Paleozoic Rocks in the Black Pine Mountains, Cassia County, Idaho

GEOLOGICAL SURVEY BULLETIN 1536

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By J. FRED SMITH, JR.

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Descriptions of eleven rock units which range in age from Devonian to Permian, the thickest parts being Early Pennsylvanian to Early Permian

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PALEOZOIC ROCKS IN THE BLACK PINE MOUNTAINS, CASSIA COUNTY, IDAHO

By J. FRED SMITH, JR.

ABSTRACT

The Black Pine Mountains in the Strevell 15-minute quadrangle are immediately north of the Utah-Idaho boundary in the southeast corner of Cassia County, Idaho. This quadrangle contains 11 Paleozoic rock units, which range in age from Devonian to Permian. All of their contacts except one and probably two are faults of chiefly low dips, and younger rocks are faulted over older ones, or over rocks of partly equivalent ages.

A fault transverse to the mountains—here called the West Dry Canyon fault—separates the range into two parts. The area south of this fault is considered to consist of three plates—lower, middle, and upper; and the area north of the fault consists of two plates, called I and II.

The lower plate to the south contains two formations, in ascending order: the Devonian Jefferson Formation, which has a minimum thickness of 276 m and consists of light-gray to almost white dolomite and lesser amounts of gray limestone and sandstone and quartzite, and the Upper Mississippian and Lower Pennsylvanian Manning Canyon Shale, which consists principally of dark-gray to black argillite and has an exposed estimated thickness of 2,000 m.

The middle plate contains three Pennsylvanian units that are partly age equivalent. These three rock sequences in part equivalent but not themselves in stratigraphic sequence are here considered as informal members of the Oquirrh Formation. The limestone member in the southern part of the quadrangle has a minimum thickness of about 2,300 m and is composed of three parts: a lower one of sandy and silty limestone, which is very fossiliferous in places, and some sandstone, quartzite, and shale; a middle part of limestone, which makes massive outcrops in places, less silty and sandy limestone, and some dolomite; and an upper part of mainly gray silty limestone. A limestone, sandstone, and quartzite member of the Oquirrh in the eastern part of the quadrangle has an exposed thickness of about 180 m. The third member of the Oquirrh in this middle plate and in the eastern part of the quadrangle has a minimum thickness of 430 m and consists of gray limestone and light- and dark-gray and black dolomite; both rock types make some massive and ledge-forming outcrops. This member is similar to the middle part of the limestone member but contains more dolomite.

The upper plate contains a Middle Pennsylvanian (Des Moinesian) to Lower Permian (Wolfcampian) sandstone and siltstone member of the Oquirrh Formation, is partly equivalent to rocks in the middle plate, and has overridden both the middle and lower plates. This member is composed principally of gray, calcareous, tan- and brown-weathering quartz sandstone and siltstone. Beds of gray silty limestone are less abundant. The estimated thickness is 2,700 m.

Rocks north of the West Dry Canyon fault transverse to the range are in two plates. In the lower plate, plate I, the beds of West Dry Canyon consist of limestone, sandy and silty limestone, and calcareous sandstone and siltstone. They have a thickness of about 2,200 m and range in age from Late Pennsylvanian (Virgilian) to Early Permian (Leonardian). These rocks are thus partly equivalent to the sandstone and siltstone member of the Oquirrh south of the transverse fault but as a whole differ from it lithologically. Unit A lies conformably above the beds of West Dry Canyon. It is distinguished by interbedded sequences of dark-gray to black chert and limestone, silty limestone, dolomite, siltstone, and sandstone, has a thickness of about 1,480 m, and is Lower Permian (probably upper Leonardian). A unit of the same age and similar lithology (except for a lack of dolomite) crops out in the northeastern part of the quadrangle. This unit is not in contact with any Paleozoic formation in the quadrangle; it may grade into or interfinger with unit A, but in the study area the two units are separated by Cenozoic deposits and their direct relations cannot be seen.

Plate II, the upper plate north of the fault across the mountains, consists of two rock units. The older one is composed of dense dark-gray limestone, which weathers light gray and commonly forms platy fragments, and of silty and sandy beds, which make up a small percentage of the 745-m thickness. The dark-gray limestone unit is the same Early Permian (Leonardian) age as unit A and its equivalent in plate I.

What is apparently the youngest Paleozoic rock unit in the area comprises sandy limestone, calcareous sandstone, some chert, and silicified limestone, some of which is mostly breccia. The minimum thickness is between 120 and 145 m. These beds are presumably Permian. The contact with the underlying dark-gray limestone appears to be conformable but may be a fault.

Color alteration indices (CAI) determined on conodonts from 32 collections indicate that the host rocks attained temperatures generally in the range of 190°–300°C north of the fault across the mountains and in the range of 300°–400°C south of the fault; some rock temperatures in the south possibly surpassed 400°C. These temperatures suggest that a postmature or high-temperature methane stage of petroleum generation was reached.

INTRODUCTION

Eleven Paleozoic map or rock units ranging in age from Devonian to Permian are recognized in the Black Pine Mountains and Strevell 15-minute quadrangle in southeastern Idaho (fig. 1). All contacts except one and possibly two are faults, of chiefly low dips (fig. 2), and so total thicknesses are not exposed or measurable for any formation. Furthermore, all except possibly the oldest unit are allochthonous or at least parallochthonous, and the areas of deposition of the rock units are uncertain. Younger rocks are faulted over older ones, or over rocks of partly equivalent ages.

The rock units are separated into a number of plates by these low-angle faults, and they are separated in addition by a fault across the mountains partly near West Dry Canyon. South of the West Dry Canyon fault, the range is considered to consist of three principal plates (fig. 3). The lower plate contains the Devonian Jefferson Formation

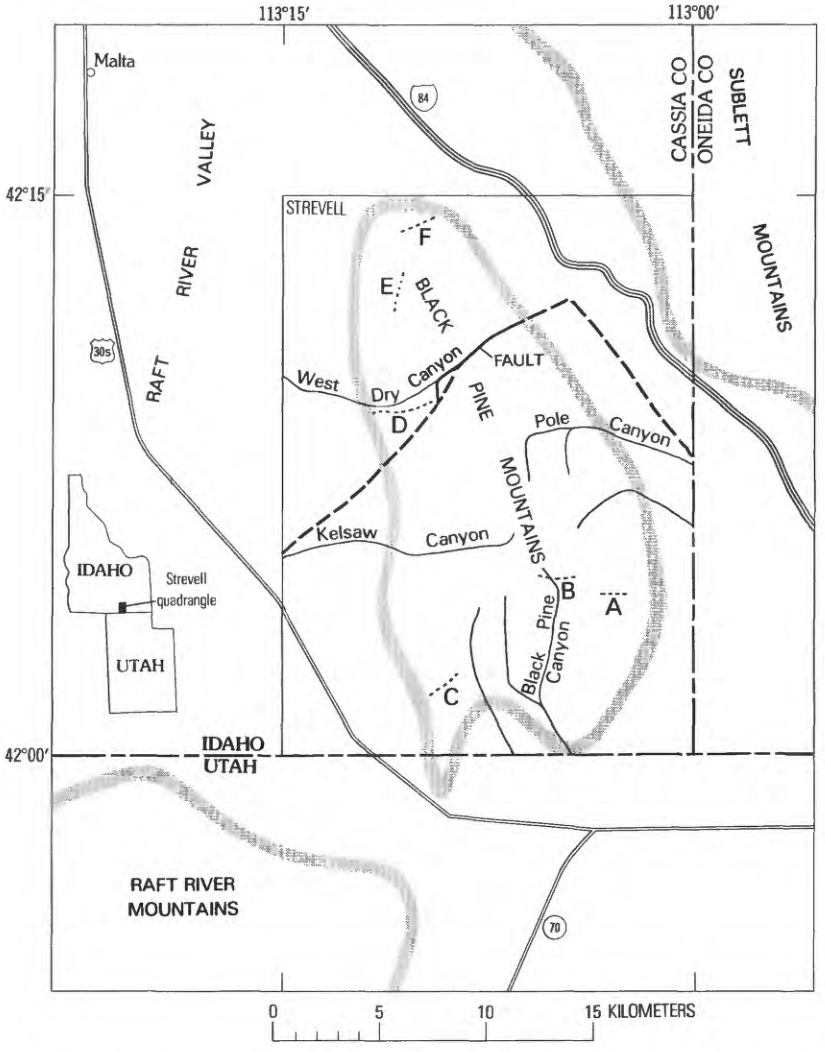


FIGURE 1.—Index map showing location of Black Pine Mountains (Strevell 15-minute quadrangle), Cassia County, Idaho, and locations of measured stratigraphic sections A through F.

and the Upper Mississippian and Lower Pennsylvanian Manning Canyon Shale. The middle plate contains three Pennsylvanian carbonate rock units of partly equivalent ages; the lowest part of one unit is also time equivalent to the highest part of the Manning Canyon Shale in the lower plate. The upper plate contains a Middle Pennsylvanian to Lower Permian sandstone and siltstone member of the Oquirrh

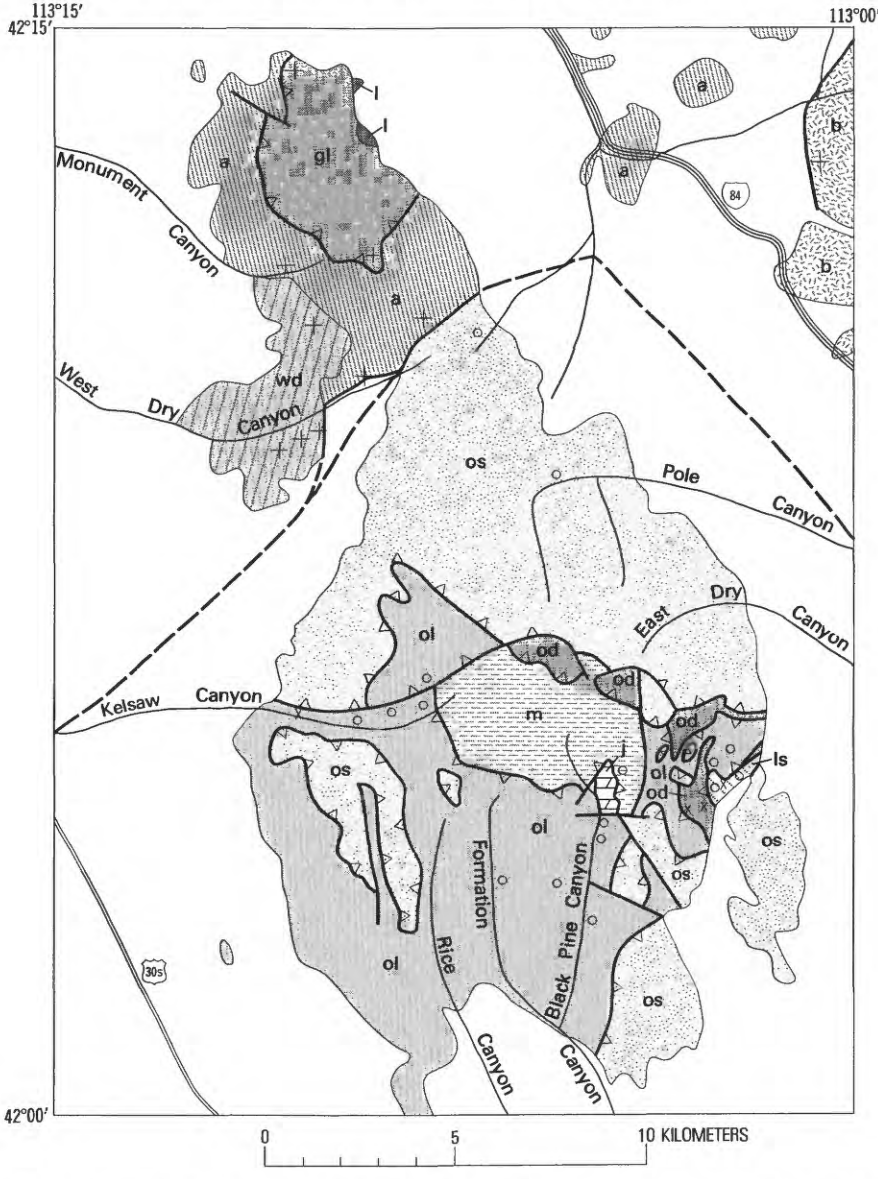
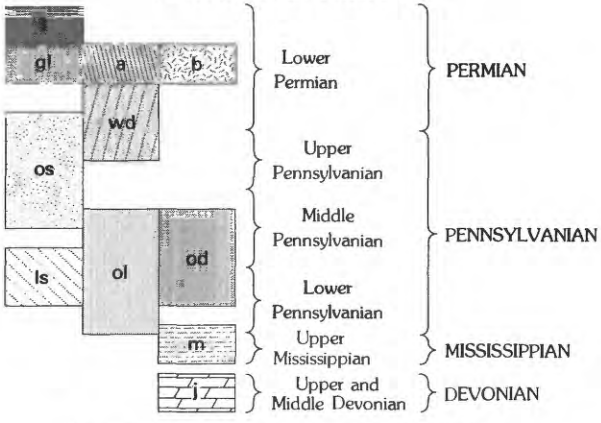


FIGURE 2.—Generalized geologic map of Paleozoic rocks in the Black Pine Mountains (Strevell quadrangle), Idaho, showing conodont localities and color alteration indices (CAI) of conodonts. Twenty-six collections were studied by B. R. Wardlaw, 4 by John Repetski, and 2 by Anita G. Harris.

Formation and has overridden all other plates and older rocks exposed. Near the southwest corner of the Strevell quadrangle, sandstone and limestone were penetrated in a borehole from a depth of

EXPLANATION

Unlabeled areas are Cenozoic rocks



ROCKS NORTH OF WEST DRY CANYON FAULT

PLATE II

- l — Limestone, silicified limestone and chert
- gl — Dark-gray limestone

PLATE I

- a — Unit A
- b — Unit B
- wd — Beds of West Dry Canyon

ROCKS SOUTH OF WEST DRY CANYON FAULT

UPPER PLATE

Oquirrh Formation

- os — Sandstone and siltstone member

MIDDLE PLATE

Oquirrh Formation

- ls — Limestone, sandstone, and quartzite member
- ol — Limestone member
- od — Limestone and dolomite member

LOWER PLATE

- m — Manning Canyon Shale
- j — Jefferson Dolomite

——— CONTACT

——— FAULT—Dashed where approximately located

—△—△— FAULT OF CHIEFLY LOW DIP—Sawteeth on upper plate

CONODONT LOCALITIES AND COLOR ALTERATION INDICES (CAI)

- x — 5.5-6.5 (4 collns.)
- o — 4.5-5.5 (15 collns.)
- + — 3 (one colln.)-4 (nine collns.)

FIGURE 2.—Continued

about 350 m to 645 m, where they overlie metamorphosed lower Paleozoic rocks similar to those in the Raft River Mountains (Oriel and others, 1978). I interpret the sandstone and limestone to be part of the upper plate rocks and the structurally lower plates to be lacking.

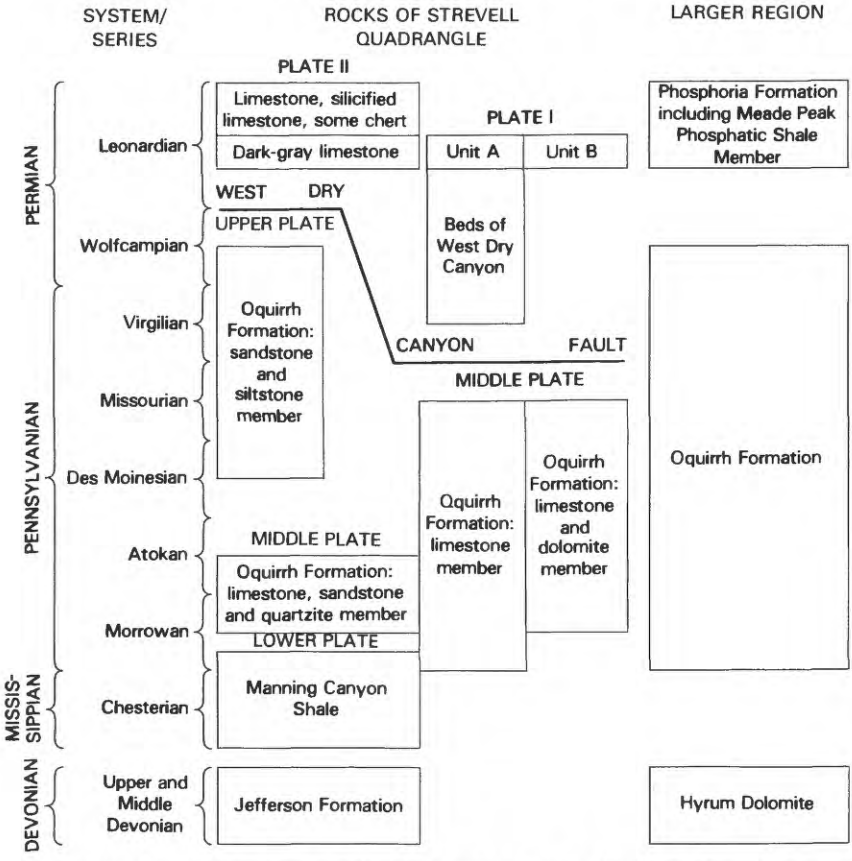


FIGURE 3.—Correlation chart of Paleozoic rock units in the Black Pine Mountains (Strevell quadrangle), Idaho. Some probably correlative formations in the region are also shown. Upper, middle, and lower plates are general structural units south of the West Dry Canyon fault. Plates I and II are north of this fault.

The nature of the contact on the metamorphic rocks is unknown, but it probably is a fault.

North of the fault across the range (West Dry Canyon fault), the rocks are in two plates (I and II) and are mostly younger than rocks south of the fault. However, the oldest unit north is partly an age equivalent of the youngest one south but largely differs from it lithologically. Plate I consists of an Upper Pennsylvanian and Lower Permian sequence of sandstone in the lowest part grading up into calcareous siltstone, silty limestone, and limestone, which is overlain apparently conformably by the Lower Permian unit A. Plate II, the upper one, contains a Lower Permian dark-gray limestone unit equivalent in age to unit A. This limestone is overlain by a thin unit of mostly limestone and silicified limestone of probable Early Permian

age, although its age is uncertain because it is the only rock unit in the area from which no fossils were recovered.

Recognition of the ages and rock types in the Black Pine Mountains would add more to the understanding of the regional Paleozoic facies relations if the geographic positions of deposition of these units were known. All formations south of the West Dry Canyon fault have moved an unknown distance in an uncertain, but probably generally eastward, direction on the low-angle faults. Juxtaposition of somewhat different facies in part of the rock units on each side of the West Dry Canyon fault suggests that one or the other or both facies were moved long distances into their present positions. On the other hand, if this area is one of rapid facies change from one facies to the other, no great lateral displacement would have been required to juxtapose them.

For assistance in the field I appreciate the work done by Stephen Thompson in 1974, Clyde L. Yancey and Gary Citron in 1975, B. T. Brady in 1976, and James N. Surabian in 1977. My thanks also go to several paleontologists, identified at appropriate places in the text, for their studies of our fossil collections, and particularly to Raymond C. Douglass and Bruce R. Wardlaw, each of whom reported on more than 20 collections. Their age determinations are essential to the stratigraphic and general geologic interpretations. Identifications of conodonts are accompanied by a CAI (color alteration index) value that indicates the postdepositional temperature reached by the host rock, as established by Epstein, Epstein, and Harris (1977).

The localities of the fossils recorded in this report are shown by the number on the geologic map of the Strevell quadrangle (Smith, 1982), to which reference should be made for information on outcrop areas and detailed structural interpretations as well as fossil localities.

Few previous geologic studies have been made in the Black Pine Mountains. Anderson (1931) reported on a reconnaissance examination of eastern Cassia County, and brief mention of rock units in these mountains has appeared in field trip guidebooks. French (1975) examined the southeastern part of the mountains for a thesis at Utah State University. Several references to the Black Pine mining district that do not contribute data on the stratigraphy of the area are not listed in the references cited.

STRATIGRAPHY

In the following discussions, the rock descriptions are presented in the measured stratigraphic sections for those units well enough exposed for good measured sections. Stratigraphic sections were not

measured of four of the mapped units and part of a fifth, so only brief narrative descriptions are presented for them. The three structural plates south of the West Dry Canyon fault include units from the base up in stratigraphic order, and the two plates north of the fault fit in general stratigraphic sequence above those to the south.

ROCKS SOUTH OF WEST DRY CANYON FAULT

LOWER PLATE

DEVONIAN SYSTEM

JEFFERSON FORMATION

The Jefferson Formation is composed principally of light-gray to almost white dolomite and also contains about 25 percent gray limestone and 8 to 10 percent sandstone and quartzite. The total area of exposure of these rocks in the Black Pine Mountains is slightly more than 0.5 km^2. Faults bound the formation on all sides, and so the measured thickness of 276 m must be a minimum.

Distorted forms of the corals *Cladopora*?, *Thamnopora*? sp., and *Tabulophyllum*? sp. (USGS 9696–SD; loc. No. 1 on geologic map (Smith, 1982)) establish the age of this formation as Devonian according to W. A. Oliver, who reported (written commun., 1976) that *Tabulophyllum*? suggests a Middle or Late Devonian age with Frasnian (early Late Devonian) being most likely. Two other collections contained *Amphipora* sp. (USGS 9535–SD; loc. No. 2 on geologic map (Smith, 1982)) and *Aulopora*? sp., *Thamnopora* sp., and cf. *Ceratophyllum* sp. (USGS 9536–SD; loc. No. 3 on geologic map (Smith, 1982)). These were reported by Oliver (written commun., 1975) to suggest a Middle Devonian age.

SECTION B.—*Jefferson Formation*

[Measured in secs. 32 and 33, T. 15 S., R. 29 E.; location on fig. 1]

	Meters
Pennsylvanian and Mississippian Systems.	
Manning Canyon Shale.	
Thrust fault.	
Devonian System:	
Jefferson Formation:	
Limestone, gray and almost white, gray-weathering; sugary texture of fine to medium-size grains; alternating gray and white beds commonly a few millimeters to as much as 20 cm thick; prominent 10-m-thick unit at base. Sparse layers as much as 4 mm thick of sandy limestone with angular, medium-size quartz grains occur particularly near the base	36

	Meters
Devonian System—Continued:	
Jefferson Formation—Continued:	
Quartzite, gray, gray-weathering; lenticular	10
Dolomite and limestone, gray, gray-weathering, banded; some beds as much as 50 cm thick	27
Sandstone, gray, brownish-gray-weathering, fine-grained, calcareous; mostly angular grains of quartz	12
Rubble-covered slope; appears to be mostly light gray to almost white dolomite with some sandstone and light- and dark-banded sugary limestone	34
Dolomite, light gray to almost white, very light gray weathering; bedding indistinct except for float of banded rock on slope in upper part. Checkered weathered surfaces in places. Some blocks of gray, brown-weathering calcareous sandstone are on slope about 30 m above base of unit	44
Dolomite and limestone, light- and dark-gray; much is thin bedded in layers commonly 1–3 mm and as much as about 12 cm thick. Limestone, some sugary, ranges from dark gray to almost white; gradations between dolomite and limestone. White calcite occurs in wiggly seams and podlike forms as much as 2 cm long and ¼ cm thick. Beds form prominent light and dark bands in places; individual bands are as much as 40 cm thick. Prominent outcrops. Distorted corals from collection USGS 9696–SD about 22 m above base	41
Dolomite, dark-gray, light-gray to dark-gray-weathering, dense; beds commonly 1 mm to 20 cm thick; bedding very indistinct in places on weathered surfaces as light and dark banding. White calcite veinlets and pods 1 cm across occur locally. Upward, some beds are more massive and appear to be as much as 1 m thick; checkered weathered surfaces. Coral *Amphipora* in float in upper part	72
Total Jefferson Formation in Black Pine Mountains area	276
Fault.	
Pennsylvanian and Mississippian Systems.	
Manning Canyon Shale.	

MISSISSIPPIAN AND PENNSYLVANIAN SYSTEMS

MANNING CANYON SHALE

The Manning Canyon Shale in these mountains consists principally of dark-gray to black siltstone that has been metamorphosed to argillite over most of the area of exposure. Black shale crops out in a few localities. The argillite has distinct slaty cleavage and bedding is obscure in many places. Locally, however, the bedding is quite distinct; some small-scale crossbeds and scour-and-fill structures a few millimeters deep occur very locally. Ripple marks with wave lengths of 4–5 cm were noted in a few localities. Quartz is the chief constituent of the argillite, which also contains micaceous minerals that produce a glitter on rock surfaces in places. Cubic cavities and forms of limonite after pyrite are abundant locally.

In a study of the metamorphism of the Manning Canyon and Chainman Shales, Christensen (1975, p. 121) determined by X-ray diffraction, infrared absorption, and petrographic examination that the Manning Canyon argillite in the Black Pine Mountains contains quartz, illite, chlorite, paragonite, paragonite/phengite, andalusite, chloritoid, pyrite, hematite, magnetite, and carbonaceous matter. These minerals are listed here without regard to their quantity or origin, whether detrital or authigenic. Christensen further stated (1975, p. 111) that these rocks were altered by dynamothermal metamorphism and that the temperatures "exceeded 350°C, based on appearance of chloritoid, but were less than 450°, the breakdown temperature of phengite." In this regard, Anita G. Harris reported (oral commun., 1977) that the color alteration index on conodonts from this formation indicates that the host rock reached a temperature of between 300°C and 400°C.

Quartzite and limestone lenses make up a relatively small part of the Manning Canyon; the quartzite forms prominent outcrops. The largest quartzite lens has a maximum thickness of about 20 m and exposed length of about 2 km with one end at a fault. This lens is a gray-, tan-, brown-, and gray-weathering orthoquartzite with scattered 4–5-mm-diameter grains, many of which are well rounded, in a matrix of angular grains of silt and very fine grained sand. Even beds, commonly 1–15 mm thick, occur prominently in this lens. Some quartzite that is dark gray to almost black does not crop out prominently, but must be lenticular also. It is made of medium, commonly well rounded quartz grains scattered through angular, very fine quartz grains; stringers and patches of black siliceous material give the rock its color. One lens a few meters long consists of rounded and oval-shaped pebbles of light-gray quartzite composed of medium quartz grains and of smooth angular pebbles of black quartzite composed of silt-size grains.

Only three limestone lenses were found in this formation, and they appear to be short and thin; poor exposures preclude any positive determinations of their sizes or shapes, and other similar lenses may be present. One lens is light gray; the others are dark gray to black and weather tannish gray. They consist of very fine grained, dense carbonate rocks containing widely scattered, angular, fine quartz grains.

No thickness of the Manning Canyon Shale has been measured in these mountains because of obvious internal structural complexities and the lack of a key bed or beds that could be traced far enough to determine the structure and stratigraphic sequence of the formation. About 2,000 m is a reasonable estimate of the exposed thickness. Contacts with other stratigraphic units are faults.

The Manning Canyon Shale in the region is Upper Mississippian

and Lower Pennsylvanian (Trimble and Carr, 1976, p. 29). From the Black Pine Mountains a conodont collection (USGS 26140–PC; loc. No. 7 on geologic map (Smith, 1982)) was reported by Anita G. Harris (written commun., 1975) to have a range of uppermost Mississippian (uppermost Chesterian) through Lower Permian based on three poorly preserved elements, including one platform fragment of *Adetognathus*? sp. The color alteration index is 5, indicating that the host rock reached a temperature of 300° to 400°C. Pectinoid clams cf. *Aviculopecten* identified by B. R. Wardlaw (written commun., 1978) were found on bedding surfaces of argillite at one locality (Field No. F–17, loc. No. 8 on geologic map (Smith, 1982)). The age of the Manning Canyon Shale in these mountains is presumed to be latest Mississippian (latest Chesterian) to Early Pennsylvanian.

MIDDLE PLATE

PENNSYLVANIAN SYSTEM

OQUIRRH FORMATION, LIMESTONE MEMBER

This member of chiefly limestone and silty and sandy limestone is composed of three parts: a lower part consisting of sandy and silty limestone, which is very fossiliferous in places, and of some sandstone, quartzite, and shale; a middle one of limestone, some dolomite, and less silty and sandy limestone; and an upper one of mostly silty limestone. Contacts between the parts of this member are gradational through thicknesses of several meters or even tens of meters, and the separate parts are not satisfactory mappable units. In places along the west side of the mountains, it is difficult to determine whether the exposures represent the middle or upper part. A minimum thickness of about 2,300 m is partly measured in the field and partly estimated from the geologic map (Smith, 1982).

The Pennsylvanian age of the limestone member of the Oquirrh is established particularly from 12 fossil collections containing conodonts studied by B. R. Wardlaw (except where noted) and 2 collections containing fusulinids studied by Raymond C. Douglass.

LOWER PART

The lower part of the limestone member of the Oquirrh Formation is more heterogeneous than either of the other two parts. It consists of silty and sandy limestone, sandstone and quartzite, some shale, and many limy beds containing fossils or fossil hash. Abrupt changes in bedding attitudes and poor exposures in some areas make accurate

thickness measurements essentially impossible. A minimum thickness of 450 m is estimated from the geologic map (Smith, 1982) and from ground observations.

Silty and sandy limestones are mostly shades of gray and tan and some shades of pink and brown. They weather from light gray to dark gray and bluish gray, and to tan, reddish tan, brown, and some pink tints. Although a very few limestone beds are fairly pure, most contain silt- and sand-size grains and range from silty and sandy limestone to calcareous sandstone and siltstone. Quite commonly, bedding in the limestone is as thin as a few millimeters and ranges from a few millimeters to about 15 cm, but it is not distinct everywhere. In places, the slopes are covered with platy fragments of thin-bedded units. Massive beds crop out locally but are much less common than in the middle and upper parts of the member. Small-scale crossbeds and scours a few centimeters deep were noted in a very few places in the sandy limestone.

Sandstone, calcareous sandstone, and quartzitic sandstone make up much less of the lower part of the limestone unit than do the limestones, but they are important in the recognition of this part. The sandstone is gray and tan, weathers the same colors, and is composed almost entirely of angular to well-rounded quartz grains that range from fine to coarse sizes and are poorly to fairly well sorted. Ferruginous stains speckle some beds. Bedding ranges from very thin to thick and is indistinct in some units. Regular layers of light and dark grains form prominent bands from 3 to about 15 mm thick in local units. Planar crossbeds in layers 25–50 cm thick form a 4-m-thick exposure at one locality.

Gray and light-purple calcareous siltstone and black shale are interbedded locally with the limestone and sandstone.

Units in this lower part are very fossiliferous in places. The fossils are commonly broken, and beds of fossil hash consist of fragments of bryozoans, brachiopod shells and spines, and crinoid columnals. Corals occur locally, and one bed of colonial corals can be traced a few meters around the axis of an overturned anticline. Worm borings 6–12 mm across and several centimeters long were observed covering a bedding surface at one locality.

Conodont collections, studied by B. R. Wardlaw (written commun., 1977 and 1978), from the lower fossiliferous part of the limestone member indicate a Lower Pennsylvanian (lower Morrowan) position and include the following (numbered localities appear on geologic map (Smith, 1982)): USGS 25535–PC, loc. No. 9, *Rhachistognathus* cf. *R. muricatus* (Dunn), probably Lower Pennsylvanian (Morrowan), CAI 5 (300°–400°C); USGS D30–PC, loc. No. 10, *Adetognathus gigantus* (Gunnell), Lower Pennsylvanian (Morrowan), CAI 5 (300°–400°C);

USGS 26116–PC, loc. No. 11, *Adetognathus* sp. and *Rhachistognathus muricatus* (Dunn), Lower Pennsylvanian (Morrowan), CAI 5 (300°–400°C); USGS D57–PC, loc. No. 12, *Adetognathus gigantus* (Gunnell), *Rhachistognathus muricatus* (Dunn), and *Spathognathodus*?, Lower Pennsylvanian (probably lowermost Morrowan), CAI 5 (300°–400°C); field No. F–108, loc. No. 13, *Adetognathus spathus* (Dunn), bar and blade fragment, Lower Pennsylvanian (Morrowan), CAI 5 (300°–400°C). According to Wardlaw, *Rhachistognathus muricatus* is diagnostic of latest Chesterian (Mississippian) and earliest Morrowan (Pennsylvanian) age rocks, whereas *Adetognathus* is rare in latest Chesterian and common in the Morrowan, and its occurrence with *Rhachistognathus* in the same sample indicates a position very close to the Mississippian-Pennsylvanian boundary, probably lowermost Morrowan.

Several collections of bryozoans were examined by O. L. Karklins (written commun., 1974 and 1976), who identified *Rhabdomeson* sp. indet., *Ascopora*?, and *Rhombopora*? sp. but found that replacement by silica had obliterated the significant skeletal structures and made specific identification impossible. He did, though, state that the forms were late Paleozoic and typical Carboniferous-Permian genera. Corals reported by W. J. Sando (written commun., 1974 and 1975) are *Heintzella*? (USGS 26116–PC, loc. No. 11 (Smith, 1982), and USGS 25538–PC, loc. No. 14 (Smith, 1982)), and *Amplexus* (USGS 26117-PC, loc. No. 15 (Smith, 1982)). This last sample also contained conodonts *Bispathodus* cf. *B. aculeatus* (Branson and Mehl), *Gnathodus*?, and unidentified bar fragments (B. R. Wardlaw, written commun., 1977). The *Bispathodus* has a narrow range from uppermost Upper Devonian to Lower Mississippian (Kinderhookian), but the conodont elements appear to be abraded, and they must be detrital in these Pennsylvanian rocks. Brachiopods (table 1) collected at several localities are mostly poorly preserved and are commonly present as scrappy bits, according to B. R. Wardlaw.

Middle Part

The middle part of the limestone member consists principally of gray limestone, which characteristically forms more massive beds than are found in the lower and upper parts. These massive units make bold outcrops in many areas, and they also weather locally to produce slopes covered with platy or chunky pieces. Silty or slightly sandy beds are present but are much less abundant than in the upper and lower parts. Very widely scattered, small chert nodules are found chiefly as loose fragments. This middle part contains few megascopic fossils. A thickness of 450 m is estimated from the geologic map (Smith, 1982) and from other field data.

TABLE 1.—*Brachiopods collected from the lower part of the limestone member of the Oquirrh Formation*

[Identifications by B. R. Wardlaw, 1977 and 1978; leaders (--), not present]

Locality no. on geologic map (Smith, 1982)	9	14	16	17	18	19	13	20	21
USGS fossil collection no.	25535 PC	35536 PC		25541 PC					
Field collection no.	F-1	F-13	F-15	F-18 and F-30	F-19	F-33	F-108	F-112	F-113
Anthracospirifer sp.	x	x	x	--	x	--	x	--	--
Anthracospirifer?	--	--	--	--	--	x	--	x	--
Antiquatonia	x	--	--	--	--	--	--	--	x
Antiquatonia	--	x	--	x	--	--	x	x	--
Buxtonia?	--	--	--	--	x	--	--	--	--
Cancrinella sp.	--	--	--	x	--	--	--	--	--
Choristites sp.	x	--	--	--	--	x	--	--	--
Cleiothyridina sp.	--	x	--	--	--	x	--	--	--
Composita subtilita (Hall)	x	--	--	x	--	--	--	--	--
Composita sp.	--	x	--	x	--	--	x	--	x
Crenispirifer sp.	--	--	--	--	--	x	--	--	--
Derbyia sp.	x	--	--	x	--	--	--	--	x
Derbtua?	--	--	--	--	--	--	--	x	--
Dielasma sp.	x	--	--	--	--	--	--	--	--
Heteralosia?	--	--	--	x	--	--	--	--	--
Hustedia sp.	--	--	--	x	--	x	--	--	--
Kutorginella?	--	--	--	x	--	--	--	--	--
Linoproductus sp.	--	--	--	--	--	x	--	x	x
Lissochonetes sp.	--	x	--	--	--	--	--	--	--
Neospirifer sp.	x	--	x	--	--	--	--	--	--
Punctospirifer sp.	--	--	x	x	x	--	--	--	--
Punctospirifer?	--	--	--	--	--	--	--	x	--
Reticularina sp.	x	--	--	--	x	--	--	--	--
Rhipidomella cf. *R. nevadensis*	--	--	x	--	--	--	--	--	--
Stenoscisma sp.	--	--	--	--	--	x	--	--	--
Echinoconchid	--	x	--	--	--	--	--	--	--
Spiriferoid	--	--	--	x	--	--	--	--	--
Large spiriferoid cf. *Neospirifer*	--	--	--	x	--	--	--	--	--

The limestone in the middle part is light to dark gray and weathers to shades of gray. It is most commonly dense but is finely crystalline in places. Bedding is completely or almost completely obscured in many massive outcrops, which may weather to form large rounded surfaces or ledgy slopes. Single massive units in places attain thicknesses of as much as about 12 m. Well-developed, regular beds from 15 to 30 cm thick occur in places, and laminated sequences of slightly sandy or silty limestone beds a few millimeters thick crop out prominently in some areas. A black, shaly and platy, carbonaceous limestone was observed only in one exposure about 30 m thick and 0.4 km long in the bottom of Formation Canyon.

Dolomite constitutes possibly no more than 10 percent of the middle part of the limestone member but is prominent in some areas. It is dense or medium to fine crystalline, gray and very dark gray, and weathers light to very dark gray; it commonly presents a finely checkered surface. The dolomite occurs as irregular blobs in the limestone and as beds as much as 4 m thick.

Over much of the southern part of the Black Pine Mountains, the limestone has been much fractured and is laced with seams of calcite, commonly 3–5 cm and as much as 25 cm apart. In places the rock is also brecciated and recrystallized.

The middle part of the limestone member of the Oquirrh Formation is Middle Pennsylvanian, because one conodont collection from it is no older than Middle Pennsylvanian and it is overlain by the Middle Pennsylvanian silty limestone forming the upper part of the member. Conodont collection numbers and identified and dated forms (B. R. Wardlaw, written commun., 1977; except as noted) follow: field No. F–52, loc. No. 22, on geologic map (Smith, 1982), *Adetognathus* sp. and *Idiognathodus* cf. *I. delicatus* Gunnell, Pennsylvanian (upper Morrowan to lower Virgilian), CAI 5 (300°–400°C); USGS D29–PC, loc. No. 23 (Smith, 1982), *Streptognathodus* cf. *S. oppletus* Ellison and *Ozarkodina* sp., Middle to Upper Pennsylvanian (probably lower Des Moinesian to Missourian), CAI 6 (400°–500°C); USGS 27018–PC, loc. No. 24 (Smith, 1982), one poorly preserved *Idiognathodus* sp., Lower Pennsylvanian (Morrowan) to Lower Permian (Wolfcampian), CAI about 5 (at least 300°C) (John Repetski, written commun., 1977); and field No. F–74, loc. No. 25 (Smith, 1982), one small encrusted, slightly broken specimen of *Neognathodus*?, probably Pennsylvanian, CAI (300°–400°C).

Upper Part

Silty limestone forms the characteristic lithology of the upper part of the limestone member of the Oquirrh Formation, and, commonly, platy fragments of silty limestone cover the slopes. However, more nonsilty beds occur than are indicated by the measured stratigraphic section. Massive limestone crops out locally to make prominent exposures, but laterally these massive beds pass into areas covered with the platy fragments. Pieces of black chert are sparse and widely scattered. In the southwestern part of the mountains, tan-weathering, calcareous and noncalcareous sandstone and siltstone compose a 400-m-thick zone of lenticular rock units in the lower half of this upper part. These tan units appear to interfinger with and probably grade northward into silty gray limestone. Gray, tan, and pink siltstone, some of which is calcareous, and less claystone also occur with the silty limestones. The thickness of 1,360 m measured for this upper part is a minimum figure because the top is covered with gravel at the mountains' edge.

The silty limestone upper part of the limestone member of the Oquirrh is also Middle Pennsylvanian. Fusulinid collection USGS f13813 (loc. No. 26 on geologic map (Smith, 1982)) contained Middle Pennsylvanian (probably upper Atokan) *Fusulinella* sp. and collection

USGS f13814 (loc. No. 27 (Smith, 1982)) also contained Middle Pennsylvanian *Fusulinella* (R. C. Douglass, written commun., 1977). Conodonts compatible with the Middle Pennsylvanian designation from collection USGS D56–PC (loc. No. 28 (Smith, 1982)) are *Adetognathus* and *Neognathodus* cf. *N. medadultimus* Merrill, Morrowan to lower Des Moinesian, CAI 4.5–5 (240°–400°C) (B. R. Wardlaw, written commun., 1977) and from collection USGS 27019–PC (loc. No. 29 (Smith, 1982)), *Idiognathodus* cf. *I. delicatus* Gunnell, *Neognathodus* cf. *N. bothrops* Merrill, Al (hindeodelliform) element, and O (ozarkodiniform) element, Morrowan through Des Moinesian, CAI 5–5.5 (300°+C) (John Repetski, written commun., 1977). Corals identified by W. J. Sando (written commun., 1975 and 1977) are *Caninia* sp. and *Multithecopora* sp. from collection USGS 26848–PC (loc. No. 30 (Smith, 1982)), and *Caninia* sp. from collections USGS 26115–PC (loc. No. 31 (Smith, 1982)) and USGS 26849–PC (loc. No. 32 (Smith, 1982)). One collection (USGS 26218–PC; loc. No. 33 (Smith, 1982)) is reported by Mackenzie Gordon, Jr. (written commun., 1976) to contain the brachiopod *Juresania nebrascensis* (Owen)?, the pelecypod *Phestia* sp., the gastropod *Euconospira*? sp. indet., and ammonoids *Metacoceras* sp., *Metacoceras* (*Huanghoceras*)? sp. indet., and a schistoceratid form, gen. and sp. indet. According to Gordon the early whorls in the schistoceratid appear to be triangularly coiled and thus typical of forms in Middle Pennsylvanian rocks. Two collections of poorly preserved bryozoans have the general appearance of upper Paleozoic forms (O. L. Karklins, written commun., 1975 and 1976).

SECTION C.—*Upper part of the limestone member of the Oquirrh Formation*

[Measured in secs. 22, 23, and 14, T. 16 S., R. 28 E.; location on fig. 1]

	Meters
Quaternary System.	
Gravel.	
Pennsylvanian System:	
Oquirrh Formation, limestone member:	
Upper part:	
Limestone, gray, gray-weathering, dense, silty; quartz silt grains stand out on weathered surface; scattered outcrops, but mostly covered with pieces 2–5 cm across; some pieces tinted red or tan. Layers of more silty limestone as much as 40 cm thick in lower part; siltier layers weather grayish tan. Silty layers 5–8 cm thick mark bedding in gray limestone in upper 2 m . .	270
Limestone, gray, gray-weathering, silty; in a few places, medium-sized angular quartz grains are scattered through the rock; platy pieces 0.5–1 cm thick; thin-bedded very silty limestone is in layers as much as 40 cm thick; tan and lighter gray pieces more abundant on slope near base	207

	Meters
Pensylvanian System—Continued	
Oquirrh Formation, limestone member—Continued	
Upper part—Continued	
Limestone, gray, silty and sandy; scattered outcrops; bedding commonly indistinct. Fusulinid collection USGS f13813 (loc. No. 26 on geologic map (Smith, 1982)) from about 40 m above the base, contains *Fusulinella* sp. In the upper 4 m the limestone is less silty and contains scattered fine- to medium-sized rounded grains of quartz; also contains bryozoans and sparse crinoid columnals .	240
Limestone, gray, gray-weathering, silty; scattered bryozoans . .	26
Siltstone and fine-grained sandstone, light-gray to tan; weather tan with brecciated-appearing surfaces in places; gray silty limestone makes up less than 1 percent of the unit	144
Sandstone and siltstone, calcareous, tan; less silty limestone. Varying strikes and some vertical dips make the measured thickness uncertain	265
Limestone, gray, gray-weathering; silty, except some near top; slopes covered with platy pieces	50
Limestone, gray; weathers gray and tan in part; silty, although some contains only a very few silt grains; both chunky and platy pieces on slope; many bryozoans in lower part	158
Total, upper part of limestone member of Oquirrh Formation	1,360

NOTE.—Gradational contact from more to less silty limestone.

Oquirrh Formation, limestone member:

Middle part.

OQUIRRH FORMATION, LIMESTONE, SANDSTONE, AND QUARTZITE MEMBER

This member consists principally of limestone, which characteristically is silty or sandy in various degrees, and contains sandstone and quartzite in lenticular units within a zone perhaps no more than 40 m thick. A straightforward sequence of the member is not determinable, because bedding attitudes are too variable within a few meters or a few tens of meters to make a reliable stratigraphic reconstruction possible. For the same reason, a thickness is not determinable. The apparent base is overlain by gravel, which covers a normal fault, and the top is a thrust fault. So, the following description is generalized and is not presented as a stratigraphic sequence. The exposed thickness is estimated to be 180 m.

Much of the limestone is light gray and weathers to form light-tannish-gray, platy pieces, many of which are 6–12 mm thick. Bryozoans are abundant in some beds. Some sandy limestone units are made of fine to coarse, well-rounded quartz grains in a gray limestone matrix without visible bedding; weathered fragments on the slopes, however, indicate that the bedding is probably thin. A characteristic lithologic type is very sandy, gray limestone in which the sand grains form layers 1.5–6 mm thick that weather brown. These layers show

small-scale, wavy bedding, scours as much as 12 mm across, small-scale crossbedding, anastamosing or irregular patterns, and some ripple bedding. Fine to medium, mostly well rounded quartz grains make up the sand in these beds. Locally, brown-weathering, nodular-appearing spots 2–8 cm across occur on the gray-weathering limestone surfaces.

Lenticular bodies of grayish-brown calcareous sandstone that weather light brown and consist of fine to coarse quartz grains form some prominent outcrops. Other bodies are tannish-gray calcareous sandstone, quartzitic sandstone, and quartzite composed of silt- and sand-sized grains, which are well rounded and well sorted in some layers but not in others. Oscillation ripple marks with wavelengths of about 5 cm are prominent in a few places.

The Pennsylvanian age of this member is established on three conodont collections. An Early Pennsylvanian (Morrowan) or Morrowan to early Atokan (early Middle Pennsylvania) age seems to be indicated. Conodont collections, their contained forms and ages as reported by John Repetski and Anita G. Harris (written commun., 1979), and map locations follow: USGS 26154–PC, loc. No. 4 on geologic map (Smith, 1982), *Declinognathodus* sp., CAI 6 (more than 350°C), Pennsylvanian (Morrowan to early Atokan); USGS 27016–PC, loc. No. 5 (Smith, 1982), *Adetognathus* sp., CAI 5–5.5 (more than 300°C), Pennsylvanian to Early Permian; and USGS 27017, loc. No. 6 (Smith, 1982), *Declinognathodus* sp. and *Adetognathus* spp., CAI 5–5.5 (more than 300°C), Pennsylvanian (probably Morrowan). *Declinognathodus* Dunn (included within *Idiognathoides*, *Streptognathodus*, or *Gnathodus* by various authors) ranges from at or near the base of the Morrowan into the Atokan.

This limestone, sandstone, and quartzite member is an age equivalent of part of the lower part of the limestone member and also part of the limestone and dolomite member of the Oquirrh Formation. It is somewhat similar to the lower part of the limestone member in that it contains sandstone and silty and sandy limestone, but shale and prominent fossil-hash beds like those in the limestone member were not noted in it and the general lithologic appearance of the two members differs. The limestone, sandstone, and quartzite member is different from the limestone and dolomite member, which it underlies at a low- angle fault contact.

OQUIRRH FORMATION, LIMESTONE AND DOLOMITE MEMBER

The limestone and dolomite member of the Oquirrh Formation is composed of gray limestone and light- and dark-gray to black dolomite, both of which commonly weather with a checkered surface. Beds crop

out on slopes with some ledges and, in places, cliffs. Limestone is the dominant exposed rock type in the lower and upper parts; dolomite is predominant in the middle part. A characteristic lithologic type, particularly in the uppermost part, consists in many places of white, sugary-textured calcite surrounding blocks of dolomite. The calcite commonly retains the original bedding of the rock, and small tight folds are locally common. Relatively short lenticular bodies of ferruginous quartzite were observed at two localities. One body is poorly exposed over a maximum length of about 150 m; the other appears to be even shorter and is ovate in cross section. Faults bound this member, and the measured thickness of 430 m is thus a minimum.

The limestone and dolomite member resembles the middle part of the limestone member of the Oquirrh but contains much more dolomite. Massive limestone in the two units is very much alike, and the dolomites are alike also but are generally much thicker in the limestone and dolomite member. According to B. R. Wardlaw (oral commun., 1978), conodont collections indicate that the lowest part of the limestone member of the Oquirrh is older than the limestone and dolomite member. The limestone and dolomite member must be at least partly the same age as the middle part of the limestone member, to which it is similar lithologically, and it may be equivalent to much of the limestone member.

A Pennsylvanian age for this member is established on two conodont collections studied by B. R. Wardlaw (written commun., 1977). Collection USGS D54–PC, loc. No. 34 on geologic map (Smith, 1982), from the topographically lower part of the member, contains *Adetognathus lautus* Gunnell, *Anchignathodus minutus* (Ellison), *Idiognathodus* cf. *I. delicatus* Gunnell, and *Xaniognathus* sp. and is Lower to Upper Pennsylvanian (upper Morrowan to Missourian), CAI 6.5 (more than 450°C). Collection USGS D55–PC, loc. No. 35 (Smith, 1982), from the topographically higher part of the formation, contains *Adetognathus lautus* Gunnell, *Idiognathodus* cf. *I. delicatus* Gunnell, *Idiognathoides* cf. *I. macer* (Wirth) and is Lower Pennsylvanian, CAI 5.5 (350°–450°C). According to Wardlaw, the occurrence of the large-platform type of *Idiognathodus* with this type of *Idiognathoides* identifies the containing beds as middle Morrowan and indicates that they are older than those containing the first and topographically lower collection (USGS D54–PC). This suggests that the member may be overturned or that it may be faulted. No indication of either structural possibility was recognized on the hill where the fossils were collected and the stratigraphic section was measured, although a low-angle fault does repeat part of the member on the next ridge to the north. Structural relations to other rock units suggest that this unit as a whole is right side up and it is considered to be so in this report, but with

the understanding that it may be overturned or that repetition of beds by unrecognized faults may have occurred. In either position, the general sequence of mostly dolomite in the middle part and mostly limestone in the lower and upper parts is the same.

SECTION A.—*Limestone and dolomite member of the Oquirrh Formation*

[Measured in the south part of sec. 34, T. 15 S., R. 28 E.; location on fig. 1]

	Meters
Pennsylvanian System:	
Oquirrh Formation, limestone member.	
Low-angle fault.	
Oquirrh Formation, limestone and dolomite member:	
Limestone, gray; some in massive units; irregular masses of very dark gray dolomite as much as 0.6 m across. Unit is mostly limestone; a layer of dark-gray dolomite 1 m thick is about 3 m below the top .	35
Limestone, much light-salmon-colored, and light-gray, massive; calcite, but less than in unit below	29
Limestone, light-gray, light-gray-weathering, finely crystalline; some very pale salmon, fine-grained limestone; much coarse breccia with angular pieces of gray limestone as much as 1 m long in a white calcite matrix	35
Limestone, light-gray, light-gray-weathering; dense as well as some very fine, sugary texture; in massive units as much as 6 m thick; calcite seamed. Some dolomite in irregular round clumps in limestone; dolomite is light gray and weathers same color, but is slightly darker than limestone; many dark-gray dolomite pieces are on slope upward from 50 m above base, and a 1-m-thick dolomite bed crops out near top; much rubble cover over upper part	80
Dolomite, light- and dark-gray, light-gray- to very dark gray weathering, massive; many loose blocks on slope. Limestone makes up about 5 percent of this unit. Across valley to north, dolomite, much of which is very dark, forms bluffs about 20 m high	41
Dolomite and limestone, both gray; dolomite is predominant; some very dark gray, very finely crystalline dolomite weathering very dark gray. Thin calcite veinlets cut the dolomite	25
Limestone, gray, gray- to light-gray-weathering, mostly dense; and gray dense dolomite weathering light gray; limestone predominant and in massive units, bedding obscure. A little limestone is slightly silty; brown-weathering, irregular knobby bands of limestone about 2–15 cm wide occur in places. Dolomite appears to be in units as much as 5 m thick. Percentage of dolomite increases upward in upper 25 m. In places in upper part, white crystalline calcite has replaced dolomite and surrounds blocks of dolomite commonly as much as 3 m across	127
Limestone, gray, light-gray- to dark-gray-weathering, mostly dense; some light-gray, fine-grained sugary limestone. Many calcite veinlets trending in all directions; also veins 0.3 m wide and irregular calcite clumps 0.6 m across and 0.5–1 m long; coarsely crystalline calcite in veins as much as 0.6 m thick	58
Total exposed thickness of limestone and dolomite member	430

NOTE.—Base of limestone and dolomite member not exposed; covered with gravel; a normal fault is concealed by the gravel.

UPPER PLATE

PENNSYLVANIAN AND PERMIAN SYSTEMS

OQUIRRH FORMATION, SANDSTONE AND SILTSTONE MEMBER

The sandstone and siltstone member of the Oquirrh Formation in the Black Pine Mountains consists principally of light-gray, medium-light-gray, and light-yellowish-gray, poorly sorted calcareous quartz siltstone and sandstone, which weather tan and brown. Sparse beds of light-gray and pink calcareous sandstone weather to form light-pink plates 6–12 mm thick and 7–10 cm across on some slopes. A few beds are noncalcareous and some are quartzitic. A much lesser percentage of the member consists of gray and dark-gray silty limestone that weathers gray. The limestone layers 0.3–0.6 m thick are scattered through the tan siltstone and sandstone, in units interlayered with calcareous siltstone and sandstone through several tens of meters, and in sections of mostly silty limestone a few meters thick; silty limestone also makes up most of the lowest part of the member. Exposures of the sandstone and siltstone member are good locally but are poor over extensive areas. In many places, bedding shows most clearly in the more calcareous gray beds where layers 1 mm to 30 cm thick are common. Some of the tan siltstones and sandstones are in beds as much as 30 cm thick but also occur in massive units with no obvious bedding and in outcrops that are entirely breccia. These breccias make prominent exposures in many parts of the area.

As well as being interlayered, the siltstones and sandstones and gray silty limestone must grade into and interfinger with one another, although exposures are generally too poor to permit observance of such relations. Along the west canyon wall of the largest tributary on the north side of Kelsaw Canyon, about 180 m of almost entirely tan weathering siltstone and sandstone appear to interfinger across about a 1-km-long rubbly slope into an interlayered sequence of tan-weathering rocks and gray silty limestone. The tan- and brown-weathering beds contain angular quartz grains of very fine sand and silt, scattered large quartz grains mostly of medium and less commonly of coarse sand sizes, and various percentages of calcite cement. The larger grains commonly are rounded and have etched or sutured margins.

The gray silty limestone beds also contain scattered fine to medium quartz grains in some layers and very sparse coarse grains. These limestones are fusulinid bearing in many places.

Conglomerate was noted at three places and probably occurs at others, but it certainly equals only a trace of the total thickness of the sandstone and siltstone member. One distinctive conglomerate bed (in NW¼ sec. 26, T. 15 S., R. 29 E.) in the lower part of the member

is composed of closely packed chert pebbles, mostly light gray with some dark gray and pink. They are set in a slightly calcareous matrix containing chert and quartz grains. The rock weathers gray and pink. Most pebbles are angular; a few are rounded; the largest pebble noted is 1 cm across. The other two conglomerates occur in the middle part of the member, as established by ages of fusulinids. One (in NW¼ sec. 23, T. 15 S., R. 28 E.), seen only as fragments on the ground surface, is made of flat limestone pebbles commonly 3 cm across; one clast observed was 25 cm long and 10 cm thick. The other conglomerate (in NE¼ sec. 21, T. 15 S., R. 29 E.) in the middle part of the member forms a bed 0.6–0.76 m thick and of an unknown but probably short length. Rounded and flattened gray limestone pebbles that weather dark blue gray are embedded in a coarse-grained sandy limestone matrix. The longest pebble seen was 5 cm long and 6 mm thick, and the largest round pebble, 4 cm in diameter.

The oldest recognized part of the member consists chiefly of silty gray limestone at and just south of the head of West Dry Canyon. This limestone is similar to that in other parts of the member, but it is not abundantly fossiliferous and it makes a fairly continuous limestone sequence rather than being interlayered with tan siltstone and sandstone beds. This limestone constitutes essentially a different lithologic unit from the rest of the member, but the change upward into the tan sandstone and siltstone is so gradual through a broad interval in an area of generally poor exposures that the lower limestone was not mapped separately. This lowest part also contains some thin, mostly nonsilty strata. As a unit it is similar to the upper part of the limestone member of the Oquirrh Formation. The only fossils found in this oldest part of the sandstone and siltstone member are *Fusulinella* sp. and *Beedeina* sp. (USGS f13944, loc. No. 37, and USGS f14008, loc. No. 36 on geologic map (Smith, 1982)) of Middle Pennsylvanian (Des Moinesian) age (R. C. Douglass, written commun., 1977 and 1978) and poorly preserved conodonts *Adetognathus* sp., *Idiognathodus* sp., and bar fragments (Field No. 124, No. 36a (Smith, 1982)) with an age range of Early Pennsylvanian (late Morrowan) to Early Permian (late Wolfcampian), CAI 5 (300°–400°C) (B. R. Wardlaw, written commun., 1980). Thus, these strata are about the same age as the upper part of the limestone member, which may indicate that the contact between the limestone member and the sandstone and siltstone member of the Oquirrh is gradational. The two members are readily separable farther south in the Black Pine Mountains, where the contacts are faults and more contrasting rock types are against each other.

An accurately determined stratigraphic sequence for the sandstone and siltstone member of the Oquirrh has not been established, princi-

pally because exposures are poor over wide areas and key beds useful in fitting pieces together have not been recognized. However, as a result of the study of 22 collections of fusulinids (table 2) by R. C. Douglass (written commun., 1974, 1975, 1976, 1977, and 1978), a general age sequence is recognized. A fit of the lithologic types to this sequence suggests that, except for the more continuous gray silty limestone in the lowest part, there are no significant lithologic differences of different ages. The chert pebble conglomerate does occur in the lower part and the limestone pebble conglomerates somewhere near the middle, but none of these was traceable far enough to establish its use as a stratigraphic marker over any large area.

A thickness of about 2,700 m is estimated for the sandstone and siltstone member of the Oquirrh in the Black Pine Mountains. This estimate is based on bedding attitudes plotted on the the geologic map (Smith, 1982) and on the stratigraphic sequence as indicated by the fusulinid collections.

The sandstone and siltstone member of the Oquirrh Formation ranges in age from Middle Pennsylvanian (Des Moinesian) to Early Permian (early Wolfcampian). Upper Pennsylvanian Virgilian strata are widespread in the member and together with lower Wolfcampian rocks make up most of the member. One fossil collection of corals (USGS 26580–PC, loc. No. 58 on geologic map (Smith, 1982)) contained *Caninia* sp. and *Multithecopora* sp. of probable Middle or Late Pennsylvanian age (W. J. Sando, written commun., 1977) and one conodont *Idiognathodus magnificus* Stauffer and Plummer, CAI 5 (300°–400°C), of Atokan to early Virgilian age (B. R. Wardlaw, written commun., 1979). Two other conodont samples from no more than 15 m stratigraphically below this collection are included under loc. No. 58 on the map. Sample Field No. F–125A contained *Adetognathus* sp., *Idiognathodus magnificus* Stauffer and Plummer, and bar fragments of Atokan to early Virgilian age, CAI 5 (300°–400°C), and F–127 contained abraded and rounded fragments of *Adetognathus* sp. and *Idiognathodus* sp. of late Morrowan to late Wolfcampian age, CAI 5 (300°–400°C) (B. R. Wardlaw, written commun., 1980). These are from an area of Upper Pennsylvanian rocks, based on fusulinids.

ROCKS NORTH OF WEST DRY CANYON FAULT

PLATE I

PENNSYLVANIAN AND PERMIAN SYSTEMS

BEDS OF WEST DRY CANYON

The beds of West Dry Canyon consist of limestone, sandy and silty limestone, and calcareous sandstone and siltstone. Silty limestone is the most prominent lithology. In the lower 600 m these strata are

TABLE 2.—*Fusulinid collections and ages from the sandstone and siltstone member of the Oquirrh Formation*

[Identifications and age determinations by R. C. Douglass]

USGS fossil collection no.	No. on geologic map (Smith, 1982)	Fusulinids	Age
f13642--------	57	*Schwagerina* sp. and *Triticites* sp.	Early Permian; early Wolfcampian.
f13639--------	56	*Triticites* sp.; fairly well preserved.	Early Permian?; early Wolfcampian suggested.
f13646--------	55	Possible *Schwagerina* sp. and *Triticites* sp. suggested; some stretched and crushed.	Early Permian?; if some specimens are *Schwagerina* sp., Early Permian is indicated
f13645--------	54	*Triticites* sp.; abundant.	Late Pennsylvanian-Early Permian?; suggests late Virgilian or early Wolfcampian.
f13811--------	53	*Triticites*, possibly two species, and *Pseudofusulinella* sp.; stretched and squeezed.	Late Pennsylvanian or Early Permian.
f13812--------	52	*Triticites* sp. and *Pseudofusulinella* sp.	Late Pennsylvanian or Early Permian.
f13638--------	51	*Triticites* sp.; fairly well preserved specimens.	Late Pennsylvanian: Virgilian.
f24994--------	50	*Triticites* sp.; scattered fragments.	Do.

f13647--------	49	*Triticites* sp. and possibly *Pseudofusulinella* sp.	Do.
f24995--------	48	*Triticites* sp. fairly common, *Pseudofusulinella*? sp. rare and staffellid rare.	Do.
f24993--------	47	*Triticites* sp.; scattered fragements	Do.
f24992--------	46	---do----------	Do.
f13806--------	45	*Triticites* sp. and *Pseudofusulinella* sp.	Do.
f13807--------	44	*Triticites* sp. abundant.	Do.
f13808--------	43	*Triticites* sp. aff. *T. cullomensis* common and *Pseudofusulinella* sp. rare.	Do.
f13809--------	42	*Triticites* sp.	Do.
f13640--------	41	*Triticites* ? sp.; abraded and crushed.	Late Pennsylvanian?
f13641--------	40	*Triticites*? sp.; fragements.	Late Pennsylvanian?
f13643--------	39	*Triticites* sp.; broken and abraded.	Late Pennsylvanian; late Missourian to early Virgilian.
f13644--------	38	*Triticites* spp.; broken and abraded.	Do.
f13944--------	37	*Fusulinella* sp. and *Beedeina* sp.	Middle Pennsylvanian; Des Moinesian.
f14008--------	36	---do----------	Do.

nearly all calcareous siltstone and sandstone, which weather tan and brown and are similar to beds in the sandstone and siltstone member of the Oquirrh Formation. The thickness of about 2,220 m was partly measured on the ground and partly measured from the geologic map (Smith, 1982). It must be a minimum thickness because the base is covered by gravel and the top where measured is a fault. About 1 km north of the section and northward, the upper contact with unit A appears to be conformable and possibly to interfinger in places. Very little rock thickness at the top seems to be missing at the line of section.

A Late Pennsylvanian (Virgilian) to Early Permian (Leonardian) age for these rocks is established by two fusulinid and four conodont collections. Fusulinids (USGS f13810, loc. No. 59 on geologic map (Smith, 1982)) from the lower sandstone and siltstone about 320 m above the gravel-covered base are *Triticites* sp. of Virgilian age (R. C. Douglass, written commun., 1976). Conodonts from three collections in ascending order and spaced about equally through the upper half of the formation were reported on by B. R. Wardlaw (written commun., 1977) as follows: USGS D51–PC, loc. No. 60 on geologic map (Smith, 1982), *Adetognathus* n. sp., *Anchignathodus* sp., *Streptognathodus elongatus* Gunnell, and bar fragments, Upper Pennsylvanian (Virgilian), CAI 4 (190°–300°C); USGS D52–PC, loc. No. 61 on geologic map (Smith, 1982), *Neogondolella* cf. *N. idahoensis* (Youngquist, Hawley, and Miller), Lower Permian, CAI 4 (190°–300°C); and USGS D53-PC, loc. No. 62 (Smith, 1982), *Sweetognathus whitei* (Rhodes), Lower Permian (upper Wolfcampian), CAI 4 (190°–300°C). A poorly preserved and encrusted conodont, *Streptognathodus* cf. *S. elongatus* Gunnell, of a probable Pennsylvanian (Virgilian) to Permian (Wolfcampian) age (B. R. Wardlaw, written commun., 1978) occurs in a sample (field No. F–111, loc. No. 63 (Smith, 1982)) from about 3 km north of the other three. This has a CAI of 4 (190°–300°C). Collections containing the youngest fauna from this formation are from a small area of mudstone, siltstone, and some limestone along the West Dry Canyon fault. Collection USGS f24996, loc. No. 64 (Smith, 1982), contained fusulinids *Schwagerina* sp. or an early form of *Parafusulina* sp. of Early Permian age, reasonably a late Wolfcampian to early Leonardian equivalence (R. C. Douglass, written commun., 1974). Another collection from the same locality, USGS 25537–PC, loc. No. 64 (Smith, 1982) also contained conodonts *Anchignathodus sp.*, *Neogondolella* n. sp. D of Wardlaw and Collinson, and bar fragments of Leonardian age, CAI 3 (110°–200°C) (B. R. Wardlaw, written commun., 1977). Other fossils from this locality included a gastropod *Cinclidonema* sp. and a fragment of an orthoconic nautiloid, possibly *Mooreoceras* sp. indet. (Mackenzie Gordon, Jr., written commun., 1974).

These beds of West Dry Canyon are thus equivalent in age to much of the sandstone and siltstone member of the Oquirrh Formation. As pointed out, the lower part of the West Dry Canyon unit is similar lithologically to the sandstone and siltstone member of the Oquirrh, but the upper part is not, and two somewhat different rock facies of the same age are near each other in the vicinity of the West Dry Canyon fault.

SECTION D.—*Beds of West Dry Canyon*

[Measured in secs. 5, 4, and 3, T. 15 S., R. 28 E. and sec. 34, T. 14 S., R. 28 E.; location on fig. 1]

	Meters
Tertiary System:	
Sedimentary rocks.	
Fault.	
Permian and Pennsylvanian Systems:	
Beds of West Dry Canyon:	
Limestone, silty, gray, gray-, tan-, and pale-pink-weathering; small chunky and platy pieces; small fragments of black chert scattered sparsely over the surface	245
Limestone, silty, gray; weathers mostly tan and in small chunky pieces; very light gray, calcareous siltstone; fragments of black chert about 1¼ cm square scattered sparsely over the slope	145
Limestone, silty, gray and dark-gray, tan- and gray-weathering; some pink-weathering, platy pieces several centimeters across and 6 mm thick; minor calcareous quartz siltstone	290
Limestone, gray, dense, gray-weathering; some calcareous siltstone; entire slope is covered with gray platy pieces in contrast to varicolored pieces of unit below	200
Limestone, nearly all silty, gray and dark-gray; weathers gray, tan, pale pink, and some rusty; bedding in some small outcrops is thin, commonly a few mm; surface covered with platy fragments mostly 8 cm or less across; minor tan and light-red limestone and calcareous sandstone. Scattered fragments of black chert; some contain cubes of limonite altered from pyrite. One thin bed of gray crystalline crinoidal limestone noted	220
Siltstone and fine-grained sandstone, calcareous, gray and tan	160
Limestone, silty, gray; and tan siltstone	110
Limestone, silty, gray, gray-weathering; contains widely scattered, medium, well-rounded quartz grains; about 1 percent is calcareous sandstone	220
Limestone, much silty, gray, gray-weathering; some containing medium, well-rounded quartz grains; gray and tan calcareous sandstone; float suggests that sandstone similar to that in sandstone and siltstone member of the Oquirrh is dominant rock type. In lower 60 m, beds are crinoidal; some contain bryozoans and a few corals	310
Siltstone and fine-grained sandstone; both slightly calcareous; light gray and weathering tan and brown; bedding obscure; angular to rounded quartz grains, moderately well sorted; a 15-cm-thick bed of gray sandy limestone noted. At top a 0.6-m-thick bed of gray limestone contains bryozoans, crinoid columnals, spines (probably of brachiopods), and fusulinids; USGS colln. f13810 contains *Triticites* sp. of Late Pennsylvanian (Virgilian) age (R. C. Douglass, written commun., 1976)	206

	Meters
Permian and Pennsylvanian Systems—Continued	
Beds of West Dry Canyon—Continued	
Limestone, silty, gray, gray- and light-gray-weathering; tan-weathering, calcareous siltstone containing scattered fine quartz grains; interbedded gray silty limestone, 0.6 m thick, and brown- and dark-brown-weathering calcareous siltstone form some distinctive outcrops . .	114
Total beds of West Dry Canyon	2,220

Base not exposed; covered with gravel.

PERMIAN SYSTEM

UNIT A

Unit A is distinguished by sequences of interbedded dark-gray to black chert and limestone, silty limestone, dolomite, siltstone, and sandstone; chert beds make the single most distinguishing feature of the unit. In some exposures the interbedded dark chert and lighter colored carbonate rocks produce a distinctive banding in zones as much as about 100 m thick. The base of the unit is placed at the base of the lowest bedded chert or at beds into which it appears to grade laterally.

At the north edge of the Strevell quadrangle, this unit joins the rock sequence to which R. L. Armstrong (written commun., 1977) has applied the name Hudspeth Cutoff Sandstone, which was introduced as a formation in the Sublett Mountains by Cramer (1971). Yancey, Ishibashi, and Bingham (1980) have revised the Hudspeth Cutoff Sandstone of Cramer (1971) to exclude the lower 340 m and the upper 100 m and thus restrict the name to the chiefly sandstone sequence. In view of uncertainties regarding the name Hudspeth Cutoff in relation to unit A in the Strevell quadrangle, the name is not used in this report for any rock unit in that quadrangle. However, part of unit A is almost certainly correlative with part of the Hudspeth Cutoff regardless of whose definition is used for the Sublett Mountains.

Lower Permian conodonts and fusulinids determine the age of unit A. Conodonts collected from the lower part of the formation and studied by B. R. Wardlaw (written commun., 1977) include: USGS D31–PC, loc. No. 65 (Smith, 1982), *Neogondolella idahoensis* (Youngquist, Hawley, and Miller), probably upper Leonardian, CAI 4 (190°–300°C); and USGS D32-PC, loc. No. 66 (Smith, 1982), *Neostreptognathodus* n. sp. C of Wardlaw and Collinson and *Ellisonia* sp., upper Leonardian, CAI 4 (190°–300°C). Fusulinids (USGS f13945, loc. No. 67 (Smith, 1982)) collected within about 150 m of the top of the formation were examined by R. C. Douglass (written commun., 1977), who reported that the sample contains an abundant fusulinid fauna but that the wall structure is destroyed in all specimens; the gross structures, however, suggest a schwagerinid of Early Permian (late

Wolfcampian) age. Another collection (field No. F–88, loc. No. 68 (Smith, 1982)) contained molds of *Plagioglypta* (scaphopod) and *Omphalotrochus* (gastropod) (B. R. Wardlaw, written commun., 1977).

According to Wardlaw the age of the conodonts makes these rocks equivalent to the Meade Peak Phosphatic Shale Member of the Phosphoria Formation. In the Sublett Mountains the Meade Peak overlies the Hudspeth Cutoff Sandstone as mapped by R. L. Armstrong (written commun., 1977). There is no recognized Meade Peak in the Strevell quadrangle.

Along the upper contact of unit A, several tens of meters of beds are truncated by the overlying formation. Very probably this is a fault contact as the overlying stratigraphic section here is somewhat different from what is presumably the normal sequence exposed in the neighboring Sublett Mountains.

Along the line of the measured stratigraphic section, reliable bedding attitudes are widely scattered in some parts. Dips are consistently northward but vary enough in degrees to make some thickness measurements somewhat inaccurate. These inaccuracies have been partly compensated for by the use of average dips for parts of the measurements. The 1,480 m is probably a reasonable figure for the exposed thickness.

SECTION E.—*Unit A*

[Measured in secs. 21 and 16, T. 14 S., R. 28 E., and the upper half in sec. 4, T. 14 S., R. 28 E.; location on fig. 1]

	Meters
Permian System:	
Dark-gray limestone.	
Probably a fault.	
Unit A:	
Siltstone, mostly gray, chiefly noncalareous, tan-, reddish-tan-, and gray-weathering; less fine grained sandstone, some of which is bimodal and contains scattered well-rounded coarse quartz grains; some dolomitic siltstone and dense gray dolomite. Lenticular chert near middle of unit. In upper 60 m, more dense black limestone, dark-gray-weathering, and gray crystalline limestone than in lower part. About 60 m above base, fine-grained gray sandstone and fine- and medium-grained bimodal gray sandstone containing gastropods (*Omphalotrochus*)	350
Chert, black and dark-gray, and interlayered gray dolomite, siltstone, and some limestone	30
Siltstone and fine-grained sandstone, calcareous	45
Chert, black, and interlayered light-gray, dense dolomite, siltstone, and some limestone; chert occurs in layers as much as 10 cm thick, in irregular nodules about 25 cm long, and in blobs not parallel to the bedding; small tight folds in places	105
Siltstone and fine-grained sandstone, light-gray, calcareous, platy; laminated silty and sandy gray limestone; and some very dark gray, gray-weathering limestone which forms mostly 6 mm thick platy and some chunky pieces	245

	Meters
Permian System—Continued	
Unit A—Continued	
NOTE.—Connection to beds in unit below was made by projection and tracing beds along strike.	
Limestone, gray, gray-weathering, thin-bedded; black chert in lower 3–4 m, sparse chert above; some calcareous siltstone and fine-grained sandstone. Limestone in uppermost part is dense and very dark gray and similar to limestone in overlying formation	145
Rubble covered on flat hilltop with fragments of thin-bedded gray limestone; near top is an outcrop of limestone and scattered small dark-gray chert nodules	110
Limestone, gray, gray-weathering; very thin bedded in places; a few pieces of crystalline limestone containing scattered small crinoid fragments; very little black chert	60
Rubble covered with pieces of limestone and dolomite and sparse chert	28
Rubble covered on bench slopes; fragments indicate limestone, dolomite, and more black chert than in unit below	53
Limestone, gray-, tan-, and pink-weathering, silty, thin-bedded to shaly; light-gray, gray-weathering dolomite, even beds as much as 25 cm thick; interspersed black chert layers 2 cm thick, decrease in number downward	87
Limestone, gray, silty; black chert; light-gray, light-gray-weathering dolomite; even-bedded dark chert and lighter colored carbonate rocks produce distinctive banding; chert layers most commonly 6–20 cm thick and limestone and dolomite layers 3–9 cm. Beds folded and faulted on a small scale in places. Weathers to form rusty-brown talus slopes	5
Limestone; lower part consists of even-bedded, 6–10-cm-thick layers of dense, dark-gray, gray-weathering silty limestone and 1–2-cm-thick layers of dense, gray, tan-weathering (with a lavender cast in places), slightly silty limestone; upper part is similar but has 30-cm-thick layers in places	42
Covered; alluvium	14
Limestone, silty, largely gray and gray weathering; a few small outcrops on a mostly rubble covered surface; some weathers tan and pink; platy fragments commonly 10–15 cm across and a few chunky pieces as much as 20 cm long. From top to about 30 m above base is much black chert in fragments that suggest that beds are 3–6 cm thick	83
Rubble-covered slope with pieces of gray-, buff-, and tan-weathering silty limestone; many chunky fragments 2.5–5 cm across; a very little black chert	1
Rubble-covered slope with pieces of mostly tan and tan-weathering calcareous siltstone and less gray and light-gray-weathering silty limestone in platy pieces 1 cm thick; some pink and reddish tints; a few pieces of black chert scattered over slope. Gray silty limestone decreases in quantity downward relative to tan siltstone and is much less prominent below the upper 45 m	75
Chert, very dark gray, and gray silty limestone, dolomite, and dolomitic siltstone; bedding indistinct but beds appear to be about 8 cm thick; much brecciated	2
Total thickness unit A	1,480

NOTE.—Contact apparently conformable with beds of West Dry Canyon below; in places, this appears to be an interfingering contact.

Beds of West Dry Canyon.

UNIT B

Unit B of chert, siltstone, and limestone exposed over a few square kilometers in the northeast corner of the quadrangle is similar to unit A but contains no dolomite. Black chert layers that appear to be as much as 25 cm thick are interlayered with gray limestone and calcareous siltstone in parts of the sequence, but very little chert occurs in other parts. Gray siltstone, mudstone, silty limestone, and limestone occur in thin beds, many of which are laminated and in places crossbedded on a small scale. The fine-grained clastic rocks weather light gray, brownish gray, and tan or buff, and the limestone beds weather gray. This unit is essentially nonfossiliferous, although pieces of fossil hash consisting of thin fragments of brachiopod shells in a limestone matrix were noted on one slope and small faint worm-like trails were observed in buff mudstone at another locality.

The minimum thickness in the Strevell quadrangle appears to be about 750 m, but no top or bottom is exposed.

This unit is not in contact with any Paleozoic formation in the mapped area. A fault bounding the west edge of the northernmost exposed part on the east edge of the quadrangle separates these beds from unit A, and probably unexposed fault or faults in the area of Cenozoic deposits separate other parts of the two formations. However, as these formations are similar lithologically and apparently of the same age, they may actually grade into or interfinger with each other.

A Permian (Leonardian) age for this unit B is established on one conodont collection (field No. F-114, loc. No. 69 (Smith, 1982)) from a bed that contained fragments of gastropods and well-preserved but sparse *Neogondolella idahoensis* (Youngquist, Hawley, and Miller) (B. R. Wardlaw, written commun., 1978). This fossil content indicates that the unit is an age equivalent of the rocks containing the youngest fossils in the beds of West Dry Canyon and of unit A, to which it is very similar lithologically, and also, according to Wardlaw, that it is roughly equivalent to the lower part of the Meade Peak Phosphatic Shale Member of the Phosphoria Formation and to the Grandeur Member of the Park City Formation. The CAI of the conodonts is 4, indicating that the host rock attained a temperature of 190° to 300°C.

This unit crops out much more extensively east and northeast of the Strevell quadrangle.

PLATE II

PERMIAN SYSTEM

DARK-GRAY LIMESTONE

The dark-gray limestone forms the most uniform lithologic unit in the Black Pine Mountains and consists almost entirely of dark-gray, dense limestone that weathers light gray and commonly forms platy fragments on the slopes. Some beds are argillaceous. Silt and fine-size quartz grains occur in some beds, and a few layers are about half quartz and half calcite. Calcareous siltstone makes up a small percentage of the rocks in the formation. Small bryozoan fragments and some spines, sections of tiny crinoid columnals, and a very few fragments of ostracodes were found in a few beds.

The dark-gray limestone is Lower Permian (upper Leonardian), as determined on two conodont collections (B. R. Wardlaw, written commun., 1977) from the lower part of the formation and made nearly 4 km apart. Both collections (USGS D28–PC, loc. No. 70, and D33–PC, loc. No. 71 on geologic map (Smith, 1982)) contained *Neostreptognathodus* n. sp. C of Wardlaw and Collinson, as well as bar fragments; the CAI is 4, indicating that the host rock attained a temperature of 190°–300°C. This same species occurs in unit A below and indicates that the dark-gray limestone is equivalent to the Meade Peak Phosphatic Shale Member of the Phosphoria Formation. Brachiopod collections also studied by Wardlaw (written commun., 1977) contained *Lissochonetes* and a juvenile overtoniid (USGS D27–PC, loc. No. 72 (Smith, 1982)) of Pennsylvanian to Early Permian age and *Leiorhynchoidea* cf. *L. nobilis* (Girty) (field No. F–83, loc. No. 73 (Smith, 1982)). The latter species according to Wardlaw is common to the upper part of the Meade Peak Member and also to siltstones and shales in the Lower Permian of the Great Basin.

Three samples of these Phosphoria age limestones contain less than 1 percent P_2O_5 as determined colorimetrically by G. D. Shipley (written commun., 1975). Sample D174844 from about 30 m above the base of the formation contained 0.33 percent P_2O_5, sample D174843 from about 75 m above the base contained 0.26 percent, and sample D174842 from about 25 m below the top contained 0.10 percent.

The upper contact of the dark-gray limestone is presumably conformable, but small tight folds and variable strikes and dips of beds near the top of the unit indicate possibly more intense deformation there than lower in the formation, and suggest that this contact may be a fault. Breccia near the base of the overlying rock sequence supports this possibility.

The measured 745–m thickness of the dark-gray limestone is a reasonable figure, but very poor exposures on the dip slopes prevent accurate measurements.

SECTION F.—*Dark-gray limestone*

[Measured in secs. 3 and 4, T. 13 S., R. 28 E.; location on fig. 1]

	Meters
Permian System:	
Limestone, silicified limestone, some chert.	
Contact not exposed; presumably it is conformable but it may be a fault.	
Dark-gray limestone:	
Limestone, dense to medium-crystalline, dark-gray, gray-weathering; beds commonly 6 mm to 8 cm thick and in places as much as 30 cm. Small tight folds near top in places make thickness measurements suspect for the uppermost part	233
Limestone, dense, dark-gray; weathers gray on platy fragments; some light-gray, tan-weathering pieces; in a few outcrops beds are 2 mm to 5 cm thick and have a rusty weathered surface	128
Limestone, dense, dark-gray, light-gray-weathering; more tan-weathering silty limestone and calcareous siltstone than lower in formation; some tan limestone	54
Limestone, dense, dark-gray, light-gray-weathering; beds as much as 10 cm thick; some silty limestone and calcareous siltstone weather to form gray and tan, platy and chunky fragments. Fine-grained sandy limestone near top	131
Limestone, dense, dark-gray, light-gray-weathering; beds commonly 2–6 mm thick; argillaceous in some layers; small platy pieces, 2–13 mm thick and generally 5–13 cm across, cover slopes. Some massive outcrops still weather to form platy fragments. About 175 m above base, some beds are lighter gray and weather tan. Spines and small bryozoan fragments were noted about 130 m above the base	198
Total thickness dark-gray limestone	745
Contact inferred to be a fault.	
Unit A.	

LIMESTONE, SILICIFIED LIMESTONE, SOME CHERT

This unit crops out in two small areas at the northeast margin of the Black Pine Mountains. It consists of sandy limestone, silicified limestone, calcareous sandstone, and some chert. Near the base is some silicified limestone breccia. A thickness of between 120 and 145 m is a reasonable estimate for the exposed rocks, but a lack of good bedding attitudes makes an accurate measurement impossible.

No fossils were found in this unit, and so its Permian age designation is based on its stratigraphic position in relation to the underlying upper Leonardian dark-gray limestone. It has no recognized correlative in nearby exposures of Paleozoic rocks, and it certainly is different lithologically from the Triassic Dinwoody Formation in the Sublett Mountains.

The following section in the NW¼ sec. 2, T. 14 S., R. 28 E. is not measured, but does describe the stratigraphic sequence:

	Meters (estimated)
Quaternary System.	
Gravel.	
Permian System:	
Limestone, silicified limestone, some chert.	
Silicified gray limestone, gray- and tan-weathering	75–90
Gray sandy limestone; limestone has a grainy crystalline texture and contains scattered medium-size rounded grains of quartz	15
Gray calcareous fine-grained sandstone, tan-weathering	2
Silicified gray limestone, gray- and brown-weathering; mostly a breccia; no obvious bedding	30–40
Estimated total thickness	120–145
Contact is presumably conformable but may be a fault.	
Dark-gray limestone.	

CONCLUSIONS REGARDING TEMPERATURES REACHED BY ROCKS EXPOSED IN THIS AREA

During study of 32 conodont collections in determining ages of rock units, the CAI (color alteration indices) of the conodonts and thus the temperatures attained by the host rocks were determined as defined by Epstein, Epstein, and Harris (1977). All these rocks reached relatively high temperatures, mostly between 190°C and 400°C, although one sample could have been as low as 110°C and another possibly as high as 500°C (fig. 2).

A temperature disconformity appears to occur across the fault that is partly near West Dry Canyon. South of the fault, attained temperatures of 14 of the 22 samples were in the range of 300°C to 400°C (CAI 5), one was below at CAI 4.5–5, and the other 7 were above with CAI of more than 5. North of the fault, 9 of the 10 collections were in the range of 190°C to 300°C. The CAI values north of the fault are at least one number lower than the values to the south, and the highest temperature attained to the north is about the same as the lowest one to the south. The pre-faulting separation, then, must have been enough to account for this difference in attained rock temperatures.

The temperatures attained by these rocks have a bearing on any search for petroleum in this area. Regardless of consideration of time of burial, texture, and composition of rock types, all indicated temperatures, and particularly those above 300°C (CAI 5 and above), suggest that a postmature or high-temperature methane stage of petroleum generation was reached (for example, Hood and others, 1975, p. 993–994; Epstein and others, 1977, p. 22–25; and Milner and others, 1977, p. 107–108) and that occurrence of oil is unlikely. These temperatures

are determined on collections from exposed rocks that seem to be principally allochthonous and that conceivably could rest on lower plate units that attained lower temperatures. The existence of cooler units is unlikely, however, at the Strevell borehole (Al Griffin-Isabell Neilson No. 1) southwest of the Black Pine Mountains about 4 km from the edge of Paleozoic outcrops. That borehole penetrated Oquirrh rocks at about 345 m and lower Paleozoic metamorphic rock units (resembling those in the Raft River Mountains across the valley to the southwest) at about 643 m (Oriel and others, 1978). The Oquirrh strata penetrated are here interpreted to belong to the siltstone and sandstone member of the Oquirrh, and their position on the metamorphosed units indicates that no lower plate of once cooler rocks exists in the borehole. No positive evidence is available regarding the possibility of a cooler lower plate in and near the Black Pine Mountains east of the borehole.

Raised temperatures were required for deposition of the gold and base-metal deposits in the Black Pine mining district in the southeast part of the mountains near the cluster of conodont collection localities east of Black Pine Canyon (fig. 2). These temperatures, however, were relatively low and probably did not exceed 125°–200°C (B. T. Brady, oral commun., 1977; partly based on information to Brady from C. G. Cunningham, 1977). These temperatures, then, appear to have been lower than those indicated by the CAI of the conodonts, and, if so, metal deposition occurred after the regional heating indicated by the CAI.

The Raft River Valley geothermal area (Williams and others, 1976) is centered about 12 km west of the Strevell quadrangle. Williams and others (1976) attributed the presence of hot water, having a maximum measured temperature at depth of 147°C, to deep circulation of meteoric water along major faults. These hot waters in the Tertiary fill in the valley, although close to the Black Pine Mountains, do not appear to have direct relations to any exposed features in the mountains.

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