrusives were forcibly emplaced along zones of weakness in the metasediments, so that they are either parallel to bedding or step from one bedding plane to the next along fault planes. It was assumed that these intrusives did not assimilate significant amounts of country rock, so that, in calculating unit thicknesses, the thickness of mafic intrusive bodies was simply subtracted. These mafic bodies are discussed in greater detail by Houston and others (1968) and Karlstrom (1977).

Depositional History of the Deep Lake Group

Summary of stratigraphy

A summary of the stratigraphic subdivision of the Phantom Lake Metamorphic Suite and Deep Lake Group is shown in Table 1. Stratigraphic units of this subdivision can be grouped into four major sedimentary cycles.

The first cycle is represented by rocks of the Phantom Lake Suite. These rocks were deposited during two periods of tectonic unrest characterized by deposition of volcanogenic sediments and flows, separated by a period of deposition of clastic rocks, in fluvial and marine depositional environments. The overall sequence appears to have been deposited during a major transgressional-regressional episode.

Table 1. *Summary of the stratigraphy of the Phantom Lake Suite and the Deep Lake Group.*

		NAME	THICKNESS METERS	LITHOLOGY	SEDIMENTARY FEATURES	SOURCE	HEAVY MINERALS	DEPOSITIONAL ENVIRONMENT
LIBBY CREEK GROUP		Headquarters Formation	650	phyllite quartzite phyllite paraconglomerate	varves trough cross-beds dropstones	NE		glacio-marine
		unconformity						
DEEP LAKE GROUP	Cycle 4	Rock Knoll Formation	380	conglomerate quartzite	quartzite, pebbles, clay galls, cross-beds, ripple marks	ESE		fluvial shallow marine
		Vagner Formation	120 - 400	phyllitic quartzite marble paraconglomerate	ripple marks, cross-beds dropstones?	ENE	pyrite	glacio-marine
		unconformity						
	Cycle 3	Cascade Quartzite	150 - 1530	pebbly arkose pebbly quartzite quartzite	black chert pebbles, tabular cross-beds, trough cross-beds,	ENE	apatite pyrite zircon	fluvial
		Campbell Lake Formation	75	phyllite paraconglomerate	faint stratification		zircon apatite	marine glacial?
	Cycle 2	Lindsey Quartzite	440	quartzite	trough cross-beds	NE	zircon pyrite	fluvial-deltaic
		Magnolia Formation (quartzite member)	420	quartz-granule conglomerate	trough cross-beds	N	zircon pyrite apatite	fluvial
		Magnolia Formation (radioactive conglomerate member)	150	quartz-pebble conglomerate	planar bedding	NE	pyrite, zircon rutile, monazite	fluvial
		unconformity						
PHANTOM LAKE SUITE	Cycle 1	Upper Phantom Lake Suite	1500 - 2000	paraconglomerate metabasalt micaceous quartzite phyllite quartzite quartz-pebble conglomerate	angular clasts amygdules trough cross-beds tabular cross-beds channels	NE	pyrite monazite, zircon garnet, apatite	continental shallow-marine marine fluvial
		Lower Phantom Lake Suite	800	paraconglomerate quartzite metavolcanic				continental?
		unconformity						
		Archean basement		granitic rocks				

The second cycle is represented by deposition of the Magnolia Formation and the Lindsey Quartzite. These rocks record a change from a high-energy fluvial system to a lower energy fluvial or fluvial-deltaic environment. Coarse sediments in the uppermost Lindsey Quartzite indicate a subsequent change to a higher-energy system.

The third cycle is represented by the Campbell Lake Formation and the Cascade Quartzite. The lower paraconglomerate of this cycle may represent either a glacial episode or tectonic activity in the source area. The phyllites of the Campbell Lake Formation are interpreted to be marine sediments deposited in deep water, presumably below the wave base. Following marine deposition of the phyllites of the Campbell Lake Formation, marine regression established fluvial conditions which persisted throughout deposition of the Cascade Quartzite. This fluvial environment lasted for a long time and represented tectonically stable conditions during which the seas gradually regressed. Deposition of the Cascade Quartzite was followed by an episode of erosion, during which thick sections of the Cascade Quartzite were removed.

The fourth cycle is represented by rocks of the Vagner Formation and the Rock Knoll Formation. This is a transgressive-regressive cycle and has many similarities to the third cycle. The lower paraconglomerate in this cycle may represent a continental glacial or glacio-marine deposit, or it may represent some other type of debris flow. The overlying marble, by either of the glacial interpretations, represents a deeper water depositional environment. The quartzites of the upper Vagner Formation and the Rock Knoll Formation indicate shallower water deposition. Deposition of the Rock Knoll Formation was followed by another episode of erosion, during which part of the Rock Knoll Formation was removed.

The lower member of the Headquarters Formation represents a fifth cycle of sedimentation. However, in this case, the repetition of paraconglomerate-phyllite-arkose sequences marks more rapid paleogeographic changes caused by climatic (or tectonic) fluctuations. Cyclical deposition appears to have ended after deposition of the Headquarters Formation. The great thickness of the Heart, Medicine Peak and Sugarloaf Quartzites and the presence of carbonate bank deposits in the Nash Formation all indicate that the Libby Creek Group was deposited on a slowly subsiding continental platform (or miogeosyncline) during a long period of tectonic stability.

The cyclical sedimentation in the three sedimentary cycles of the Deep Lake Group may reflect regional climatic or tectonic events in the Proterozoic. If so, the paraconglomerate units at the bases of the cycles can be used for time-stratigraphic and lithostratigraphic correlations with other Early Proterozoic metasedimentary sequences in North America. In particular, similar sedimentary cycles and paraconglomerate units have been described by Roscoe (1969) in the Huronian Supergroup of southern Ontario, and this suggests that the Deep Lake Group may be the same age as the Huronian Supergroup (S.M. Roscoe, oral communication; Houston and Hills, in preparation).

Stratigraphic evidence for unconformities

The existence of a major unconformity between rocks of the Deep Lake and Libby Creek groups was proposed by Houston and others (1968) to explain the fact that rocks of the Libby Creek Group lie in apparent depositional contact with Archean rocks south of the present study area. The present study indicates that there may be several other important unconformities in the metasedimentary rocks of the Medicine Bow Mountains. For example, an unconformity between the lower and upper Phantom Lake suites would explain the change from deposition of volcanogenic deposits to deposition of fluvial and shallow marine conglomerates and sandstones. Also there may be an unconformity between the upper Phantom Lake Suite and the Deep Lake Group. The existence of this unconformity is supported by the appearance of micaceous quartzite clasts in the radioactive conglomerate member of the Magnolia Formation which resemble units in the upper Phantom Lake Suite and by the absence of volcanic clasts. However, proof of the existence of these unconformities awaits detailed stratigraphic study of the rocks of the Phantom Lake Suite which crop out north of the area of Plate I.

Another unconformity in the Deep Lake Group occurs at the base of the Vagner Formation. Evidence for this unconformity is the thinning of the Cascade Quartzite on the south limb of the major northeast-trending anticline. As shown in Plate I, this unit changes from about 4900 feet (1500 m) thick on the north limb of the fold to less than 1600 feet (500 m) thick on the south limb. This drastic thinning of the formation over a lateral distance of about 2.5 miles (4 km) is difficult to explain by facies change. In the present study, the thinning is interpreted to be the result of erosion of about 3300 feet (1000 m) of Cascade Quartzite from the south limb of the anticline prior to deposition of the paraconglomerate of the Vagner Formation.

A major unconformity lies between the Deep Lake Group and Libby Creek Group at the base of the Headquarters Formation. Plate I shows that the lower paraconglomerate of the Headquarters Formation lies on rocks of the Rock Knoll Formation in the eastern area and on rocks of the Cascade Quartzite in the central area. This unconformity represents a period of erosion during which about 1600 feet (500 m) of sediment of the Rock Knoll and Vagner formations were removed in the central area.

Summary of paleocurrent data

A summary of mean paleocurrent directions for each of the formations of the Deep Lake Group and for the upper Phantom Lake Suite is given in Plate II. These paleocurrents are mainly directed to the southwest, but there are also currents directed to the south and west. The rose diagram of current directions for the combined Phantom Lake Suite and Deep Lake Group (Plate II) averages out these variations and shows a prominent southwest-directed mean paleocurrent. This mean direction indicates that most of the sediments of the Phantom Lake Suite and Deep Lake Group were derived from a source to the northeast and transported down a southwest-dipping paleoslope. The strong unimodal nature of the paleocurrent distribution and the persistence of the southwest direction in time and space indicate that disruption of the primary currents by secondary currents acting across the paleoslope was minor (Pettijohn, 1957). This supports the interpretation that most of the sediments in the Deep Lake Group were deposited in a fluvial system. The small variance of the paleocurrent distribution for the total Deep Lake Group (see Plate II) also suggests a dominantly fluvial environment of deposition for the sediments of the Deep Lake Group (Potter and Pettijohn, 1963).

The source of sediment during most of the depositional period was to the northeast. This source was Archean granitic rocks and older sedimentary rocks including quartzites, chert beds, and some greenstones. All of these rock types are exposed in the Laramie Range, 50 miles (80 km) northeast of the Medicine Bow Mountains (Hills and Armstrong, 1974).

As shown in Figure 18, inclinations of cross-bedding in the Cascade Quartzite, the Lindsey Quartzite, and the Magnolia Formation are remarkably similar, and this strengthens the idea that these formations were deposited in similar (i.e., fluvial) depositional environments. In contrast, the cross-bedding in the upper Phantom Lake Suite has lower inclinations and may represent a different depositional environment (i.e., marine).

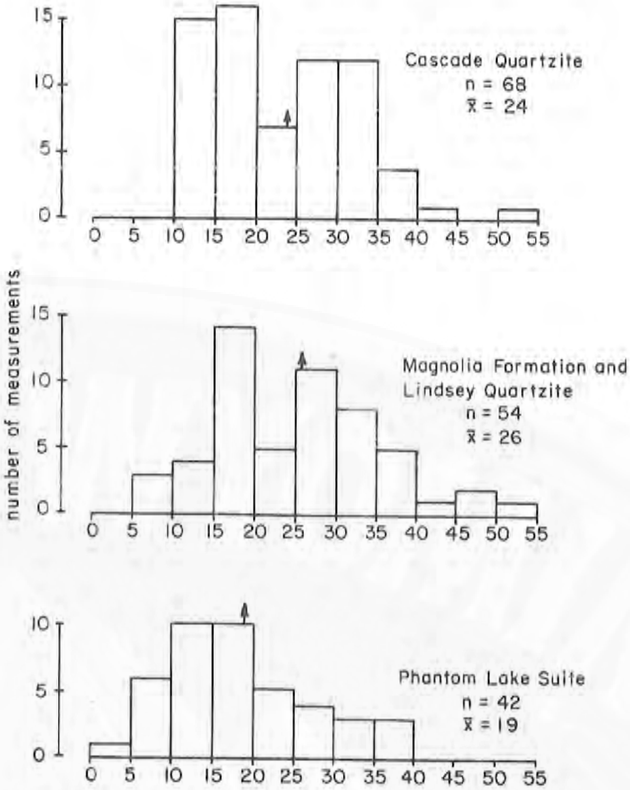


Figure 18. *Inclination of cross-bedding in the Phantom Lake Suite and Deep Lake Group. n = number of measurements; $\bar{x}$ = mean inclination (arrows).*

URANIUM POTENTIAL OF THE PHANTOM LAKE SUITE AND DEEP LAKE GROUP

Introduction

The only mineral deposits that have been mined from the area of outcrop of the Phantom Lake Suite and Deep Lake Group are quartz veins which carry native gold, chalcopyrite, pyrite, and hematite. Gold was mined from these veins between 1880 and 1910 (Houston and others, 1968), and periodic but intensive prospecting during this interval produced several mines and many prospect holes.

Renewed interest in the economic potential of the metasedimentary rocks of the Medicine Bow Mountains centers on the possibility of stratiform uranium mineralization in quartz-pebble conglomerates. This type of uranium deposit has been found in Early Proterozoic metasedimentary rocks in Canada, South Africa, Brazil, and Australia (Robertson, 1974). The lithologic characteristics, tectonic settings, and depositional environments of these known uranium-bearing quartz-pebble conglomerates are very similar to those of the rocks of the Deep Lake Group and upper Phantom Lake Suite.

Summary of the fossil placer model

The best known Precambrian uranium-bearing quartz-pebble conglomerates are the Blind River - Elliot Lake deposits in southern Ontario (Robertson, 1976; Roscoe, 1969) and the Witwatersrand deposits in South Africa (Minter, 1976; Pretorius, 1975). Similar, but smaller, deposits occur at Jacobina, Brazil (Cox, 1967; Gross, 1968), in Australia (Richards, 1972; Robertson, 1974), and in India (Viswanatha and others, 1977). All of these known occurrences are strikingly similar in lithology, tectonic setting, depositional environment, and age. A review of each of these characteristics of known deposits is presented below to facilitate evaluation of the economic potential of the rocks in the Medicine Bows.

In all of these areas, uranium mineralization occurs in the matrix of quartz-pebble conglomerates that are part of thick sequences of quartz-rich continental platform sediments. Other lithologies in these sequences include drab, green, or yellow-gray quartzites, and paraconglomerates and limestones. The major uranium mineral in the conglomerates is uraninite, associated with pyrite and sometimes with gold. The uraninite, gold, and pyrite in the conglomerates are considered to be detrital minerals that were transported and concentrated by sedimentary processes (Minter, 1976; Roscoe, 1969), so that the deposits are called fossil placers.

The tectonic setting of Precambrian fossil placer uranium deposits is similar for all known occurrences. In every case, the metasedimentary rocks that contain the uranium mineralization were deposited in intracratonic or marginal basins adjacent to Archean granite-greenstone terranes. These metasedimentary rocks are the oldest quartz-rich continental platform sediments observed on their respective continents, and are usually only mildly deformed and metamorphosed (Robertson, 1974).

The depositional environments of uranium-bearing quartz-pebble conglomerates is considered by most workers to be fluviatile. Minter

(1976) has demonstrated that the Witwatersrand ores were deposited in shifting channels of a braided river system. Similarly, Roscoe (1969) and Robertson (1976) considered the Blind River - Elliot Lake ores to have been deposited in cold, rapidly flowing rivers. Other units associated with the fluvial ore-bearing sediments were deposited in a variety of continental, shallow marine, and transitional depositional environments. In addition, certain units in the Huronian Supergroup are interpreted to be continental glacial or glacio-marine deposits (Roscoe, 1969; Robertson, 1976). On a large scale, the uranium-bearing metasedimentary sequences usually overlie sequences of volcanic flows and volcaniclastic sediments and underlie the oldest red-colored, hematite-bearing sediments (Robertson, 1974).

The age of Precambrian fossil placer uranium deposits is invariably greater than 2000 m.y. The Witwatersrand sequence is between 2300 and 2800 m.y. old (Anhaeusser, 1973) and the Huronian Supergroup of southern Ontario is older than 2160 m.y. (Fairbairn and others, 1969). The absence of uranium-bearing quartz-pebble conglomerates in younger terranes has been interpreted as evidence that the atmosphere in the Early Proterozoic was characterized by a low partial pressure of oxygen (Roscoe, 1973). This interpretation relies on the fact that uraninite and pyrite can only be transported as detrital minerals in the absence of abundant free oxygen.

Characteristics of the Phantom Lake Suite and Deep Lake Group which fit the fossil placer model

The lithologies of rocks in the Phantom Lake Suite and Deep Lake Group are very similar to the lithologies in the Huronian Supergroup of southern Ontario. This lithologic similarity was observed by Van Hise and Leith (1909), Blackwelder (1935), Houston and others (1968), Young (1973), S.M. Roscoe (oral communication, 1977), and Houston and Hills (in preparation). In particular, radioactive, pyritic, quartz-pebble conglomerate, drab yellow-gray quartzite, sericitic quartzite, and paraconglomerate units are strikingly similar to rocks of the Huronian Supergroup. Houston and others (1977) proposed a correlation between metasedimentary rock units of the Medicine Bow Mountains and the Huronian Supergroup based on these similarities (Table 2).

The tectonic setting of the Phantom Lake Suite and Deep Lake Group also fits the fossil placer model, in that the metasedimentary rocks were deposited adjacent to the granite-greenstone terrane known as the Wyoming Province, are the oldest quartz-rich clastic metasediments in southeastern Wyoming, and are only mildly deformed and metamorphosed.

Likewise, the depositional environments of rocks of the Phantom Lake Suite and Deep Lake Group fit the fossil placer model. The radioactive conglomerate member of the Magnolia Formation is interpreted to be fluvial in origin, and the paraconglomerate units higher in the Deep Lake Group are probably glacio-marine deposits. Sedimentation of most of the Deep Lake Group appears to have been cyclical in nature, and Table 2 shows that these cycles

Table 2. *Lithostratigraphic correlation of Early Proterozoic rocks in the Medicine Bow Mountains of Wyoming with those in the Huronian Supergroup of Canada.*

MEDICINE BOW MOUNTAINS WYOMING AFTER KARLSTROM, 1977			
LIBBY CREEK GROUP	Medicine Peak Qtzite	Sandstone Qtz-pebble cgl.	Shallow marine
	Heart Fm.	Sandstone Siltstone Sandstone	Marine?
	Headquarters Formation	Shale Arkose Paraconglomerate	Glacio-marine
DEEP LAKE GROUP	Rock Knoll Fm.	Conglomerate Sandstone, shale	Shallow marine
	Vagner Fm.	Shale Limestone Paraconglomerate	Glacio-marine
	Cascade Qtzite	Pebbly arkose Pebbly sandstone	fluvial
	Campbell Lake Fm.	Shale Paraconglomerate	Glacial
	Lindsey Qtzite	Sandstone	Fluvial-deltaic
	Magnolia Fm.	Qtz-granule ss. Qtz-peb cgl.	Fluvial
PHANTOM LAKE SUITE	upper Phantom Lake Metamorphic Suite	Boulder cgl. Basalt	Subaerial?
		Micaceous sandstone Shale, sandstone	Marine
	lower Phantom Lake Metamorphic Suite	Volcanoclastic graywackes, flows and tuffs	Subaerial?

HURONIAN SUPERGROUP ONTARIO, CANADA AFTER ROSCOE, 1969			
COBALT GROUP	Lorraine Fm.	Sandstone Qtz- pebble cgl.	Shallow marine
	Gowganda Fm.	Graywacke Siltstone Sandstone Paraconglomerate	Glacial, glacial-marine
QUIRKE LAKE GP.	Serpent Fm.	Sandstone	Fluvial-deltaic, shallow marine
	Espanola Fm.	Dolomite Limestone Sandstone	Shallow marine
	Bruce Fm.	Paraconglomerate	Glacio-marine
HOUGH LAKE GP.	Mississagi Fm.	Sandstone	Shallow marine
	Pecors Fm.	Siltstone	Shallow marine
	Ramsey Lake Fm.	Paraconglomerate	Glacial shallow water
ELLIOT LAKE GROUP	McKim Fm.	Siltstone	Shallow marine
	Matinenda Fm.	Sandstone Qtz-peb cgl.	Fluvial
	Thessalon Fm.	Basalt	Subaerial
	Livingstone Creek Fm.	Subarkose	Marine

ARCHEAN METASEDIMENTS, GNEISSES, AND GRANITE correspond closely with similar cycles that have been proposed for the Huronian Supergroup.

The age of the metasediments is one uncertainty in applying the fossil placer model. Radiometric age dating tells us only that the rocks of the Phantom Lake Suite and Deep Lake Group are older than 1700 m.y. and younger than 2500 m.y. (Hills and others, 1968). However, in the absence of detailed age dating, the approximate age of the rocks can be inferred from lithostratigraphic correlation of the metasedimentary rocks in the Medicine Bow Mountains with other Early Proterozoic metasedimentary rocks in North America. Such a correlation suggests that the Phantom Lake Suite and Deep Lake Group were deposited more than 2000 m.y. ago (Houston and Hills, in preparation) and are, therefore, old enough to contain fossil placer uranium deposits.

This lithostratigraphic correlation is based on several lines of reasoning. First, Table 2 shows that the sedimentary cycles observed in the Medicine Bows are similar to sedimentary cycles observed in the Huronian Supergroup of southern Ontario which was deposited more than 2200 m.y. ago (Fairbairn and others, 1969). These cycles may reflect regional tectonic or climatic changes which can be used for time-stratigraphic correlation. In particular, if the paraconglomerates in the upper Deep Lake Group and lower Headquarters Formation are glacial or glacio-marine deposits, they may represent the same glacial events that deposited the Bruce and Gowganda formations of the Huronian Supergroup (Table 2).

Second, the presumed glacial paraconglomerates of the Headquarters Formation are overlain by the aluminous quartzites of the Medicine Peak Quartzite. Young (1973) proposed that this sequence, tillites - aluminous quartzites, represents a regional climatic change from glacial conditions to subtropical conditions which can be used as a time marker for early Proterozoic rocks in North America.

Third, the occurrence in the Phantom Lake Suite and Deep Lake Group of pyritic, radioactive conglomerates suggests that the sediments were deposited prior to the development of abundant free oxygen in the atmosphere. If the uranium minerals and the pyrite are detrital minerals, they must have been transported in an atmosphere with a low partial pressure of oxygen, such as existed before 2000 m.y. ago (Roscoe, 1969; 1973). The pyrite in the conglomerates of the lower Deep Lake Group occurs in the matrix, and often the grains are well rounded: a detrital origin is certainly possible. The argument that the sediments of the Phantom Lake Suite and Deep Lake Group were deposited in a low-oxygen atmosphere prior to 2000 m.y. ago is strengthened by the predominance of yellow-green and gray sediments and the absence of primary hematite in red sediments (Robertson, 1974).

Description of radioactive units in the Phantom Lake Suite and Deep Lake Group

There are at least three radioactive units in the Phantom Lake Suite and Deep Lake Group. A summary of the characteristics of these units is given in Table 3.

The oldest unit that shows anomalously high radioactivity is a metavolcanic rock in the lower Phantom Lake Suite which crops out near Crater Lake. This unit includes metavolcanic schists (metatuffs?) and mafic agglomerate. Scintillometer readings of surface radioactivity show values of up to five times background (L.R. Lanthier, oral communication). These rocks are not necessarily of economic interest in themselves, but it is possible that units of this type in the lower Phantom Formation were a source for detrital uranium in the overlying radioactive conglomerates.

The second major radioactive unit is the conglomerate that occurs near the base of the upper Phantom Lake Suite. In the western part of the study area, this conglomerate has a medium-grained, micaceous, arkosic matrix and contains pebbles of quartz, quartzite, mafic schist, and felsic metavolcanics. The clasts in this outcrop are not concentrated at the lower contact of the paraconglomerate, but become more abundant higher in the section. This suggests that the conglomerate was deposited on unconsolidated sands (Palonen, 1973). Scintillometer readings on this outcrop are highest in the coarsest layers and reach values up to six times background (see Table 3). Extensive radioactive quartz-pebble conglomerates in the northern Medicine Bows, north of the study area near the town of Arlington, may also be part of the upper Phantom Lake Suite; however, the exact stratigraphic position of these conglomerates is poorly understood. Scintillometer readings of surface radioactivity in these conglomerates show readings of up to 24 times background.

The third major radioactive unit in the Medicine Bow Mountains is the radioactive conglomerate member of the Magnolia Formation. This unit crops out in the core of the anticline near Arrastre Lake and along the North Fork of Rock Creek. Scintillometer readings show that surface radioactivity is more than five times background near Arrastre Lake and more than four times background along the North Fork of Rock Creek. A heavy-mineral separate from the conglomerate near Arrastre Lake shows much higher radioactivity than the whole-rock samples (see Table 3), and this indicates that the uranium in these rocks is concentrated in the heavy mineral fraction.

The radioactive conglomerates in the upper Phantom Lake Suite and the Magnolia Formation have many characteristics in common with uranium-bearing rocks in the Huronian Supergroup. In both areas, the rocks contain radioactive minerals and pyrite and are considered to be fluvial deposits. However, the conglomerates in the Medicine Bow Mountains are relatively immature, poorly to moderately sorted, arkosic conglomerates, whereas high-grade uranium ore zones in the Huronian Supergroup tend to be more mature, well-sorted, quartz-pebble conglomerates. Thus, it appears unlikely that the radioactive units seen so far in the Medicine Bow Mountains are directly analogous to ore zones in the Huronian Supergroup. It is possible that the conglomerates in the Phantom Lake Suite and Deep Lake Group represent a more proximal facies of fluvial deposition than conglomerates in the Huronian Supergroup.

Surface leaching and subsurface radioactivity

There are several indications that oxidation of surface outcrops in the Medicine Bow Mountains has leached pyrite and uranium from the radioactive conglomerate units. First, pyrite grains are only locally preserved in the conglomerates, having been partly or completely altered to iron oxides. Second, abundant holes and cube-shaped casts filled with iron oxide are scattered throughout the matrix of the conglomerates, attesting to original abundance of pyrite greatly exceeding present abundance.

Uranium has been leached from surface outcrops in the Medicine Bow Mountains. Miller and others (1977) analyzed the radon content of ground water in the Arrastre Lake area and compared those data with the uranium content of surface rocks, ground water, and bog material. Radon is a short-half-life (3.8 days) daughter product of uranium 238. It cannot migrate long distances in water and is a positive indication of nearby uranium. Miller and others (1977) found that the radon content of waters in the Arrastre Lake area was several orders of magnitude greater than could be accounted for by decay of surface uranium 238. They concluded that subsurface rocks contain far more uranium than do surface rocks.

Recommendations for future exploration

Several stratigraphic units in the Medicine Bow Mountains show anomalously high radioactivity (see Table 3): these units should be mapped and sampled in greater detail. Among these, quartz-pebble conglomerates in the northern Medicine Bow Mountains have the highest surface uranium content and seem to have the most economic promise. Unfortunately, the stratigraphic position of these conglomerates is not known, and a stratigraphic, structural, and sedimentological study of the rocks in the northern Medicine Bows is needed. It will be particularly important to correlate unmapped units in the northern Medicine Bows with units defined in this study, to map the configuration and source of bodies of radioactive conglomerate, and to identify any major unconformities in the Phantom Lake Suite and Deep Lake Group.

Radioactive units of potential economic importance are most likely to be arkosic quartz-pebble conglomerates that occur in distinct channels. Pyrite is usually present in these conglomerates but often is strongly oxidized, leaving reddish casts, and leaving rust-colored stains on the outcrops. Such conglomerates should be sampled from the basal, coarse-grained parts of known channels. If major unconformities can be identified, the conglomerates overlying the unconformity are excellent targets. In particular, the possible unconformity between volcanogenic rocks of the lower Phantom Lake Suite and quartzites of the upper Phantom Lake Suite deserves attention.

A combination of exploration techniques should be used in the Medicine Bow Mountains. Mapping and scintillometer sampling of outcrops are still needed in the northern Medicine Bows. This geologic exploration should be combined with geochemical sampling of bogs and ground water in suitable localities, following Miller and others (1977). Ultimately, drilling will be necessary to evaluate the uranium content of subsurface rocks and to determine how much uranium has been leached from surface outcrops.

Summary

The Medicine Bow Mountains of southeastern Wyoming contain an 8 mile (13 km) thick section of low-grade metasedimentary rocks that was deposited near the southern margin of the Wyoming Archean craton between 2500 and 1700 m.y. ago. These metasediments are divided into three groups, separated by unconformities: the Phantom Lake Metamorphic Suite (oldest), the Deep Lake Group, and

Table 3. *Location and characteristics of radioactive conglomerates in the Medicine Bow Mountains. Geochemical data from Houston and others (1977), and Graff and Houston (1977). Scintillometer used was a McPhar, model no. TV-1A; background readings average 4500 counts per second.*

UNIT	TYPE OF CONGLOMERATE	LOCATION	MAXIMUM SCINTILLOMETER READING, (COUNTS/SEC.)	U, PPM.	TH, PPM.
Magnolia Formation	Arkosic, quartz-pebble conglomerate; contains pyrite	Arrastre Lake area NW ¼, sec. 10, T.16N., R.80W.	22,000	9 samples 2.8 - 8.4	9 samples 20 - 38
Magnolia Formation	Heavy mineral separate from above conglomerate	"	--	89	No data
Magnolia Formation	Arkosic, quartz-pebble conglomerate; contains pyrite	North Fork Rock Creek NW ¼, sec. 22, T.17N., R.79W.	20,000	5 samples .5 - 11.2	No data
Phantom Lake Suite	"	Western part of study area NW ¼, sec. 23, T.16N., R.81W.	25,000	No data	No data
Upper Phantom(?) Lake Suite	"	Northern Medicine Bows NW ¼, sec. 6, T.18N., R.78W.	40,000	128	No data
Upper Phantom(?) Lake Suite	"	Northern Medicine Bows NW ¼, sec. 5, T.18N., R.78W.	> 30,000	80	No data
Lower Phantom Lake Suite	Mafic tuff and mafic agglomerate	Near Crator Lake SW ¼, sec. 35, T.18N., R.79W.	> 20,000	No data	No data

the Libby Creek Group (youngest).

The Phantom Lake Suite, which is nearly 1.9 miles (3 km) thick, is poorly understood, but is divided into a lower Phantom Lake Suite containing dominantly metavolcanic rock, and an upper Phantom Lake Suite containing dominantly micaceous quartzite. The boundary between the lower and upper Phantom Lake Suites appears to be an unconformity which is overlain by a radioactive, arkosic quartz-pebble conglomerate.

The Deep Lake Group, approximately 2.1 miles (3.3 km) thick, is divided into six formations. (1) The Magnolia Formation contains a radioactive, arkosic quartz-pebble conglomerate which grades up-section into a trough-cross-bedded, coarse-grained quartzite; (2) the Lindsey Quartzite is a fine-grained, trough-cross-bedded quartzite; (3) the Campbell Lake Formation is a thin paraconglomerate-phyllite sequence which serves as a stratigraphic marker; (4) the Cascade Quartzite is a pebbly quartzite which contains distinctive black chert pebbles; (5) the Vagner Formation unconformably overlies the Cascade Quartzite and contains paraconglomerate, marble, and phyllite; and (6) the Rock Knoll Formation contains quartzite, minor phyllite, and quartzite-pebble conglomerate.

The depositional history of the Phantom Lake Suite and Deep Lake Group involves four sedimentary cycles (see Table 2). The first cycle, the Phantom Lake Suite, is poorly understood, but appears to be a transgressive-regressive cycle which included deposition of volcanic flows, volcanogenic sediments, radioactive quartz-pebble conglomerates, paraconglomerates, shales, and micaceous, fine-grained quartzites. The second cycle involves fluvial conglomerates, fluvial sandstones, and fluvial-deltaic sandstones of the Magnolia Formation and Lindsey Quartzite and is a fining-upward cycle which represents the gradual decrease in the energy of a river system. The third and fourth cycles both appear to be transgressive-regressive sequences which began with deposition of presumed glacial paraconglomerates, continued by deposition of marine shale and limestone, and ended by deposition of arkosic sandstone in outwash fans. Each of the four cycles appears to record a major marine transgression followed by marine regression.

Paleocurrent study indicates that most of the Deep Lake Group and parts of the upper Phantom Lake Suite were derived from a source area to the northeast which contained Archean metasedimentary and granitic rocks. The strongly unimodal, low-variance distribution of paleocurrent measurements suggests that sediment was transported in rivers that flowed down a southwest dipping paleoslope.

There are several major unconformities in the Phantom Lake Suite and Deep Lake Group. The best documented unconformities occur in the upper part of the Deep Lake Group. As shown in Table 2, an unconformity separates rocks of the third cycle from rocks of the fourth cycle, and another separates rocks of the fourth cycle from rocks of the Libby Creek Group. Both unconformities represent erosion of thick sections of the underlying sediments prior to deposition of glacial paraconglomerates. These unconformities are particularly important because they represent major tectonic and climatic events during a period of transition from cyclical deposition of the Deep Lake Group to non-cyclical, miogeosynclinal deposition of the overlying Libby Creek Group. If these major tectonic and climatic events were regional in extent, the paraconglomerates overlying these unconformities can be used for time-stratigraphic correlation of the Early Proterozoic rocks in North America (see Table 3).

There may also be several important unconformities in the Phantom Lake Suite. For example, metavolcanic rocks of the lower Phantom Lake Suite may be separated from quartz-rich clastic rocks of the upper Phantom Lake Suite by an unconformity, and rocks of the Magnolia Formation may lie with angular unconformity on volcanics of the Upper Phantom Lake Suite. Present stratigraphic information on the Phantom Lake Suite is inadequate to prove the existence of these unconformities.

The upper Phantom Lake Suite and the Magnolia Formation contain radioactive quartz-pebble conglomerates that are of potential economic importance. Surface outcrops of these conglomerates do not contain economic concentrations of uranium. Nevertheless, several factors suggest that these units deserve further study. First, the lithologies, tectonic setting, depositional environments, and age of the metasedimentary rocks in the Medicine Bow Mountains are similar to those of the Huronian Supergroup of southern Ontario. This suggests that the Phantom Lake Suite and Deep Lake Group are likely hosts for fossil placer uranium deposits. Second, geological and geochemical studies of outcrops in the Arrastre Lake area of the Medicine Bow Mountains (Miller and others, 1977) indicate that both uranium and pyrite have been leached from surface outcrops and that subsurface rocks are more strongly radioactive than surface rocks. The radioactive units will have to be drilled before their economic potential can be properly evaluated.

The primary targets for future exploration are arkosic, pyrite-bearing quartz-pebble conglomerates in the upper Phantom Lake Suite and the Magnolia Formation. Units of the upper Phantom Lake Suite that crop out in the Northern Medicine Bows are the most radioactive units found so far, but radioactive units in the western part of the study area, near Arrastre Lake, and along the North Fork of Rock Creek (see Table 3), also deserve attention.

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APPENDIX

DETAILED STRATIGRAPHIC SECTIONS OF FORMATIONS OF THE DEEP LAKE GROUP*

IA. Type-section for Magnolia Formation

Location - SE¼NW¼ and SW¼NE¼ sec. 10, T.16N., R.80W.; follows line N65W through drill-hole PL-1 (from Exxon)‡ which intersects the surface 857 m (2810 feet) north and 1107 m (3630 feet) east of the southwest corner of sec. 10. PL-1 drilled 40° from vertical toward N65W to a depth of 393 m (1289 feet).

Comment - Section is reconstructed from both surface data (0-40 m; 115-195 m; 376-555 m) and subsurface data (0-376 m). The type section may be cut by a north-trending normal fault which would shorten the section, making the total thickness given below a minimum thickness.

Lithologic descriptions

upper contact - poorly exposed, but appears to be a gradational contact between quartzite member of Magnolia Formation and overlying Lindsey Quartzite. Quartzites become finer-grained and less arkosic upwards across contact.

376-553 m (1233-1814 feet) - mainly medium- to coarse-grained quartzite with local layers of quartz-granule conglomerate and chlorite phyllite. Weathers pink to rust. Trough crossbeds in 10-15 cm sets fairly common. Poorly exposed.

320-376 m (1050-1233 feet) - fine- to very-coarse-grained quartzite in fining upwards stratification sequences 15-150 cm thick with very coarse to coarse quartzite at base grading up through trough crossbedded medium-grained quartzite to ripple laminated argillite.

311-320 m (1020-1050 feet) - fault zone; mainly chloritized amphibolite and friable, oxidized quartzite.

254-311 m (833-1020 feet) - fine-grained quartzite with scattered trough crossbeds and quartz granules.

193-254 m (633-833 feet) - speckled, very-fine grained quartzite. Specks are megacrysts of chlorite and biotite up to several mm in diameter. Contains numerous laminations of dark minerals —biotite, chlorite, pyrite.

Contact between quartzite member of Magnolia Formation (above) and conglomerate Member of Magnolia Formation (below) - in PL-1, contact is sharp between very-fine-

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*See Karlstrom and Houston (1979) or Karlstrom (1977) for reference to detailed geologic mapping.

‡drill core is currently being stored at the Geology Department, University of Wyoming.

grained, speckled quartzite of quartzite member and polymictic conglomerate of conglomerate member.

182-193 m (597-633 feet) - polymictic conglomerate and very-coarse-grained arkosic quartzite; clasts of vein quartz, quartzite, mafic rock, and felsic gneiss (?) up to 15 mm in diameter. Weathers rust-red because of stain from oxidized pyrite grains. Locally 2-4 times background radioactivity on surface.

180-182 m (590-597 feet) - fault zone; this fault may shorten section in PL-1, removing some of upper conglomerate member.

147-180 M (482-590 feet) - coarse- to very-coarse-grained pebbly arkosic quartzite with local conglomerate layers. Quartzite is poorly to moderately sorted and locally mildly radioactive (2-3 times background) on surface.

135-147 m (443-482 feet) - polymictic conglomerate with clasts up to 55 mm in diameter of fine-grained quartzite, quartz, mafic volcanics, and felsic volcanics (?).

106-135 m (348-443 feet) - polymictic conglomerate, locally brecciated and sheared.

75-106 m (246-348 feet) - very coarse polymictic conglomerate with clasts up to 10 cm in diameter and scattered lenses of coarse-grained arkose 1-2 m thick.

64-75 m (209-246 feet) - basaltic tuff with scattered quartz pebbles.

28-64 m (92-209 feet) - coarse polymictic conglomerate with some 1-2 m thick mafic tuff layers; clasts in conglomerate are mafic rocks, quartzite, and vein quartz with mafic clasts more abundant at base. Locally radioactive on surface (4 to 6 times background). Weathers rust-red.

12-28 m (39-92 feet) - medium-grained, moderately to poorly sorted arkosic quartzite with scattered clasts of radioactive, pyritic quartzite. Contains pyrite and weathers rust-red on surface. Locally radioactive on surface.

base - 12 m (0-39 feet) - very-coarse-grained arkosic quartzite with local layers of polymictic conglomerate. Locally radioactive on surface.

lower contact - an unconformity between coarse-grained arkosic quartzite or polymictic conglomerate and underlying metabasalt. The contact is placed above the highest metabasalt unit of substantial thickness (i.e., neglecting lenticular mafic units less than 3 m thick) and at the base of the lowest arkosic conglomerate or coarse-grained arkosic quartzite.

IB. Reference locality for quartzite member of Magnolia Formation

Location - east of Stamp Mill Lake, NW¼SW¼ sec. 15, and NE¼SE¼ sec. 16, T.16N., R.80W.

Comment - section is incomplete, upper and lower contacts are covered, but outcrops are fairly extensive and representative of unit.

Lithologic description - This area exposes a more than 200 m thick section of buff colored fine- to coarse-grained, moderately to poorly sorted arkosic quartzite and quartz-granule conglomerate with 5-10 cm layers of phyllitic, chloritic quartzite. Includes abundant medium-scale trough crossbed sets (about 25-50 cm). Locally, outcrops are rust-red stained from oxidized pyrite grains.

IIA. Type-section for Lindsey Quartzite

Location - along a north-trending line close to the boundary between NW¼ sec. 2, and NE¼ sec. 3, T.16N., R.80W.

Comment - this area exposes a nearly continuous section of about 535 m (1755 feet) of Lindsey Quartzite. This thickness may be greater than the true stratigraphic thickness, because of repetition by a northeast-trending fault in this area; true thickness, as seen in other areas, may be closer to 450 m. We have not measured this section in detail, but it is the best exposure of the Lindsey Quartzite we know of, and is therefore defined as the type-section.

Lithologic descriptions

upper contact - not exposed along boundary between sec. 2 and sec. 3 because upper Lindsey Quartzite is truncated by mafic intrusive. However, an offset 600 m to east shows coarse-grained, pyritic quartzites of the upper Lindsey overlain by diamictites of the Campbell Lake Formation. Where best exposed — west of the type section — this contact varies from a sharp contact to a gradational change over about one meter.

450-535 m (1312-1755 feet) - very-coarse-grained quartzite and fine-grained quartz-granule conglomerate. Contains pyrite and pyrite casts. Locally mildly radioactive on surface.

300-450 m (984-1312) feet) - fine- to medium-grained quartzite with phyllite layers and phyllite partings which form olive green remanents on exposed bedding surfaces. Occasional quartz granules up to 5 mm. Some planar crossbeds.

base - 300 m (0-984 feet) white to light gray, medium- to coarse-grained quartzite with lenses of quartz-granule conglomerate. Both trough and planar crossbeds present. Thickness of this unit given above is a maximum; true stratigraphic sequence may be considerably less, and observed thickness may be result of repetition by faulting.

lower contact - gradational with more arkosic quartzites and quartz-granule conglomerates of the underlying quartzite member of Magnolia Formation.

IIB. Reference section for Lindsey Quartzite

Location - 500 m west of Lindsey Lake, in NE¼ sec. 27, and NW¼ sec. 26, T.17N., R.79W.

Comment - This area contains extensive outcrops with low dip and abundant sedimentary structures.

Lithological descriptions - Quartzites are very-fine- to medium-grained with frequent phyllite layers ranging from partings to 10 cm thick layers. Trough crossbeds are abundant and occur in sets averaging 8-12 cm thick. Planar crossbeds and ripple marks are also present.

III. Type-section for Campbell Lake Formation

Location - SW¼NE¼ sec. 4, T.16N., R.80W.

Comment - units trend NNE and outcrops have been glacially scoured, so that exposures are fairly good.

Lithologic descriptions

upper contact - gradational contact between phyllitic quartzite of upper Campbell Lake Formation and gray, medium-grained quartzite of lower Cascade Quartzite. Contact is drawn at the highest laminated phyllitic quartzite.

30-65 m (98-213 feet) - gray, phyllitic, fine-grained quartzite, locally crossbedded.

12-30 m (39-98 feet) - black to dark gray, fine-grained chloritic phyllite and quartz-rich phyllite.

base - 12 m (0-39 feet) - diamictite: poorly sorted, matrix-supported conglomerate. The matrix makes up 80% of rock and is medium- to coarse-grained, poorly sorted subarkose containing 20-40% feldspar, 10-40% mica, and 2-5% rock fragments. Clasts are white granite, phyllite, and quartzite and range up to 76 cm in diameter with an average of about 5-10 mm.

lower contact - variable from sharp to irregular to gradational. Unit below diamictite is a quartz-pebble conglomerate with pebbles 5 mm - 1 cm in diameter.

IV. Type section for Cascade Quartzite

Location - NW¼ sec. 4, T.16N., R.80W.

Comment - This area contains a semicontinuous exposure of a 1450 m thick section of Cascade Quartzite.

Lithologic descriptions

upper contact - covered

865-1450 m (2837-4756 feet) - pink, highly feldspathic, coarse-grained, pebbly arkosic to subarkosic quartzite. Matrix contains orthoclase, microcline, and plagioclase. Pebbles are well-rounded vein quartz and granite(?) up to 1 cm in diameter; average 5 mm. Weathers to friable, sandy texture.

133-865 m (436-2837 feet) - pyritic, pebbly quartz arenite and subarkose. Pebbles are well-rounded, moderately-well-sorted quartz and distinctive black chert pebbles up to 3 cm in diameter; they occur in lenses several cm thick, often exposed on bedding surfaces. Pyrite occurs as sparse euhedral grains less than 1 mm in diameter.

base - 133 m (0-437 feet) - light gray to white, medium-grained quartz arenite, locally trough crossbedded with troughs 15-30 cm deep.

lower contact - gradational with underlying phyllitic quartzite of Campbell Lake Formation. Contact placed above highest gray, laminated phyllitic quartzite and below lowest clean quartz arenite.

V. Type-section for Vagner Formation

Location - west of Vagner Lake, SW¼ sec. 1, T.16N., R.79W.

Comment - This area exposes the lower two units of the Vagner Formation very well. However, the upper phyllite unit is truncated by a mafic intrusive.

Lithologic descriptions

upper contact - not exposed; phyllite truncated by mafic intrusive. To the east, the upper contact is formed by a large reverse fault which places Headquarters Formation or Rock Knoll Formation against Vagner Formation.

103 - >168 m (338 - >551 feet) - greenish-gray phyllite and very-fine-grained laminated phyllitic quartzite locally crossbedded.

43-103 (141-338 feet) - marble containing alternating layers 1-3 cm thick of carbonate and calcareous quartzite. Contains numerous disharmonic folds with amplitude of several cm which are interpreted to be soft sediment deformation features. Bedding usually pronounced. Weathers to buff color.

base - 43 m (0-141 feet) - diamictite: poorly sorted, matrix-supported conglomerates. Matrix is coarse-grained subarkose; clasts are white granite, quartzite, mafic schist, and metabasalt and range up to 16 cm in diameter. Locally, clasts appear to have been glacially rafted dropstones.

VI. Type-section for the Rock Knoll Formation

Location - southeast face of Rock Creek Knoll, sec. 35, T.17N., R.79W.

Comment - the section described below is modified from Blackwelder (1926, p. 626).

Lithologic descriptions

upper contact - generally an abrupt, conformable contact between quartzites of the Rock Knoll Formation and overlying gray to black diamictite of the Headquarters Formation. Headquarters units strongly foliated.

31-330 m (1017-1246 feet) - interbedded grayish, fine- to medium-grained quartzite and conglomerate. Conglomerates occur in 7 cm to 7 m thick beds and contain quartz, quartzite, and granite pebbles up to 5 cm in diameter. (This unit = Blackwelder's units 6-16.)

241-310 m (790-1017 feet) - massive, pale-gray quartzite with olive-colored phyllitic partings. (This unit = Blackwelder's unit 5.)

119-241 m (390-790 feet) - massive, grayish-white, quartzite, partly schistose in lower 85 m. (This unit = Blackwelder's units 3 and 4.)

79-119 m (249-390 feet) - massive, gray to white, fine- to medium-grained quartzite with clay pellets, thin conglomerate layers, and planar crossbeds in 1-2 m thick sets. (This unit = Blackwelder's units 1 and 2.)

0-76 (0-249 feet) - poorly exposed, fine- to medium-grained quartzite with phyllitic partings. Contains some planar crossbeds.

lower contact - base of unit not exposed; lower contact is a major reverse fault which places Rock Knoll quartzites against phyllite of the upper Vagner Formation.


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