



Geology of a portion of the Pine Creek Quadrangle, Teton and Lincoln counties, Wyoming
by Robert Arthur Lunceford

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE
in Earth Sciences

Montana State University

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Abstract:

The Pine Creek Quadrangle lies in western Wyoming in the transition between the Wyoming and Snake River ranges at the north end of the Wyoming overthrust belt.

Roughly twenty-six Holocene landslides were mapped in the central and western parts of the area, which are almost exclusively associated with the shale and mudstone of the Cretaceous Bear River and Aspen formations. The Pleistocene Bailey Creek landslide lies in the northeastern corner of the map area; the development was a complex event involving at least two separate sliding episodes.

The older landslide dammed Bailey Creek and the Snake River causing the bed loads to be deposited upstream.

Approximately 12,250 feet of Mississippian through Lower Cretaceous strata crop out in the map area. Paleozoic strata consist of limestone of the Mississippian Mission Canyon Limestone of the Madison Group; shale and quartzitic sandstone of the Mississippian, Pennsylvanian, and Permian Wells Formation; and chert, sandstone, and phosphatic mudstone of the Permian Phosphoria Formation. Triassic age strata include, in ascending order, siltstone and limestone of the Dinwoody Formation; sandy siltstone and shale of the Woodside Formation; sandstone and limestone of the Thaynes Formation; siltstone and sandstone of the Ankareh Formation; and sandstone of the Triassic (?) - Jurassic (?) Nugget Sandstone. Strata of Jurassic age comprise the Twin Creek Limestone, chiefly consisting of shaly limestone; sandstone and siltstone of the Preuss Sandstone; and limestone and sandstone of the Stump Sandstone, in ascending order. Lower Cretaceous strata consist of, in ascending order, sandstone, limestone, and shale of the Gannett Group; shale and sandstone of the Bear River Formation, and overlying Aspen Shale. Conglomerate also occurs in the upper Aspen which is interpreted to be a tongue of the overlying Frontier Formation exposed to the north and south of the map area.

Mississippian through Early Triassic age strata were deposited in a transitional area that included the overthrust belt between a miogeosyncline on the west and a shelf area that covered most of Wyoming. The miogeosyncline began to be deformed in Late Triassic time and a high area on the west rose and shed detritus eastward into the marginal basin in southeastern Idaho and western Wyoming.

The map area is situated between the eastward moving Absaroka and Darby thrusts which lie just off the western and eastern margins, respectively. The Little Greys fault has a minimum displacement of 1,500 feet of Aspen Shale and resulted from overturning along the associated Little Greys anticline. The central part of the map area, consisting of 7,000 feet of Aspen Shale, is probably further deformed by overturned folding not evident in the outcrop.

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GEOLOGY OF A PORTION OF THE PINE CREEK
QUADRANGLE, TETON AND LINCOLN
COUNTIES, WYOMING

by

ROBERT ARTHUR LUNCEFORD

A thesis submitted in partial fulfillment
of the requirements for the degree

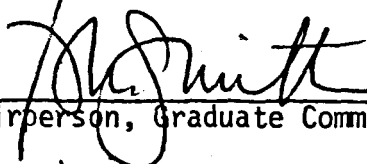
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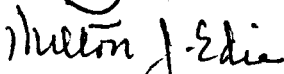
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ABSTRACT

The Pine Creek Quadrangle lies in western Wyoming in the transition between the Wyoming and Snake River ranges at the north end of the Wyoming overthrust belt.

Roughly twenty-six Holocene landslides were mapped in the central and western parts of the area, which are almost exclusively associated with the shale and mudstone of the Cretaceous Bear River and Aspen formations. The Pleistocene Bailey Creek landslide lies in the northeastern corner of the map area; the development was a complex event involving at least two separate sliding episodes. The older landslide dammed Bailey Creek and the Snake River causing the bed loads to be deposited upstream.

Approximately 12,250 feet of Mississippian through Lower Cretaceous strata crop out in the map area. Paleozoic strata consist of limestone of the Mississippian Mission Canyon Limestone of the Madison Group; shale and quartzitic sandstone of the Mississippian, Pennsylvanian, and Permian Wells Formation; and chert, sandstone, and phosphatic mudstone of the Permian Phosphoria Formation. Triassic age strata include, in ascending order, siltstone and limestone of the Dinwoody Formation; sandy siltstone and shale of the Woodside Formation; sandstone and limestone of the Thaynes Formation; siltstone and sandstone of the Ankareh Formation; and sandstone of the Triassic (?) - Jurassic (?) Nugget Sandstone. Strata of Jurassic age comprise the Twin Creek Limestone, chiefly consisting of shaly limestone; sandstone and siltstone of the Preuss Sandstone; and limestone and sandstone of the Stump Sandstone, in ascending order. Lower Cretaceous strata consist of, in ascending order, sandstone, limestone, and shale of the Gannett Group; shale and sandstone of the Bear River Formation, and overlying Aspen Shale. Conglomerate also occurs in the upper Aspen which is interpreted to be a tongue of the overlying Frontier Formation exposed to the north and south of the map area.

Mississippian through Early Triassic age strata were deposited in a transitional area that included the overthrust belt between a miogeosyncline on the west and a shelf area that covered most of Wyoming. The miogeosyncline began to be deformed in Late Triassic time and a high area on the west rose and shed detritus eastward into the marginal basin in southeastern Idaho and western Wyoming.

The map area is situated between the eastward moving Absaroka and Darby thrusts which lie just off the western and eastern margins, respectively. The Little Greys fault has a minimum displacement of 1,500 feet of Aspen Shale and resulted from overturning along the associated Little Greys anticline. The central part of the map area, consisting of 7,000 feet of Aspen Shale, is probably further deformed by overturned folding not evident in the outcrop.

INTRODUCTION

Location and Access

The map area lies in western Wyoming between the Wyoming and Snake River ranges which compose part of the Wyoming overthrust belt. It is bordered on the north by the Snake River and on the south by the Little Greys River and comprises the central three-fifths of the Pine Creek Quadrangle including portions of T. 36 and 37 N. and R. 117 and 118 W., Teton and Lincoln counties, Wyoming (Fig. 1). Most of this area is generally inaccessible with few roads present. The Little Greys River road borders the southern margin of the map area, and with permission of the landowner, access can be gained to the northeastern corner by a private road on the east side of the Snake River. A major part of the area is accessible by the use of pack and game trails. Additionally, relatively easy access to the northern margin is attainable by crossing the Snake River in a boat or raft.

Procedure

Mapping of the Pine Creek area was done on U.S.G.S. 1:24,000 topographic maps, and black and white aerial photographs of approximately the same scale. Field work began in June 1975 and continued to September. An additional week was spent in the field in August of 1976. Traverses were made every one-half to one-fourth mile along ridge tops, although this spacing varied somewhat with the amount of tree cover and available outcrops.

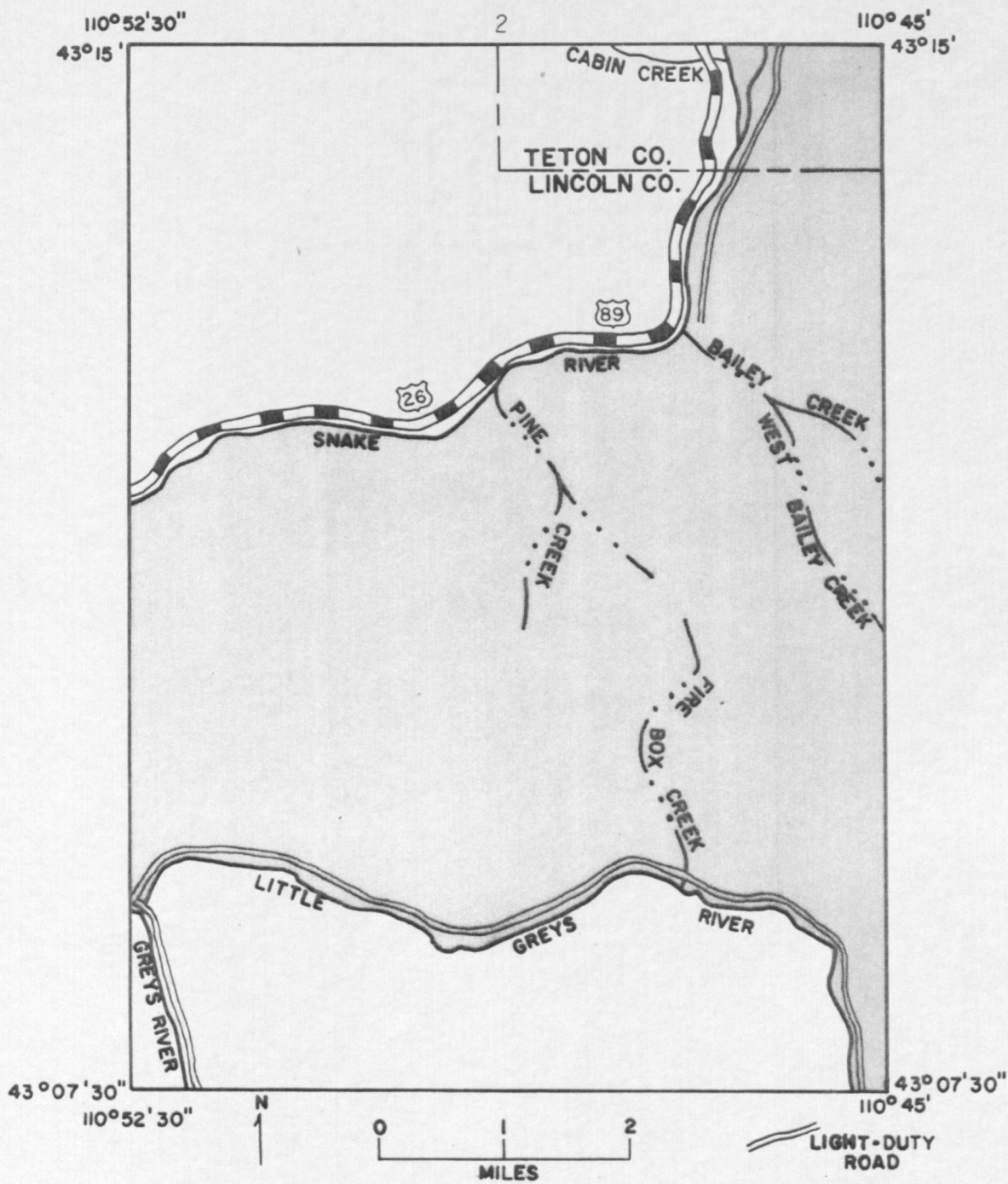


Figure 1. Index Map, Pine Creek Quadrangle.
Map area shaded.

Purpose

The primary purpose of this study is to provide a detailed geologic map of the area. The need for the map is twofold: (1) to provide information on the geology of the Pine Creek Quadrangle which represents a significant gap in the previously mapped portions of the surrounding overthrust belt (Fig. 2) and (2) to continue the ongoing U.S.G.S. investigation into the coal and phosphate resources of this region. A second purpose is to provide a detailed summary of stratigraphic work in the region of the overthrust belt.

Previous Work

The geology of the Pine Creek Quadrangle was first described by geologists of the Hayden surveys in the latter part of the 19th century (see Schultz, 1914.) This area was later investigated in greater detail by Schultz (1914), Boeckerman and Eardley (1956), and by Ross and St. John (1960). In addition, numerous theses on the geology adjacent to the Pine Creek Quadrangle have been completed by students at the University of Michigan (see Wanless, et al., 1955, and Boeckerman and Eardley, 1956). Reports on the economic resources and geology of the nearby region, useful because of the included stratigraphic information, were published by Veatch (1907), Mansfield (1927), and Staatz and Albee (1966). The stratigraphy of the map

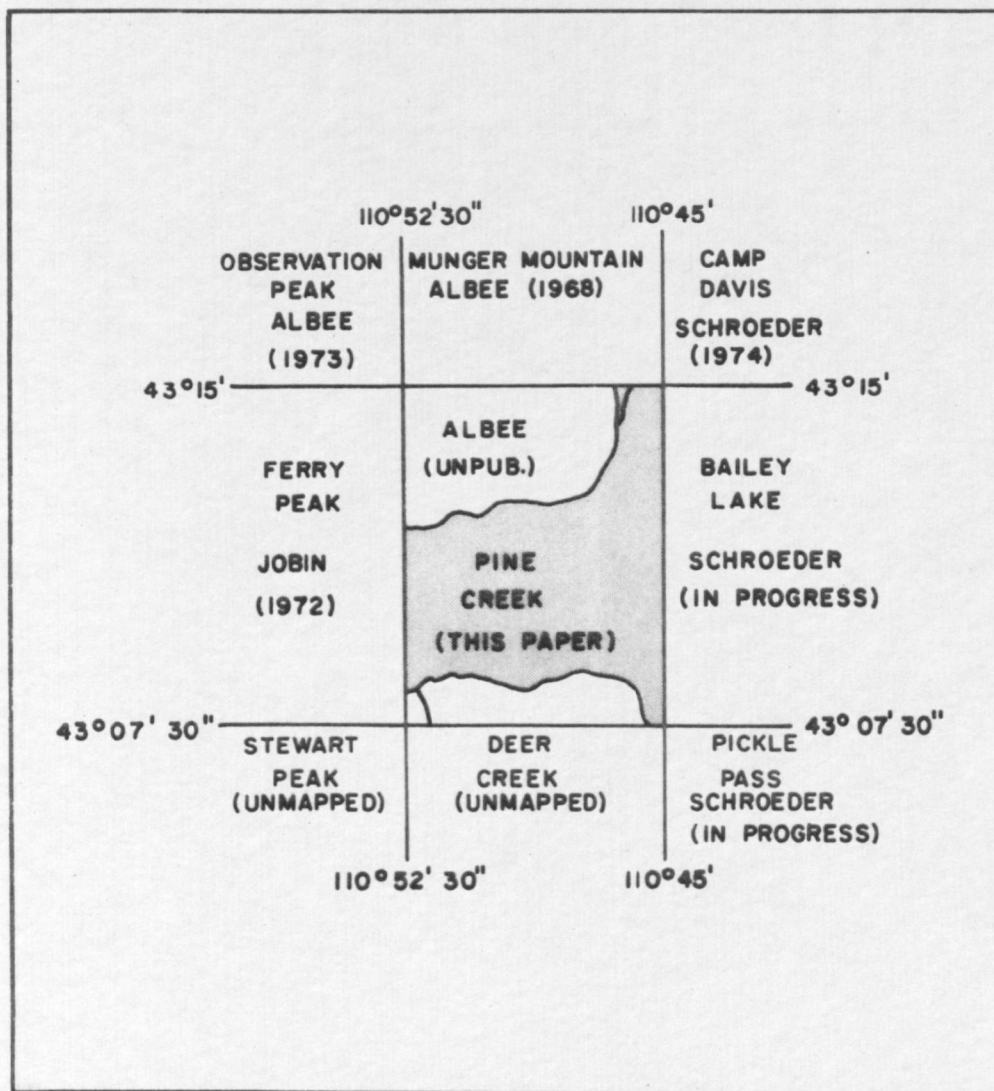


Figure 2. Index map of published and in-progress geologic quadrangles adjacent to Pine Creek Quadrangle. Map area shaded.

area and the region adjacent to it was studied extensively by Wanless et al. (1955).

Several geologists have investigated the tectonics of the overthrust belt and a number of notable reports have been published. Eardley (1960, 1967) and Crosby (1968, 1969) investigated the phases of orogeny and patterns of movement; the mechanics of deformation were studied by Rubey and Hubbert (1959); and Armstrong and Oriel (1965) summarized the temporal, spatial, and stratigraphic relations of the overthrust belt.

GEOGRAPHY

Geomorphic Setting

The study area lies in the Middle Rocky Mountain Province of the Rocky Mountain System, and at the transition between the northern end of the Wyoming Range and the southern end of the Snake River Range. Topographically a major part of the area is characterized by parallel, northwest-trending ridges and valleys, developed in response to the interbedded resistant and nonresistant strata involved in the regional northward-trending structural grain of the Wyoming overthrust belt. The subsequent drainages which follow the structure are, therefore, parallel over much of the area. These streams have not attained any graded state, as evidenced by the lack of flood plains and by extensive headward erosion. Because of the youthful state of its drainage much of the area remains as highlands.

The Snake and Little Greys rivers, and Bailey Creek over part of its length, directly crosscut the structure and present an interesting geomorphic problem. It is suggested here that these streams may have developed by superposition from a Middle Pliocene basin fill or lake level.

Several lines of evidence lead to this speculative conclusion. The nearest Tertiary material, the Middle Pliocene Teewinot Formation, is exposed north of the Pine Creek Quadrangle in Jackson Hole (Love, 1956a) and 7 miles west, in the Alpine area (Merritt, 1956). It is

not known whether these formations are correlative. However, they do have similar lithologies and fossils, and both are suggested to have formed in a lacustrine environment (Love, 1956a, Merritt, 1956). The Teewinot Formation at Alpine has conglomerate beds (Merritt, 1956) unlike the Teewinot exposed in Jackson Hole (Love, 1956a) suggesting that the Snake River Range was a highland area prior to Middle Pliocene time. Further evidence of high topography in this area is implied by the occurrence of large slide blocks within the Teewinot which are interpreted to have slid westward off the Snake River Range (Love, 1956b). If a connection between the Teewinot at Alpine and Jackson Hole areas existed north of the Snake River Range, then it seems likely that Teewinot strata would have been preserved in the downwarped Teton Basin directly west of the Teton Range. Love (1956a) did not mention any exposures of Teewinot strata in this area. Therefore, the probable connection between Jackson Hole and Alpine during deposition of the Teewinot was through the south end of the Snake River Range. This conclusion implies that a Middle Pliocene cover may have extended over the study area and that the Snake and Little Greys rivers could have been lowered over the buried topography. Alternately these drainages may have developed from the lake level without great accumulations of lacustrine material as in the deeper basins in Alpine and Jackson Hole. During the Pleistocene the erosive power of these rivers greatly increased as pre-Wisconsin piedmont ice

melted. Such ice existed at least as near as Munger Mountain (Montagne, 1976, personal communication), 6 miles north of the map area.

If it can be proven conclusively that the Teewinot at Jackson Hole and the Teewinot at Alpine were not continuous, then a mechanism other than superposition must be considered. One possibility may be the establishment of the Snake River drainage as the Teewinot lake at Jackson Hole spilled over its bank at the south end. As an alternate hypothesis the Snake and Little Greys rivers may have developed by headward erosion across the Pliocene topography which certainly was more subdued than it is at present, and drained into the Teewinot lake on the downfaulted block of Alpine. Further investigation is needed to determine whether or not the Teewinot sediments in both the Jackson Hole and Alpine areas are correlatives.

Mass-wasting is the most dynamic and notable geomorphic process in the area. Approximately twenty-six landslides were mapped, both ancient and recent. Most of these landslides are located in the central and western parts of the map area and are almost exclusively associated with shale and mudstone of the Cretaceous Bear River and Aspen formations.

Landslides

Small Landslides

Smaller landslides within the Pine Creek Quadrangle are all fairly recent and most probably are at least 50 years old judging from the thick growth of aspen and lodgepole pine on some of the deposits. They range in size from small deposits approximately 600 feet long and 300 feet across to larger landslides approximately 8,000 feet long and 2,000 feet across. The largest of these small landslides is visible from U.S. Highway 26-89 just west of Elbow Campground and is approximately $1\frac{1}{2}$ square miles in area. Another large landslide is located on the west side of Cow Camp Creek near the northern margin of the map area. All of these landslides are of the slump type (Thornbury, 1969, p. 46-67), although, in some cases, the upper surface of the slide debris has been subsequently modified by mudflows as evidenced by the hummocks and sparse vegetation. Small springs and ponds have developed on the surface of the larger slides. Others, such as the large slide west of Iron Rim Creek, near the western margin of the map area, appear less modified by continued downslope movement of debris, and the surface is quite subdued with a thick growth of aspen and lodgepole pine. Along the break-away scarps of most of the slides in the area are several large arcuate tensional cracks along which material has moved downhill but with no rotational component. Most

of the slides formed on Bear River-Aspen dip slopes and probably resulted from water saturation along bedding planes and joints. However, three of the larger landslides along the Snake River moved parallel to the strike of the beds and probably resulted from a combination of oversteepened canyon walls, and saturated bedding and joints.

One exception to the Bear River-Aspen landslide association is the slide that occurred in the breached core of the Little Greys anticline and that is coincident with the axial trace (Fig. 19). It involves the sandstone and shale of the Lower Gannett Group, Stump, Preuss, and Twin Creek formations and is probably a direct result of oversteepening by the Little Greys River and concentrated fracturing in the core of the anticline.

Large Landslides -- Bailey Creek Landslide

The Bailey Creek landslide, named by Love and Montagne (1975, personal communication) lies on the south bank of the Snake River in the northeastern part of the map area (Pl. 1). This Pleistocene landslide was initiated on the west flank of Grayback Ridge within limestone and quartzite of the Madison Group and Wells Formation. It is a complex feature, involving at least two separate sliding events, of which the earlier dammed both the Snake River and Bailey Creek,

resulting in deposition of the bed loads upstream and the formation of a lake in the Snake River Canyon.

Several observations regarding the general appearance of the slide are significant in analyzing its origin and development. The flat to subdued surface of the landslide is covered with a thick growth of lodgepole pine, and typical signs of landsliding, such as ponds and springs, are absent. The landslide debris, which reaches a maximum thickness of approximately 100 feet near the northern margin of the Snake River, partially covers Thaynes, Ankareh, Nugget, and Twin Creek strata. No landslide debris occurs on the west side of the Snake River. The margins of the landslide have been incised by one large and one small canyon. A well-lithified breccia unit (Fig. 15), composed principally of Madison limestone and Wells quartzite (see Cenozoic strata section), crops out along the north wall of the smaller of these canyons (Pl. 1) in the middle of the landslide debris. In addition, a conglomerate unit, with nearly identical lithology to that of the breccia unit, is exposed along Bailey Creek at the southern margin of the slide (Pl. 1). This unit thickens downstream and the sorting, stratification, and slope imply that it is a fluvial unit. Fragments of the Madison Group and Wells Formation are also deposited 2½ miles south of the landslide along Bailey Creek in a series of recent mudflows. Love (1976, personal

communication) mentioned that several break-away scarps are apparent along Grayback Ridge in this general area.

Other deposits in the area adjacent to the landslide have important implications regarding its development. Gravel, which may attain thicknesses of 400 feet (Albee et al., 1975, p. 17), is deposited from 25 to 50 feet above the level of the Snake River north of the Bailey Creek landslide. Additionally, lacustrine deposits crop out above the Snake River north of Hoback Junction $7\frac{1}{2}$ miles north (Love, 1976, personal communication).

Based on the physical characteristics of the slide and the nature of the deposits adjacent to it, it is clear that the origin and development of the Bailey Creek landslide was complex. It has been suggested that the landslide resulted in the damming of Bailey Creek and the Snake River. This is implied by the gravel and lacustrine deposits along the Snake River and the conglomerate unit along Bailey Creek. The landslide debris, upon deposition, must have been strongly lithified according to Love (1976, personal communication), forming a durable dam in the Snake River and Bailey Creek.

The landslide originated high on the west flank of Grayback Ridge where strata from the Madison Group and Wells Formation are exposed. Recent mudflows and break-away scarps attest to the basic instability of these strata where they are exposed on dip slopes. The landslide may have been initiated by oversteepening resulting

from erosion by Bailey Creek, saturation of bedding planes, and jointing normal to bedding planes.

Considerable time elapsed between deposition of the landslide units underlying and overlying the breccia unit (Fig. 3) as suggested by the strong lithification of the breccia compared to the adjacent landslide debris. Sheetwash greatly modified and reworked the surface of the initial slide allowing for lithification to occur before the overlying slide covered this surface.

Based on the field relationships, the following history of the Bailey Creek landslide is suggested. During the Pleistocene, a large slip surface developed in the westward-dipping limestone and quartzite of the Madison Group and Wells Formation. A large mass of this water-saturated material moved down the west flank of Grayback Ridge and along Bailey Creek and came to rest near the mouth of Bailey Creek, completely covering strata of the Ankareh, Nugget and Twin Creek formations. As a consequence, Bailey Creek and the Snake River were dammed by the slide debris; coarse cobbles and boulders of Paleozoic and Mesozoic sandstone and quartzite accumulated along the Snake River; and quartzite and limestone gravel along Bailey Creek. Material derived from the landslide was reworked and deposited by sheetwash processes and some of the debris became lithified by ponding and dessication. Following this, a new slide from Grayback Ridge covered the subdued surface. Erosion continued to modify the upper

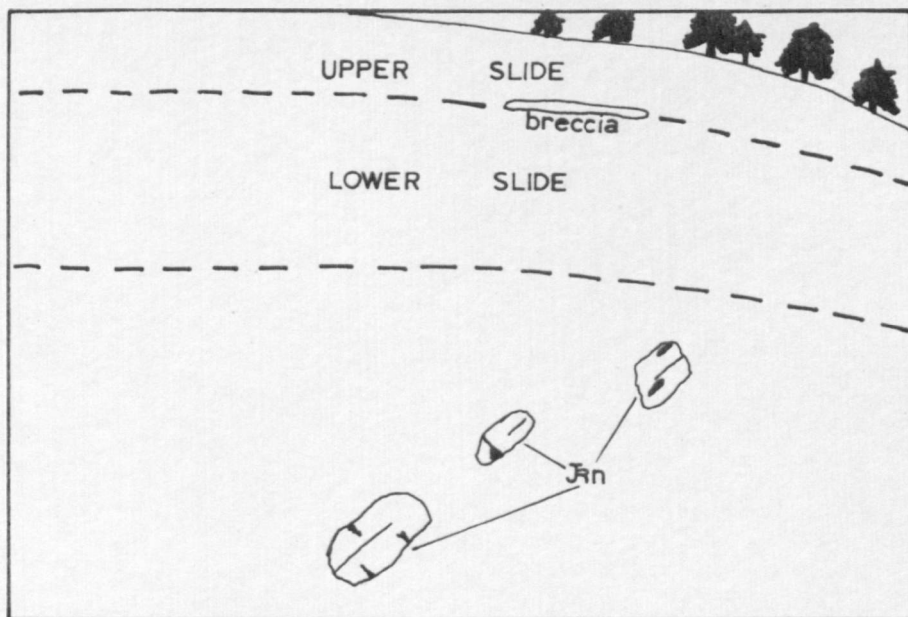


Figure 3. Upper landslide and older lower landslide separated by breccia unit. Note strong lithification of breccia unit compared to adjacent landslide debris. Jn is Nugget Sandstone.

surface of this later slide and lateral streams developed which incised the margins, and the last vestiges of the dam were removed by the Snake River. These sequential events are illustrated in Figure 4.

Terraces

Several terraces border the Snake River Canyon in the map area and north in the Munger Mountain Quadrangle (Albee, 1968). The nature of the deposits forming on the terraces is discussed below (see Cenozoic strata section, page 87) but they generally are covered by well rounded boulders and cobbles. The two terrace sets occur at distinct levels: an older higher surface 200-250 feet above the present river level and a lower surface 10-25 feet above the river. Four miles upstream in the vicinity of Astoria Hot Springs, Albee (1968) mapped two terraces of the older, higher set which are correlatable with the terrace along the west margin of the Bailey Creek landslide, based on the similarity of the elevations above the Snake River. Albee (1968) suggested that these gravel terraces resulted from the damming of the Snake River at the mouth of Bailey Creek.

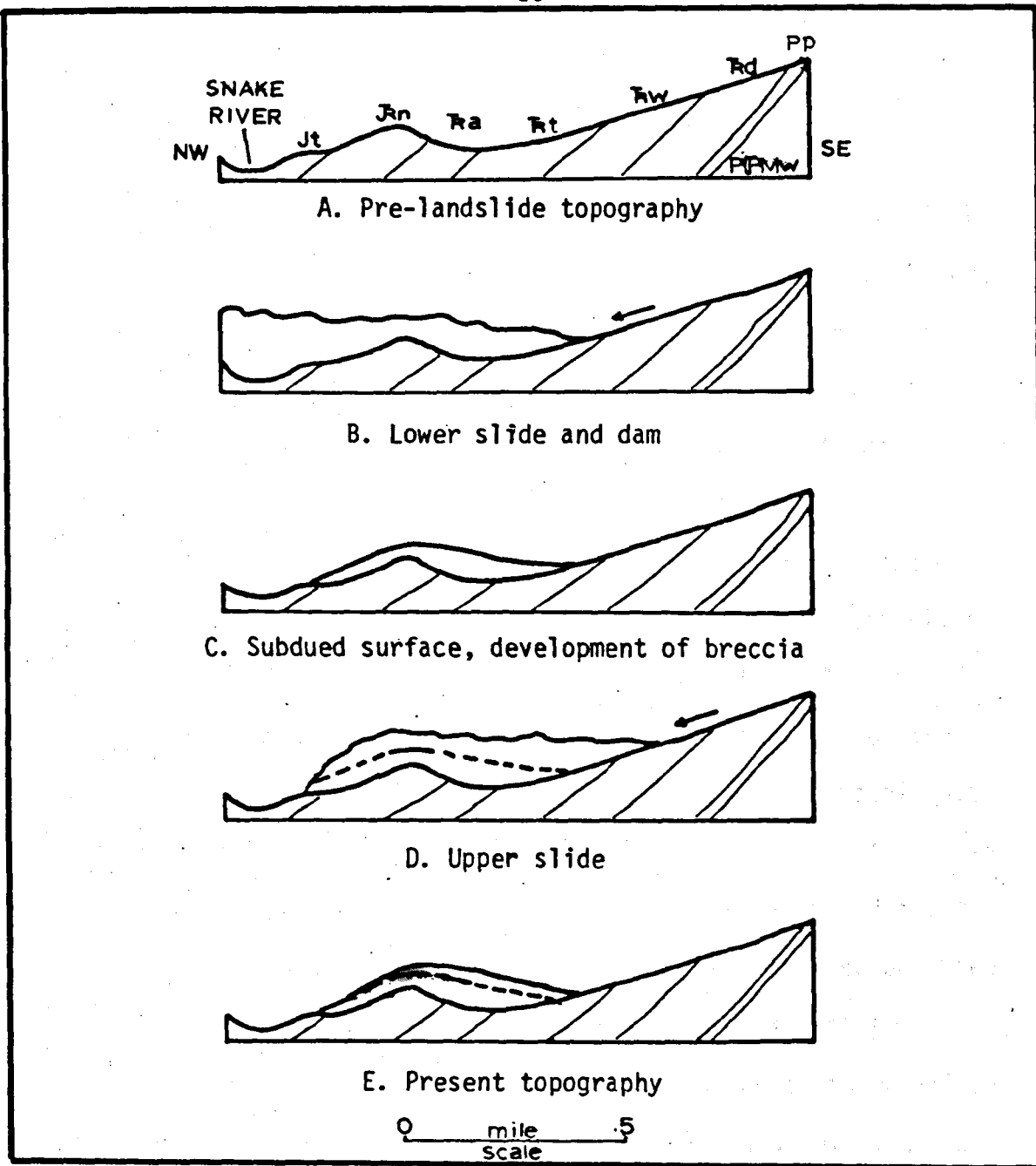


Figure 4. Hypothetical development of Bailey Creek landslide and dam. Formations are (MPPW) Wells Formation, (PP) Phosphoria Formation, (Rd) Dinwoody Formation, (Tw) Woodside Formation, (Rt) Thaynes Formation, (Ra) Ankareh Formation, (Jn) Nugget Sandstone, (Jt) Twin Creek Limestone. Scale approximate.

STRATIGRAPHY

Introduction

The stratigraphic section within the map area consists of Mississippian through Cretaceous strata (Fig. 5). The section is predominantly marine, although nonmarine strata were deposited during the Early Triassic and Early Cretaceous. Clastic rocks dominate the section, although carbonate deposition occurred during the Mississippian, Early Triassic and Middle Jurassic, reflecting the tectonic history of the overthrust belt and adjacent parts of Wyoming, Idaho, and Utah.

The elements of this tectono-sedimentary system consist of a shelf on the east where the strata are thin, and a miogeosyncline on the west where the rocks are thick, and a transitional area between, which includes the overthrust belt. The position of the transitional area shifted throughout the Paleozoic and Mesozoic with major impact on the lithologies and sites of maximum deposition. In Late Triassic time, the miogeosyncline began to break up and a different pattern emerged whereby a high area on the west rose and shed detritus eastward into the marginal basin. Destruction of the miogeosyncline in late Mesozoic time was a precursor to the development of large north-south trending folds and eastward moving thrust faults which eventually resulted in the deformation of the Pine Creek area (Armstrong and Oriel, 1965).

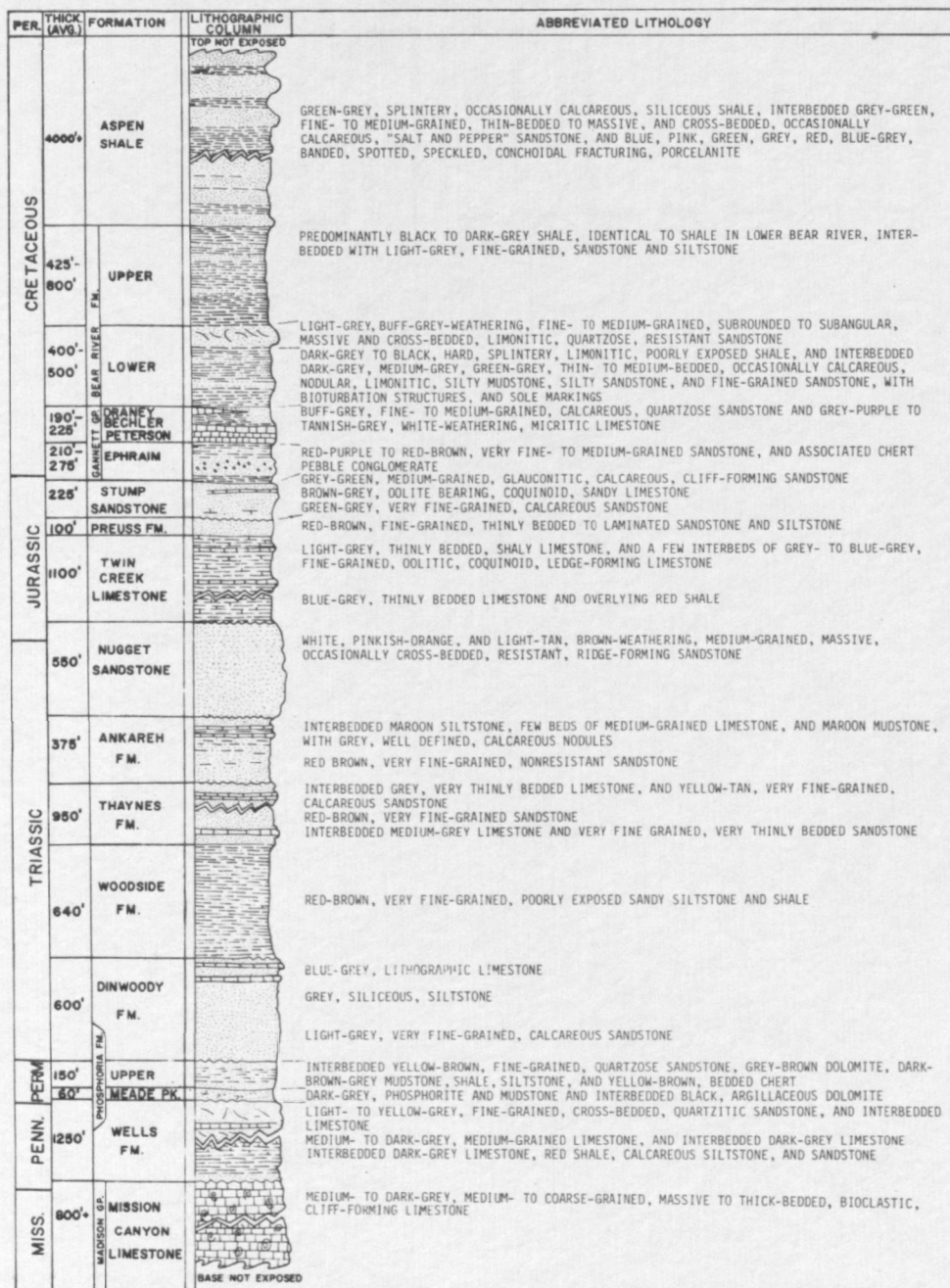


Figure 5. Generalized stratigraphic section, Pine Creek Quadrangle, south of Snake River. Not to scale.

Paleozoic Rocks

Introduction

The exposed Paleozoic section is approximately 2,260 feet thick in the map area and includes limestone of the Mission Canyon of the Madison Group of Mississippian age, clastics and carbonates of the Wells Formation of Mississippian, Pennsylvanian, and Permian age, and phosphatic mudstone and clastics of the Permian Phosphoria Formation. Exposures of these strata are confined to the northeastern corner of the map area where they form resistant outcrops along the flank of Grayback Ridge.

Mississippian Strata -- Madison Group

Previous Work. The Madison Group, including the overlying Mission Canyon Limestone and underlying Lodgepole Limestone, has been extensively studied throughout its extent in Montana, the Dakotas, Utah, Idaho, and Wyoming. Andrichuk (1955) studied the stratigraphy and sedimentation of the Madison Group in Wyoming and southern Montana. Strickland (1956), and Sando and Dutro (1960) investigated the Madison in western Wyoming, and Sando (1967a) studied the Madison in portions of the overthrust belt, including areas adjacent to the Pine Creek Quadrangle. Wanless et al. (1955) measured sections of the Madison Group at Pow Wow Point one mile east of the northeast corner of the Pine Creek Quadrangle, at Hoback Canyon east of the

map area, and at other localities in the Teton, Gros Ventre, and Snake River ranges.

Age and Contacts. The age of the Madison Group has been well documented by abundant fossil data and represents an interval of virtually continuous deposition from early Kinderhook to early Meramec time (Sando, 1967b). The contact of the Madison with the underlying Darby Formation of Devonian age is a regional unconformity (Benson, 1966). A dark shale unit overlies the Darby and underlies the Lodgepole throughout the thrust belt and southwestern Montana (Benson, 1966, Fig. 2) that should be included with the Madison in western Wyoming (Benson, 1966). The contact of this unit with the overlying Madison Group is a disconformity, although the time interval represented by the gap is short (Haun and Kent, 1965). This shale unit was deposited at the same stratigraphic position as the Cottonwood Canyon member of the Madison Limestone of west-central Wyoming (Love and Keefer, 1969).

Correlations. The Madison Group has had a confusing history of nomenclature as outlined by Sando and Dutro (1960, 1974). Collier and Cathcart (1922) were the first to use the name Madison as a group in their work in the Little Rocky Mountains of Montana and divided it into an overlying Mission Canyon Limestone and underlying Lodgepole Limestone. Andrichuk (1955) and Strickland (1956) separated the Madison Group into a tripartite division but Sando

and Dutro (1960) rejected these subdivisions and recognized only the Lodgepole Limestone and Mission Canyon Limestone in western Wyoming. This twofold nomenclature has persisted and is used throughout Montana as well. East of the overthrust belt, the name Madison Limestone is used because the Lodgepole and Mission Canyon Limestone are not recognizable as distinct lithic units (Sando, 1967a, p. 537). West of the thrust belt in southeastern Idaho and northwestern Utah, the Lodgepole Limestone name is used and the Brazer Dolomite is the approximate temporal and lithic equivalent of the Mission Canyon Limestone (Sando, 1967b, p. 35).

Lithology. Only the upper 800 feet of the Mission Canyon Limestone is exposed in the extreme northeastern part of the map area. Here, it consists of medium- to dark-grey, medium- to coarse-grained, massive- to thick-bedded, bioclastic limestone that forms prominent cliffs. The upper part of the Mission Canyon contains a few dolomitic limestone and brecciated limestone beds. The Lodgepole in the adjacent Ferry Peak Quadrangle is composed of dark-blue-grey to medium-grey, thin- to medium-bedded, very fine-grained limestone with abundant bioclastic beds in the upper part (Jobin, 1972).

The lithology of the Madison Group is remarkably uniform throughout its extent consisting mainly of carbonate strata with very few clastic interbeds. The most significant change in lithology is the high percentage of dolomite in the area which roughly corresponds

with the Wyoming shelf. In southeastern Idaho, the overthrust belt, and southwestern Montana, dolomite is a minor lithologic component (Andrichuk, 1955). Locally, east of the map area near Cream Puff Mountain in the lower end of Hoback Canyon, the Mission Canyon Limestone contains several beds of gypsum up to 50 feet thick (Wanless et al., 1955).

Environment of Deposition. The depositional environment of the Madison Group in the study area was open marine with moderately deep water during deposition of the Lodgepole and shallower water during deposition of the Mission Canyon. During the Late Mississippian regression (Haun and Kent, 1965), parts of the sea became barred (lower Hoback Canyon area) and evaporites were precipitated in restricted basins. Eventually, a karst surface developed on the exposed Madison strata and the ensuing solution effects extended down to the evaporite beds, leaching out soluble constituents and producing collapse breccias (Sando, 1967b).

Pennsylvanian Strata -- Wells Formation

Previous Work. Not much significant work has been done on the Upper Mississippian to Lower Permian Wells Formation since it was named by Richards and Mansfield (1912) for exposures in Wells Canyon, Idaho. However, several papers have been published on the lithologically and temporally equivalent Amsden and Tensleep formations of

west-central and central Wyoming (see Mallory, 1967). Wanless et al. (1955) utilized Amsden and Tensleep terminology and measured a section on the west flank of Grayback Ridge, directly across from Cabin Creek on the northern border of the map area, and at Hoback Canyon, five miles to the northeast.

Age and Contacts. The age of the Wells Formation is complicated by the lack of diagnostic faunal data and is based on the ages of its temporal and lithic equivalents. The Wells is considered to be Mississippian to Permian in age by U.S. Geological Survey geologists in the area (e.g., Albee, 1968, Jobin, 1972). The Mississippian (Chester) age is based on the age assignment of the underlying Amsden Formation (Mallory, 1967) which was included in the Wells in the map area. The lithologically and temporally equivalent Tensleep Sandstone is lowermost Permian (Wolfcamp) at the western limit of its exposure (Mallory, 1967). A Permian age is also indicated by the conformable contact of the Wells with the overlying Grandeur Member (Leonard) of the Park City Formation in southeastern Idaho (McKelvey et al., 1959) which was also mapped with the Wells in the Pine Creek area. A regional disconformity is present at the base of the Wells where the Amsden is in contact with the underlying Madison Group, although the nature of this contact is not discernable in the study area.

Correlations. Use of the name Wells Formation is confined to westernmost Wyoming south of Jackson, extreme southeastern Idaho, and northern Utah. Amsden and Tensleep terminology is used in the Gros Ventre Range and eastward for strata deposited during the same time as the Wells. In southwestern Montana and Yellowstone Park, the Quadrant Formation and underlying Amsden are equivalent to the Wells.

Lithology. In the map area the Wells Formation is approximately 1,250 feet thick and can be divided into two major units. The lower unit of the Wells consists of medium- to dark-grey, medium-grained limestone and interbedded dark-grey limestone in the upper part and interbedded dark-grey limestone, red shale, and yellow-grey to red, calcareous siltstone and sandstone in the lower part (Jobin, 1972). The upper unit predominantly consists of light- to yellow-grey, fine-grained, cross-bedded, quartzitic sandstone and some interbedded, medium-grey, white-weathering, massive, cherty dolomite and dolomitic limestone. Sandy, massive limestone beds, probably equivalent to the Grandeur tongue of the Park City Formation, were included with the upper few feet of the Wells in the map area.

At the type locality, the Wells includes a lower sandy and cherty limestone unit, a middle sandy unit, and an upper calcareous sandstone or siliceous limestone unit (Richards and Mansfield, 1912). McKelvey et al. (1959, p. 15) later assigned the upper siliceous

limestone to the Grandeur Member of the Park City Formation. Although Richards and Mansfield's type section description is generalized, their middle unit is somewhat less quartzitic with calcareous sandstone and limestone predominating and their upper unit is dominated by limestone, the opposite of that found in the Wells in the map area. This trend continues farther to the west where the Oquirrh Formation of southeastern Idaho is predominantly limestone and sandy limestone, intercalated with minor amounts of calcareous sandstone (Beus, 1968, Fig. 10). East and north of the Pine Creek area the Wells equivalents are lithologically similar to the Wells in the study area (see Wanless et al., 1955, p. 31-34, Plate 18).

The underlying Amsden Formation throughout its extent in Wyoming can be separated into three lithologic divisions: (1) a basal sandstone, the Darwin Member, (2) a medial red shale unit, and (3) an upper cherty limestone unit (Mallory, 1967). The Tensleep Sandstone is predominantly sandstone and quartzite with broadly lenticular carbonate beds comprising less than 20 percent of the total (Mallory, 1967).

Environment of Deposition. Wells strata were deposited on a broad shelf in western and central Wyoming. Detritus was shed from western and eastern sources (Armstrong and Oriel, 1965) into a basinal area in southeastern Idaho which was appreciably more calcareous than the margins. Early unstableness resulted in the emergence and

submergence of the shelf area which gradually gave way to a partial withdrawal of the sea in Late Pennsylvania time (Mallory, 19/2).

Limestone was deposited alternately with sandstone in the study area as minor fluctuations in the water depth occurred. Wind and current distribution and oscillations of the sea constantly shifted a system of dunes, beaches, barrier islands and carbonate shoals, producing complex interbedding.

Permian Strata -- Phosphoria Formation

Previous Work. Permian age strata are represented by the Phosphoria Formation which has been subdivided into two units which include strata from the intertonguing Shedhorn Sandstone and Park City Formation. Several studies have been undertaken on these rocks since the U.S. Geological Survey began investigating the western phosphate field prior to 1910. A detailed listing of these early contributions is beyond the scope of this paper but an excellent review can be found in Sheldon's (1963) work on the mineral resources and stratigraphy of the Permian rocks of western Wyoming. More recent work on the Phosphoria Formation and its equivalents which includes the area of this study has been undertaken by Sheldon (1955, 1956, 1957), McKelvey et al. (1956, 1959), and McKee et al. (1967). Wanless et al. (1955) measured sections of the Phosphoria Formation

at Martin Creek, just to the north of the map area, and in the adjacent Snake River and Hoback ranges.

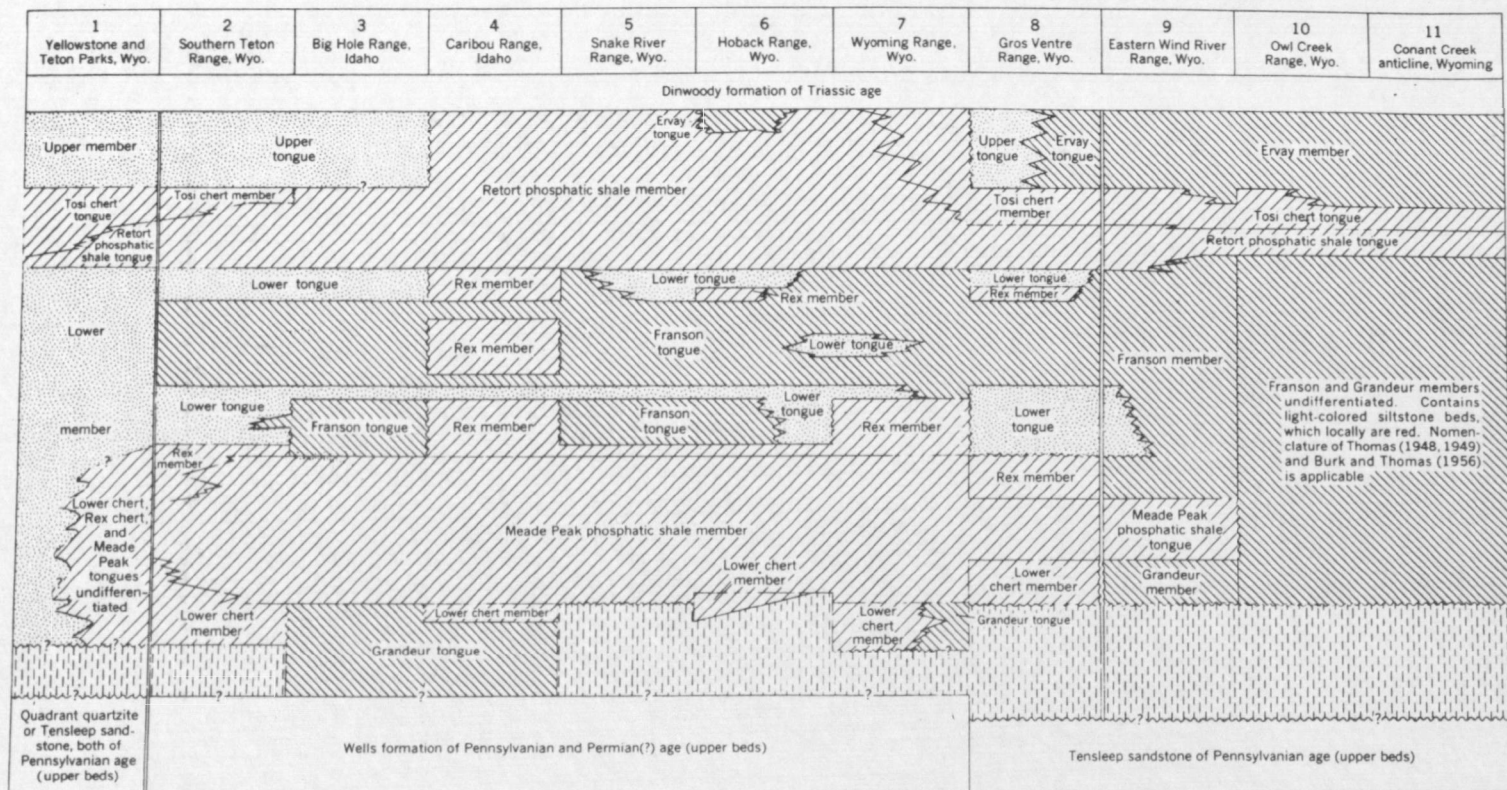
Age and Contacts. The Phosphoria Formation and the rocks that intertongue with it are considered to be Permian in age based on abundant fossil data (McKelvey et al., 1959). The lower contact with the Wells Formation in the Pine Creek Quadrangle is not exposed due to cover so it is undetermined whether or not this contact is conformable there. However, in the north part of the adjacent Wyoming Range, Sheldon (1963, p. 84) indicated that the Meade Peak Member of the Phosphoria Formation rests with sharp disconformity on the Wells. Richards and Mansfield (1912, p. 692) noted in this same region the absence of the Grandeur Member and the presence of a basal breccia. This erosional hiatus increases in magnitude from the study area to the Big Horn Basin of central Wyoming where as much as 130 feet of Tensleep Sandstone may have been eroded (Agatston, 1954).

Correlations. A severe problem has existed with Phosphoria Formation nomenclature. A discussion of the problem is beyond the scope of this paper but an excellent description is provided by McKelvey et al. (1959) and Sheldon (1957) and a solution and justification are presented by McKelvey (1959). The problem arose because of the intertonguing of members and tongues of the Phosphoria, Park City, and Shedhorn formations, and the lensing nature of some of the beds. These strata include, from base to top, the lower chert, Meade

Peak Phosphatic Shale, Rex Chert, Retort Phosphatic Shale, and Tosi Chert members of the Phosphoria Formation. The Grandeur, Franson, and Ervay members make up the Park City Formation from base to top, and the Shedhorn Sandstone consists of the lower and upper members. The nomenclature and intertonguing relationships are summarized in Figures 6 and 7.

Following the precedent set by U.S. Geological Survey geologists, the Phosphoria Formation was divided into lower and upper units for purposes of mapping in the Pine Creek Quadrangle. The lower unit consists of the Meade Peak Member, and the upper unit includes the Rex Chert Member, Retort Phosphatic Shale Member, the lower tongue of the Shedhorn Sandstone, and the Franson Tongue of the Park City Formation. All other members were not present in the map area.

Lithology. The lower Phosphoria in the Pine Creek Quadrangle consists of 60 feet of dark-grey to dark-brown phosphorite and mudstone with a few thin interbeds of black, argillaceous dolomite. The phosphorite occurs as oolites, pisolites, pellets, and as dense structureless types. The lower Phosphoria does not contain any resistant rocks and forms a low, densely vegetated swale that is underlain by black soil. The upper Phosphoria is 150 feet thick and includes dark-brownish-grey mudstone, shale, and siltstone with interbedded phosphorite of the Retort Phosphatic Shale Member, friable, yellow-brown, fine-grained, quartzose sandstone of the lower tongue



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E X P L A N A T I O N

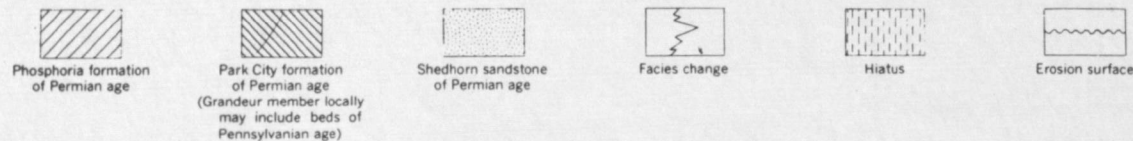


Figure 6. Nomenclature and intertonguing relationships of rocks of Permian age of western Wyoming and southeastern Idaho. Refer to Figure 7 for index map (Sheldon, 1963).

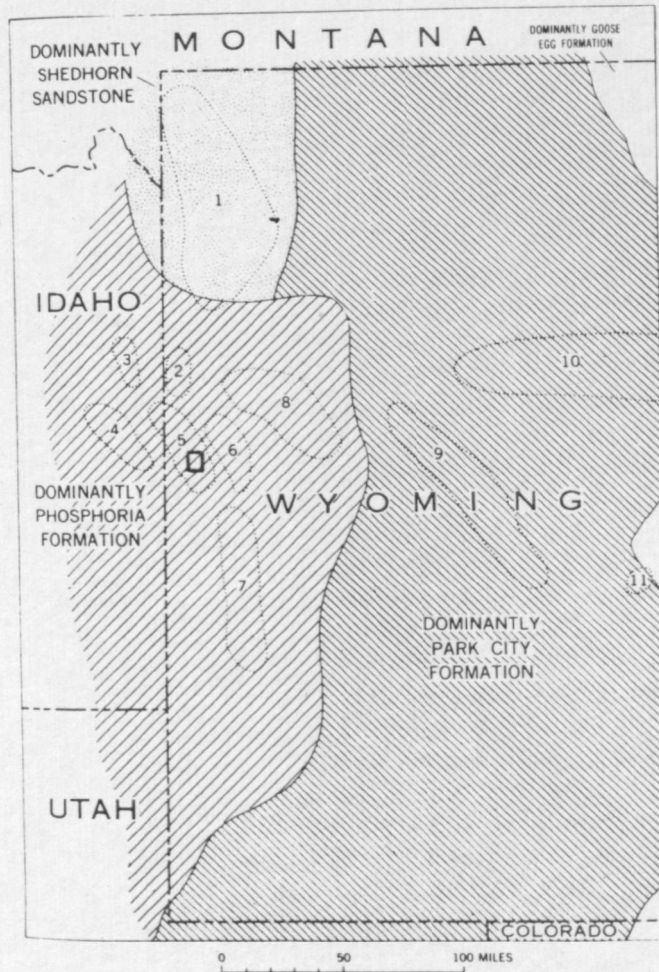


Figure 7. Index map for Figure 6. Symbols and patterns same as for Figure 6 (Sheldon, 1963). Pine Creek Quadrangle outlined.

of the Shedhorn Sandstone, grey-brown, massive dolomite of the Franson Tongue, and yellow-brown to yellow, bedded chert of the Rex Chert Member. The upper unit of the Phosphoria is only slightly more resistant than the lower unit.

The Phosphoria Formation and associated rocks of Phosphoria age show a wide lithologic variation. Generally the dominant facies in southwestern Idaho, western Wyoming, southwestern Montana, and northwestern Utah includes dark shale, phosphorite, and chert; in northwestern Wyoming, sandstone; in west-central and northern Utah, carbonate; and in central and eastern Wyoming, light-colored greenish and reddish shale. These facies interfinger, and tongues of each facies type extend long distances into areas dominated by other types (Sheldon, 1963). In addition to these generalized facies types, Sheldon (1963, p. 74) noted an interesting relationship between chert and apatite. Regionally, the distribution of apatite and chert increases to the west, but where apatite is locally concentrated, chert is impoverished. Chert and dark mud have a similar inverse relationship but chert extends farther east than either dark mud or apatite and the quantity of dark mud is greatest in southeastern Idaho.

Environment of Deposition. The environment of deposition of the Phosphoria Formation and associated Permian rocks in the study area was extremely varied but, in general, was open marine with the

deepest parts in east-central Idaho and adjacent parts of Montana and Utah (McKelvey et al., 1959). Shoaling of the sea floor increased to the east with the eastern margin represented by restricted shallow basins. Due to tectonic movements, the above-described facies transgressed and regressed across western Wyoming two times, and minor fluctuations of climatic and oceanographic conditions produced the intricate interbedding (McKelvey et al., 1959).

Mesozoic Rocks

Introduction

The Mesozoic section in the map area, in excess of 10,000 feet thick, includes siltstone, sandstone, and limestone of the Triassic Dinwoody, Woodside, Thaynes and Ankareh formations; the Triassic (?) - Jurassic (?) Nugget Sandstone; and limestone of the Jurassic Twin Creek, Preuss, and Stump formations; and the shale and sandstone of the Cretaceous Gannett Group and Bear River and Aspen formations (Fig. 5). These Mesozoic rocks cover the major portion of the Pine Creek Quadrangle from the flank of Grayback Ridge to the Absaroka thrust, west of the border of the map.

Triassic Strata -- Previous Work

Strata of Triassic age include, in ascending order, the Dinwoody, Woodside, Thaynes, and Ankareh formations (Fig. 8).

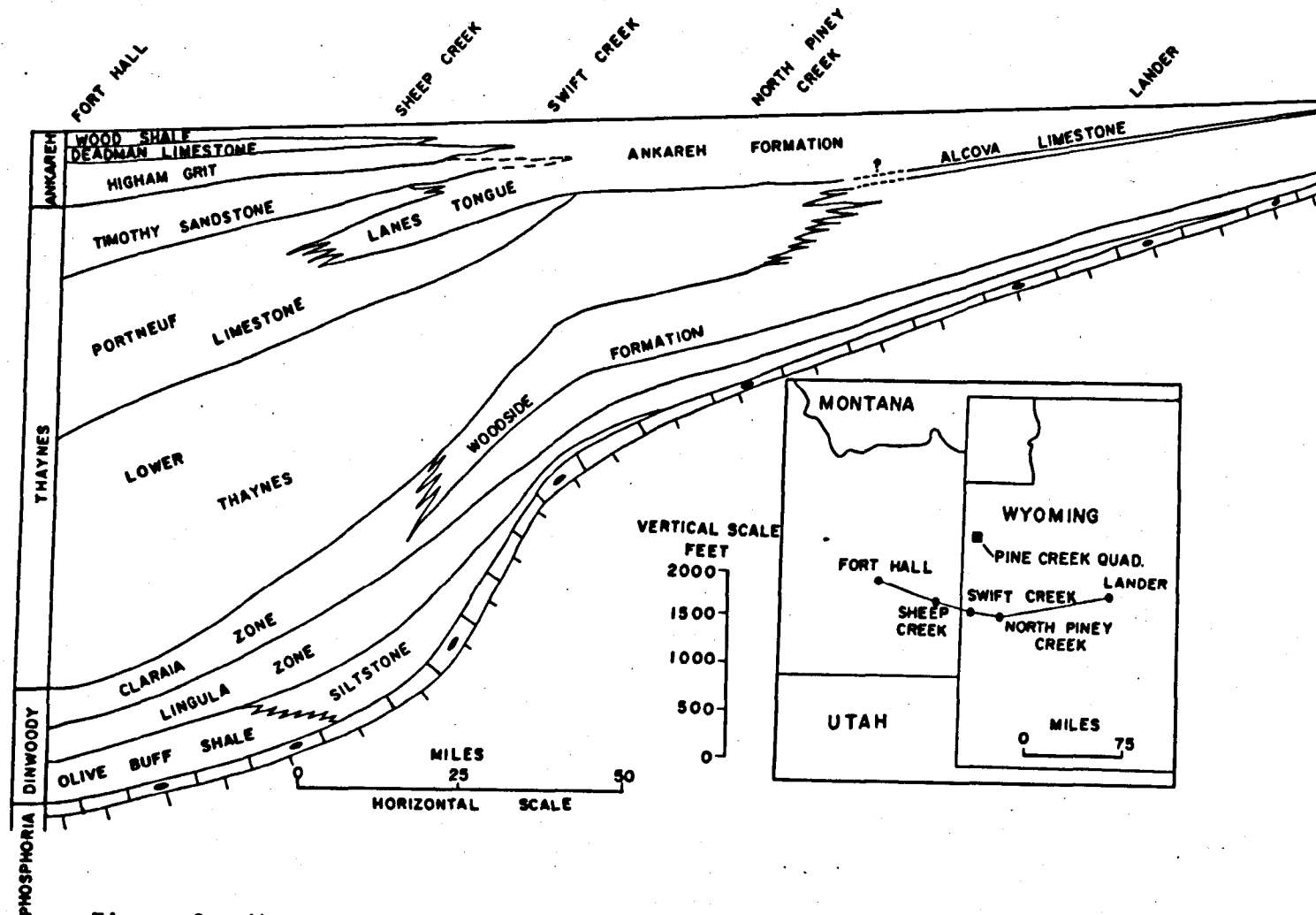


Figure 8. West-east cross-section showing stratigraphic relationships for the Triassic of western Wyoming and southeastern Idaho. Note intertonguing relationships and onlap of Dinwoody over Phosphoria and Thaynes over Woodside (after Kummel, 1954, 1955).

Previous work on these formations has consisted of regional stratigraphic studies covering western Wyoming and adjacent areas of Idaho. Newell and Kummel (1942) concentrated on Lower Triassic strata of the thrust belt region and Mansfield (1920) and Kummel (1954) reported on the Triassic section throughout the overthrust belt and adjacent parts of southeastern Idaho. Picard et al. (1969) reported on the Thaynes Formation and its equivalents, from extreme eastern Idaho to west-central Wyoming, and High and Picard (1969) examined the Ankareh and its lithologic and temporal equivalents at Munger Mountain, 6 miles north of the study area, and at other localities in central Wyoming. Newell and Kummel (1942) measured a partial section of Triassic strata within the map area just to the north and east of the Bailey Creek landslide along the west flank of Grayback Ridge. Wanless et al. (1955) measured Triassic sections at Munger Mountain, Red Pass, 4½ miles north of the map area, and at Hoback Canyon.

Dinwoody Formation

Age and Contacts. The Early Triassic (Otoceratan to Flemingtan) age of the Dinwoody Formation has been well documented by faunal evidence (Kummel, 1954). The contact with the underlying Phosphoria Formation appears in some places to be conformable and in others disconformable. In southeastern Idaho, the contact with

the Phosphoria is not well exposed but where it is, it appears to be gradational (Kummel, 1954). Although the contact with the Phosphoria was obscured in the study area, Wanless et al. (1955, p. 41) mentioned the presence of a basal conglomerate a few inches thick "at many places" in the area adjacent to the Pine Creek Quadrangle. Love (1939, 1948) also noted evidence of a local unconformity between the Phosphoria and Dinwoody formations in this general area. In western Wyoming, Newell and Kummel (1942, p. 938-939) outlined evidence for an unconformity at the base of the Dinwoody as (1) marked leaching of chert beds at the top of the Phosphoria Formation, (2) marked northeastward overlap of lower Dinwoody strata by upper Dinwoody on the Phosphoria surface from southwestern Wyoming into central Wyoming, and (3) discovery by Alfred Fischer (personal communication in Newell and Kummel, 1942) that upper beds of the Phosphoria are locally truncated by basal beds of the Dinwoody Formation. In northern Utah, just east of Provo, there is stronger evidence of an unconformity where the Woodside rests disconformably on the Phosphoria. South, in central Utah, there is also evidence of an erosional disconformity between the Permian Kaibab Limestone and overlying Triassic Moenkopi Formation (Newell and Kummel, 1942, p. 938). These relationships indicate a regional unconformity between the Triassic and Permian that probably increases in magnitude between the study area and northern Utah. However, Oriel (in McKee

et al., 1959, p. 3-4) offered an alternative hypothesis and suggested that the contact between the Phosphoria and Dinwoody could be explained by regressive overlap. If this is true, then little, if any, time elapsed between deposition of these units. Continuous deposition is also suggested by a crude similarity of the facies patterns between Dinwoody and Phosphoria rocks produced by regressive overlap (Sheldon, 1963). The problem remains unresolved and further studies on the nature of this contact in the northern part of the overthrust belt are needed.

Correlations. The Dinwoody Formation was named by Blackwelder (1918) for exposures in Dinwoody Canyon in the Wind River Range. Dinwoody nomenclature is used throughout the thrust belt, southeastern Idaho, extreme southwestern Montana, and central Wyoming.

Lithology. In the map area, the Dinwoody Formation, roughly 600 feet thick, consists of very light-grey, very fine-grained, calcareous sandstone in the lower part. The upper part includes grey, siliceous siltstone, and occasional beds of bluish-grey, lithographic limestone. The siltstone and sandstone beds are very thinly bedded and resistant, forming distinctive talus. Shale, which is common in the middle part of the Dinwoody in the area adjacent to the Pine Creek Quadrangle (see Wanless et al., 1955), was not encountered in the field area, probably due to the extensive talus cover from the overlying part of the Dinwoody.

Regionally, the lithologic variation in the Dinwoody is not significant. Newell and Kummel (1942, p. 941) subdivided the Dinwoody into three major, lithologically distinct units which are fairly extensive. The lowest unit, the basal siltstone, consists of friable, unfossiliferous, buff siltstone. This sequence has not been observed in southwestern Idaho; the facies equivalent there is represented by a buff silty shale. The medial unit is the Lingula zone which consists predominantly of silty, olive-buff to grey shale intercalated with thin, blocky limestone, ranging from dark-bluish-grey to brown. These strata are characterized by profuse well-preserved Lingula. The upper unit, the Claraia zone, the most extensive sequence, is typified by locally abundant molds of the pelecypod Claraia. Lithologically, it consists of resistant, light-brown, calcareous siltstone beds less than one foot thick. This unit also contains local, interbedded, light-grey, silty limestone and is differentiated from the medial zone by the small amount of shale. These strata are deposited in an onlap relation as illustrated in Figure 8. In the southern Wind River Mountains, the upper Claraia zone rests directly on the Phosphoria Formation (Newell and Kummel, 1942).

Environment of Deposition. During the early Triassic, a transgression of the sea resulted in open marine conditions in southeastern Idaho and western Wyoming. Water depth was greatest in

southeastern Idaho where shale was deposited. Most of western Wyoming was a broad shelf with shallow water, a well-aerated sea-floor, and active bottom currents (Kummel, 1955).

Woodside Formation

Age and Contacts. Although the Woodside Formation is barren of fossils, it is considered to be of Early Triassic age, based on its stratigraphic relationship with the overlying Early Triassic Thaynes Formation. Furthermore, in southeastern Idaho, the lower half of the Woodside is the time equivalent of the Lower Triassic Dinwoody Formation (Fig. 9) on the basis of the intertonguing relationships of the units (Newell and Kummel, 1942). A zone of intertonguing of the Dinwoody and Woodside follows a line from southwestern Montana along the Idaho-Wyoming border that turns abruptly westward in northern Utah. Red beds are predominant east of this line, and subordinate to the west (Kummel, 1955). The nature of the contact of the Woodside and Dinwoody formations within the field area is indeterminable because of talus cover.

Correlations. The Woodside Formation was named by Boutwell (1907) for strata exposed in Woodside Canyon near Park City, Utah. Woodside terminology is utilized throughout the thrust belt, northern Utah, and southeastern Idaho because the Woodside retains its lithologic integrity over this area. East of the thrust belt in central

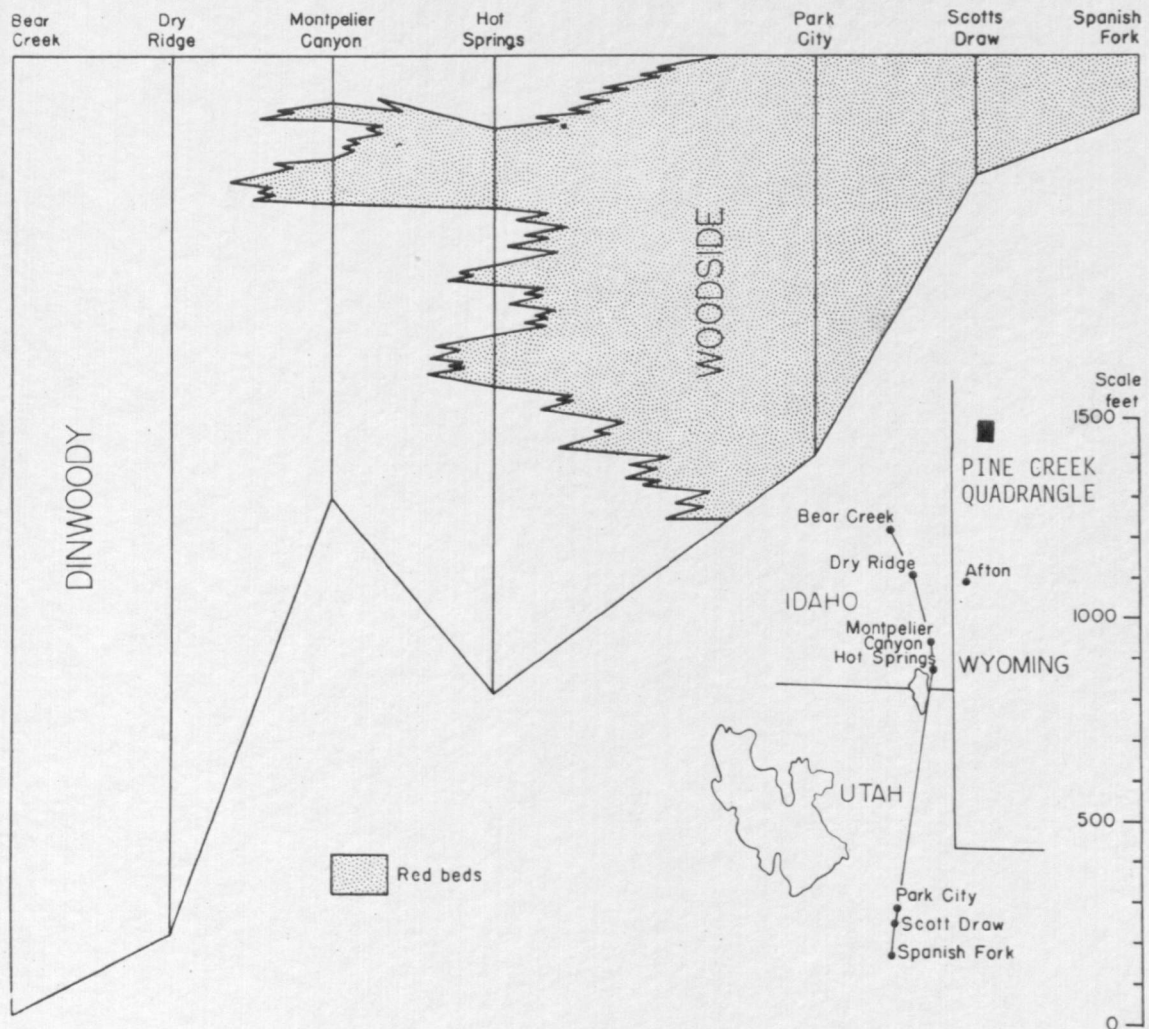


Figure 9. Correlation diagram of Dinwoody and Woodside formations showing intertonguing relationships between Provo, Utah and Henry, Idaho and the resultant time equivalency of the lower part of these units (Kummel, 1953).

Wyoming, the Woodside is partly temporally equivalent to the Red Peak Formation (Fig. 10) of the Chugwater Group (Picard, et al., 1969).

Lithology. In the map area, the Woodside Formation consists of 640 feet of red-brown, very fine-grained, sandy siltstone and shale. These lithologies are generally very poorly exposed but the formation is easily mapped on the basis of the red color of the soil.

Throughout its area of exposure, the Woodside shows negligible variation in lithology. Newell and Kummel (1942) reported the presence of a few thin beds of limestone in Woodside sections in the Hoback and Gros Ventre ranges and Kummel (1954, p. 171) mentioned a few thin non-red beds in the Salt River Range. In northern Utah and in the Uinta and Wasatch ranges, the Woodside consists almost entirely of red beds; only a few thin non-red beds are present (Kummel, 1954). It is extremely probable that these non-red lithologies represent a tongue of the underlying marine Dinwoody. Picard et al. (1969, p. 2278) speculated that the Woodside at the Munger Mountain section is probably correlative with part of the lower platy facies and underlying silty claystone facies of the Red Peak Formation of west-central Wyoming (Fig. 10).

Environment of Deposition. The environment of deposition of the Woodside was continental on westward- and northward-prograding deltas and coastal plains. The presence of occasional beds of marine

WESTERN WYOMING

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WEST-CENTRAL WYOMING

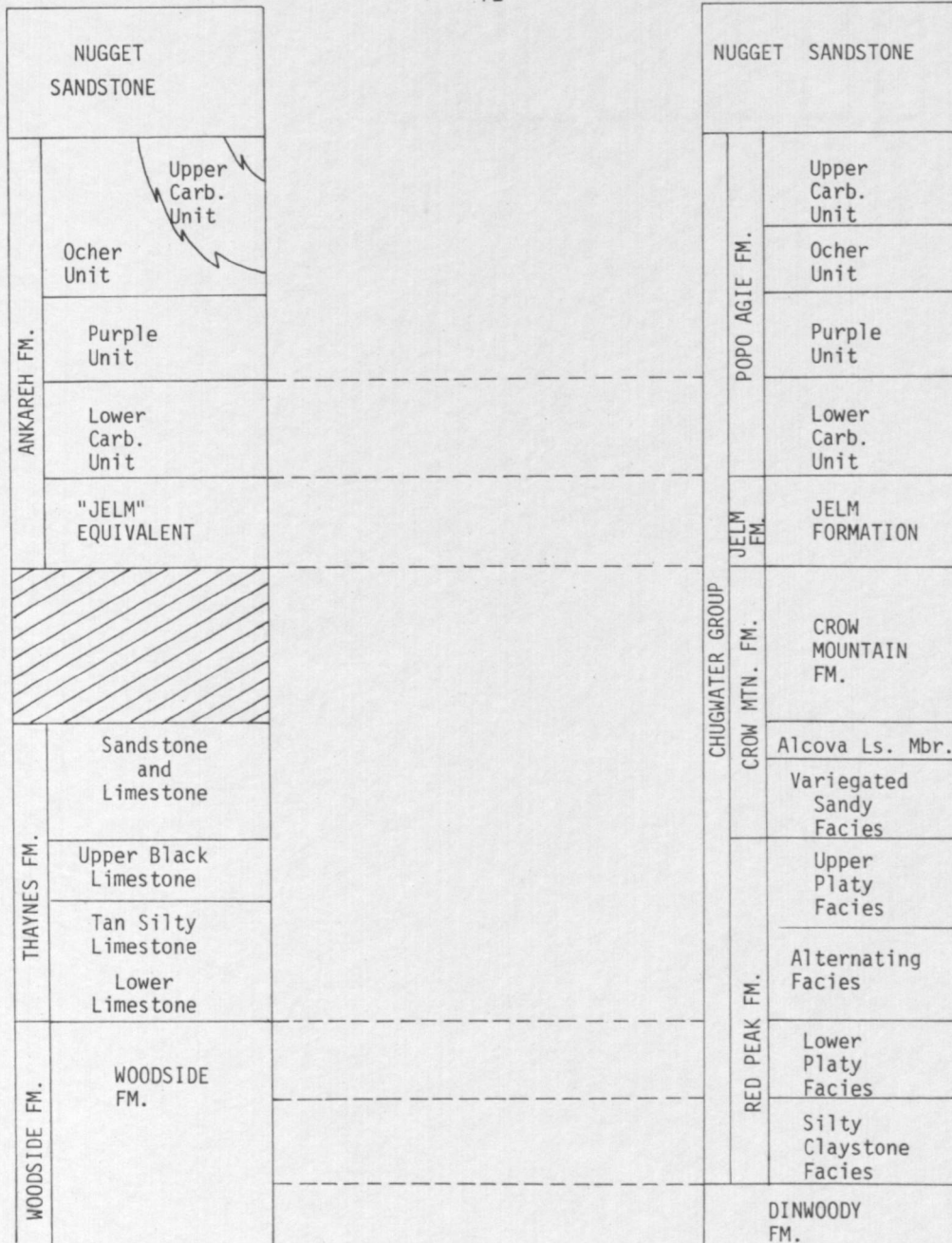


Figure 10. Nomenclature and stratigraphic correlations of Middle and Upper Triassic formations in western and west-central Wyoming (after Picard *et al.*, 1969, and High and Picard, 1969).

limestone suggest that tectonic oscillations allowed the Dinwoody sea to periodically invade this broad coastal plain-delta complex.

Thaynes Formation

Age and Contacts. The Thaynes Formation is considered to be Early Triassic in age according to Kummel (1954, 1955) on the basis of fossil data. Dating of this unit is made more difficult by the intertonguing relationship with the overlying Ankareh and the underlying Woodside formations. A facies dividing line, similar to that of the Woodside, exists for the Thaynes Formation, and passes southward from the Idaho-Wyoming boundary through the Wasatch Mountains of Utah. East of this line, red beds are common, and to the west, red beds are absent or of minor importance (Kummel, 1955). Complications of this pattern are created by an eastward-extending marine tongue of the Thaynes, the Alcova Limestone, which at various times has been correlated with many parts of the Thaynes and post-Thaynes rocks but is now considered by Picard et al. (1969) to be an upper tongue of the Thaynes. To the west, the Lanes Tongue of the overlying Ankareh Formation extends into the upper Thaynes but is not present as far west as Fort Hall, Idaho (Fig. 8) (Kummel, 1954, 1955). This tongue may be represented in the map area by the red-brown, very fine-grained sandstone that occurs near the middle to upper part of the Thaynes.

The Thaynes is in an onlap relationship with the Woodside on the east. This pattern is complicated, however, by intertonguing relationships and the stratigraphic position of the eastward extending Alcova Limestone. These relationships are illustrated in Figure 3. This contact was obscured in the study area.

Correlations. Boutwell (1907) named the Thaynes for exposures in Thaynes Canyon, near Park City, Utah. Correlations based on stratigraphic position of the Thaynes Formation with equivalents in surrounding regions is made more difficult by intertonguing and facies changes. Mansfield (1916) raised the Thaynes Formation to Group rank and designated three formations, in ascending order, the Ross Fork Limestone, the Fort Hall Formation, and the Portneuf Limestone. The lack of persistence of these formations, however, resulted in the abandonment of Mansfield's scheme, although the name Portneuf Limestone was given member status by Kummel (1954, p. 172) because it is more persistent than the other two units. Kummel (1954, p. 172) also included the Timothy sandstone member in the upper Thaynes in southeastern Idaho (Fig. 8). East of the thrust belt in central Wyoming, the Thaynes is the partial temporal equivalent of the Red Peak and Crow Mountain formations (Fig. 10) of the Chugwater Group (Picard et al., 1969). The Alcova Limestone in this region is also correlated with the upper Thaynes.

Lithology. In the Pine Creek Quadrangle, the Thaynes Formation consists of a lower unit of interbedded, medium-grey, medium-bedded, limestone and very fine-grained, very thinly bedded sandstone; a medial unit of red-brown, very fine-grained sandstone; and an upper unit of grey, very thinly bedded lithographic limestone, and yellow-tan, very fine-grained, calcareous sandstone. In addition, a 4 foot thick basal breccia unit occurs in the Thaynes Formation approximately one-half mile south of the Bailey Creek landslide. Here, the angular and occasionally subrounded clasts, up to $3\frac{1}{2}$ inches in diameter, are imbedded in a silty, calcareous matrix. This unit was not observed north of this locality. The Thaynes Formation is approximately 950 feet thick in the Pine Creek Quadrangle, though poor exposure of the upper contact with the Ankareh made accurate measurements impossible.

In the region adjacent to the map area, the Thaynes Formation does not show significant lithologic variation. Kummel (1954, p. 173) proposed that the Thaynes Formation in southeastern Idaho be subdivided into seven lithologic units which are, in ascending order:

- (1) lower limestone, (2) lower black limestone, (3) tan silty limestone, (4) upper black limestone, (5) sandstone and limestone,
- (6) the Portneuf Limestone, and (7) the Timothy Sandstone Member.

Picard, et al. (1969, p. 2280-2281) suggested that Kummel's lithologic divisions, with the exception of the Portneuf Limestone, can be

correlated between southeastern Idaho and western Wyoming, based on lithologic similarity, thickness changes, and interpreted facies.

Environment of Deposition. A second advance of the Early Triassic sea resulted in deposition of the Thaynes Formation in western Wyoming and the interfingering of these marine deposits with continental rocks along the margins of the sea. Due to the abundance of dolomite and gypsum in the Hoback and Munger Mountain sections, Picard et al. (1969) proposed that the Thaynes in this area was deposited in a shallow-water marine environment that was restricted by carbonate banks in eastern Idaho.

The basal breccia unit in the Thaynes in the map area may have resulted from a local shoaling, suggesting a disconformity between this unit and the underlying Woodside. If this shoal were exposed for a sufficient period of time, desiccation of the Woodside sediments would have occurred. Coarse clasts, removed by subaerial erosion, would have been transported short distances and deposited in the surrounding basin.

Ankareh Formation

Age and Contacts. The age of the Ankareh Formation is questionable because no diagnostic fossils have been found but it is considered to be of Middle or Late Triassic age by Kummel (1954), based on its stratigraphic position. In central Wyoming, the partly

temporally equivalent Crow Mountain and Jelm formations are separated by a pronounced disconformity according to High and Picard (1969, p. 1995). They suggested that this Middle Triassic hiatus can be correlated with a similar disconformity in northeastern Utah that separates the Triassic Moenkopi and Garta formations. Furthermore, the Timothy Sandstone is unconformably overlain by the Higham Grit, suggesting that this hiatus is present in southeastern Idaho (Kummel, 1954). No evidence of an unconformity was noted between the Ankareh and Thaynes in the study area, but based on the disconformable relationships in the surrounding region, it is probable that the contact between these two formations is not conformable.

Correlations. The Ankareh Formation was named by Boutwell (1907) for strata exposed near Park City, Utah. He originally included an overlying, prominent white sandstone, the Nugget, but later (1912) restricted the name Ankareh to include all strata overlying the Thaynes and underlying the Nugget. In southwestern Idaho, Mansfield (1927) recognized the following post-Thaynes Triassic rocks: Timothy Sandstone, Higham Grit, Deadman Limestone, and Wood Shale, in ascending order (Fig. 8). To avoid confusion, Kummel (1954, p. 179) proposed reducing all previously named post-Thaynes strata in northern Utah and western Wyoming to member rank and using the name Ankareh for these rocks. In addition, he assigned the Timothy Sandstone to the uppermost part of the Thaynes, designated the Higham Grit and

Deadman Limestone as independent formations, and considered the Wood Shale to be a western extending tongue of the Ankareh (Fig. 8). East of the thrust belt in central Wyoming, the Ankareh is the temporal equivalent to the Popo Agie and underlying Jelm formations (Fig. 10) of the Chugwater Group (High and Picard, 1959).

Lithology. The Ankareh is generally very poorly exposed within the map area, concealed beneath a talus cover from the overlying Nugget. At the best exposure on the northern margin of the Bailey Creek landslide, it consists of a lower unit of red-brown, very fine-grained sandstone and an overlying unit of maroon siltstone, both of which weather to a red soil. Grey, round, well defined, calcareous nodules and a few, thin, grey, medium-grained limestone beds occur in the upper siltstone unit at the mouth of Cabin Creek along the northwestern border of the map area and farther north at Munger Mountain. Within the map area, the Ankareh Formation is estimated to be 350-400 feet thick, although accurate measurements were difficult to obtain because of the poor exposure.

Regionally, the Ankareh shows several significant lithologic changes. In central and west-central Wyoming, the Jelm Formation consists of argillaceous limestone, carbonate-cemented sandstone, and red siltstone and sandstone (High and Picard, 1969). At Munger Mountain, north of the map area, the lower part of the Ankareh includes a tongue of the Jelm which consists of red, platy siltstone.

The middle beds here consist of the lower carbonate unit of the Popo Agie Formation which, according to High and Picard (1969, p. 1006), is little changed from the eastern sections of central Wyoming. The upper Ankareh at Munger Mountain includes limestone and siltstone, and pebbly conglomerate which is interpreted to be a facies change in the ocher unit of the Popo Agie of west-central Wyoming (High and Picard, 1969). Figure 10 summarizes these relationships. Love (1948, p. 99-100) described the Popo Agie Formation in the area from eastern Jackson Hole to the Wind River Mountains as:

...ocher colored, oolitic, siliceous, dolomitic claystone, with limestone pellet conglomerate, purple and red shale, and red silty sandstone. A widespread zone of highly siliceous, bright, ocher-colored dolomitic claystone containing numerous siliceous and limy geodes and siliceous oolites in great abundance is present near the top of the member.

This lithology is similar to the Ankareh in the region adjacent to the map area. The Deadman Limestone and Timothy Sandstone of southeastern Idaho are, according to Kummel (1954), correlative to similar sections of Ankareh measured by Wanless et al. (1955) in the vicinity of the map area.

Environment of Deposition. The Ankareh Formation records a variable and changing depositional environment in southeastern Idaho and western Wyoming. West of the basin, in central Idaho, a northeast-trending ridge rose in early Late Triassic time, shedding coarse detritus eastward to form the Higham Grit (McKee et al., 1959, p. 17).

This event transformed the shallow marine and paralic conditions that prevailed in western Wyoming during deposition of the lower Ankareh to fluvial and lacustrine environments dominant during deposition of the upper Ankareh (High and Picard, 1969).

Jurassic Strata -- Previous Work

Jurassic strata exposed within the study area include the Nugget Sandstone (Triassic ? and Jurassic ?), the Twin Creek Limestone, the Preuss Sandstone, and the Stump Sandstone (Fig. 5). Jurassic strata were examined by Mansfield (1920) in southeastern Idaho, by Imlay (1950) in the overthrust belt, and by Pipiringos (1957, 1968) in south-central Wyoming. Additionally, Dobrovolsky (1941) studied the Jurassic and Cretaceous sequence in the Camp Davis area, 2 miles northeast of the map area. Wanless et al. (1955) measured Jurassic sections at Cabin Creek on the northern border of the map area, at Munger Mountain, and at other localities in the Teton, Gros Ventre, and Hoback ranges. Significant regional work that included the study area was undertaken on the Twin Creek by Imlay (1953, 1967), on the Preuss by Imlay (1952), and on the Preuss and Stump in the area adjacent to the Pine Creek Quadrangle by students from the University of Michigan (Ore, 1975, personal communication).

Nugget Sandstone

Age and Contacts. The true age of the Nugget Sandstone is unknown due to the lack of diagnostic fossil evidence. The overlying Twin Creek Limestone was dated as Middle Jurassic and the underlying Popo Agie Member of the Chugwater Group was dated as Late Triassic (Staatz and Albee, 1966), indicating that the Nugget could be Late Triassic, or Early Jurassic, or both. On the basis of an intertonguing relationship with the Triassic Popo Agie Member, Love (1957) suggested that the Nugget was Triassic. However, High and Picard (1965) demonstrated that the Nugget was separated from the Popo Agie by a disconformity. Some workers (Pipiringos, 1968, Oriel in McKee et al., 1959) concluded that the Triassic-Jurassic boundary lies somewhere within the Nugget. High and Picard (1969), however, postulated a Late Triassic and Early Jurassic tectonic event in Wyoming that resulted in the folding and truncation of the Popo Agie. They concluded, therefore, that the Nugget should be assigned a Jurassic age because of the time involved in the folding and truncation of the Popo Agie. They extended this postulated erosional unconformity to western Wyoming to separate the Ankareh and overlying Nugget. However, no evidence of this relationship can be seen in the map area.

Correlations. Veatch (1907) named the Nugget for strata exposed in southwestern Wyoming and defined it as including a lower red-bed member and an upper light-colored sandstone member. Gale

and Richards (1910, p. 479-480) later restricted the name Nugget to the upper sandstone member and included the red-bed sequence in the Ankareh. Because the Nugget retains its lithologic character in south-central and western Wyoming, southeastern Idaho, and north-eastern Utah, the name Nugget is used throughout this region. The Nugget is the partial temporal and lithologic correlative of the Navajo Sandstone of central Utah (Harshbarger, Repenning, and Irwin, 1957).

Lithology. The Nugget in the map area is a brown-weathering, white, pinkish-orange, and light-tan, medium-grained, massive, quartzitic sandstone. It is occasionally cross-bedded, and ripple marks have been observed in the Nugget adjacent to the Pine Creek Quadrangle (Wanless et al., 1955, p. 47-48). It is a prominent ridge former and produces a coarse, distinctive, brown talus. In the map area, the Nugget Sandstone is 550 feet thick where the most accurate measurement was obtained along the north side of the Bailey Creek landslide. This thickness is consistent with Albee's (1960) measurements in the adjacent Munger Mountain Quadrangle. Wanless et al. (1955) measured approximately 275 feet of Nugget at Cabin Creek on the north border of the map area, suggesting that this unit thickens and thins along its strike.

The Nugget in the map area is lithologically similar to that found throughout its area of exposure. Wanless et al. (1955)

indicated that the Nugget is well cemented in the Hoback and Snake River ranges and less tightly cemented in the Gros Ventre and Teton ranges. In the northern Snake River Range the Nugget is very fine-grained and locally calcareous (Staatz and Albee, 1966). In south-central Wyoming the Nugget is soft and friable, and predominantly very fine-grained (Pipiringos, 1957).

Environment of Deposition. The environment of deposition of the Nugget is questionable and was either marine or eolian or both. The Nugget-Navajo sandstone body has been regarded by many (Harshbarger *et al.*, 1957, Stokes, 1961) as a classic example of an eolian, interior-desert facies. However, Wright and Dickey (1963) suggested, primarily on the basis of intertonguing relationships of the Navajo with the marine Carmel Formation, that part of the Navajo was marginal marine. Marzolf (1969) also concluded that the basal portion of the Navajo could be marine or marginal marine based on primary sedimentary structures. Staatz and Albee (1966) and Pipiringos (1968) also suggested that the Nugget could be the product of subaqueous deposition. Stanley *et al.* (1971, p. 13) concluded that "eolian conditions prevailed within a variable belt of coastal dunes adjacent to a very shallow sea which gradually transgressed across the cratonic margin." Their reconstructions are generalized and largely conceptual but the implication is that part or all of the Nugget could be marine in origin.

Twin Creek Limestone

Age and Contacts. The Twin Creek Limestone is Middle to Late Jurassic (Early to Late Bajocian to Early Callovian) in age based on fossil data (Imlay, 1967). Although angularity is rarely seen (Peterson, 1972), the contact with the underlying Nugget Sandstone is a significant regional disconformity which has long been recognized (e.g. Mansfield, 1920). This sharp contact, marked by a zone of leaching in the last few feet of the Twin Creek, is well exposed on U.S. Highway 26-89 about 1 mile south of the mouth of Cabin Creek at the north border of the map area.

Correlations. The Twin Creek was named by Veatch (1907) for strata exposed in southwestern Wyoming. The name Twin Creek is used throughout western Wyoming, southeastern Idaho, and north-eastern Utah. The Carmel Formation and Twelvemile Canyon Member of the Arapien Formation of central and north-central Utah are the partial temporal equivalents of the Twin Creek. East of the thrust belt, the basal Twin Creek is known as the Gypsum Spring Formation and the overlying beds are partly temporally equivalent to the Lower Sundance Formation (Imlay, 1967).

Lithology. Within the map area, the Twin Creek Limestone is generally poorly exposed. The basal part of the Twin Creek at Cabin Creek along U.S. Highway 26-89 consists of blue-grey, thinly bedded limestone and an overlying bed of red shale. Peculiarly, there is

no basal limestone breccia as at other localities in the adjacent region (see Wanless et al., 1955). The medial and upper parts of the Twin Creek consist of light-grey, thinly bedded, shaly limestone that breaks into distinctive "pencil"-shaped fragments. This detritus weathers to a light-grey soil devoid of much vegetation. Interbedded with the shaly limestone are three or more beds of ledge-forming, grey- to blue-grey, massive- to thickly bedded, fine-grained limestone. Within these fine-grained limestone beds are 1-2 foot thick beds of fine- to medium-grained oolites and a few coquina beds. In the map area, the Twin Creek Limestone is approximately 1,100 feet thick, significantly more than the 871 feet measured by Wanless et al. (1955) at Cabin Creek at the north border of the Pine Creek Quadrangle. Albee (1968) measured 950 feet, and Jobin approximated the thickness at 900-1,000 feet in the Murger Mountain and Ferry Peak quadrangles, respectively.

In the map area, Twin Creek strata are lithologically similar to those in the adjacent region. Wanless et al. (1955) divided the Twin Creek into eight characteristic units which are, in ascending order, (1) oolitic limestone, (2) shale, dark calcareous fossiliferous, (3) shale, calcareous, reddish, (4) limestone, oolitic, grey, (5) shale, calcareous, less fossiliferous than unit 2, (6) limestone, oolite bearing, (7) Gryphaea shale zone, and (8) oolitic limestone with some interbedded shale. In his regional study, Imlay (1967)

divided the Twin Creek into seven members which from bottom to top are named Gypsum Spring, Sliderock (unit 1 above), Rich (unit 2), Boundary Ridge (unit 3), Watton Canyon (units 4, 5, 6), Leeds Creek (unit 7), and Giraffe Creek (unit 8). Regionally, these members show significant lithologic variation which Imlay (1967) discussed in great detail.

Environment of Deposition. The Twin Creek was deposited during the first marine transgression from the north during Middle Triassic time. The greatest subsidence and resulting deposition occurred in the Twin Creek trough of southeastern Idaho, western Wyoming, and northern Utah. The sea was warm and shallow with prevailing, dry climatic conditions and as water depth varied, deposition in lagoonal environments occurred (Imlay, 1967).

Preuss Sandstone

Age and Contact. Imlay (1952) suggested that the Preuss Sandstone is Late Jurassic (Middle to Late Callovian) in age. He based this conclusion on the fossils found in overlying and underlying units and on regional stratigraphic relationships. The contact with the underlying Twin Creek Limestone is gradational and, in most places, occurs in less than 10 feet (Imlay, 1950). This contact is well-exposed in the core of the Little Greys anticline along the Little Greys Road and along the same anticline on the south bank of

the Snake River. The red-brown color of the Preuss makes the contact with the grey, calcareous shale of the underlying Twin Creek easily discernable.

Correlations. Mansfield and Roundy (1916) named the Preuss Sandstone for exposures northeast of Montpelier, Idaho. Preuss Sandstone terminology is applied in the same area as that of the Twin Creek Limestone, eastern Idaho, westernmost Wyoming, and north-central Utah (Imlay, 1952). Based on stratigraphic position, the Preuss is correlated with the Entrada Sandstone of south-central Wyoming and is partially temporally equivalent to the Sundance Formation of central Wyoming (Imlay, 1952).

Lithology. Within the map area, the Preuss consists of red-brown, fine-grained, calcareous, thinly bedded to laminated sandstone and siltstone. Salt casts are found in some of the lower beds exposed on the east flank of the Little Greys anticline along the Little Greys River. The Preuss is generally non-resistant cropping out only where steep scarp slopes restrict vegetation. In the Pine Creek area, the Preuss Sandstone was mapped with the overlying Stump Sandstone because of its thinness. Preuss and Stump thicknesses combined are 300 feet at the north end of the Little Greys anticline, 450 feet at the south end, and 300 feet in the northeastern corner of the map area. The thickness of these units ranges from 190-400

feet in the Mungler Mountain Quadrangle (Albee, 1968) to 225-275 feet in the Ferry Peak Quadrangle (Jobin, 1972).

Regionally, several important lithologic trends occur within the Preuss Sandstone. In the Wasatch Mountains of northern Utah, the Preuss is softer, siltier, and darker red than in Wyoming but it is still predominantly a fine-grained sandstone (Imlay, 1952). West of the Bannock thrust in southeastern Idaho, a marine tongue, the Wolverine Canyon Limestone, is present just below the middle of the Preuss (Imlay, 1952, p. 174). It consists principally of yellowish-grey, sandy limestone, yellowish sandstone and one oolite bed (Imlay, 1952). Imlay reported exposures of this member only west of the Bannock thrust. However, Kirkham (1924) noted the presence of 18 feet of grey crossbedded limestone 170 feet above the Preuss on Fall Creek, Bonneville County, Idaho that Imlay thought may be a thin extension of the Wolverine Canyon Member. Wanless, et al. (1955) mentioned a 5 to 8 foot thick "nearly white sandstone with striking current ripple marks" that occurs near the middle of the Preuss in all measured sections adjacent to the Pine Creek area that is probably the sandstone unit of the Wolverine Canyon Limestone. The sandstone was not observed in the map area but it is probably present but concealed because of poor exposure.

Environment of Deposition. The presence of marine limestone suggests that the Preuss is of marine origin or was deposited in

lagoons connecting with the sea. The red sandstone and salt beds probably formed in a series of highly saline lagoons bordering a positive area in central Montana. Lateritic soils, developed as a result of a warm and humid climate on the island, were the main source of iron oxide and sand in the Preuss (Imlay, 1952). In early Late Jurassic time the northeast-trending high on the west again rose, supplying additional detritus to the Preuss and overlying Stump formations.

Stump Sandstone

Age and Contact. The age of the Stump Sandstone is middle Late Jurassic (Oxfordian) (Imlay, 1950). The contact with the underlying Preuss Sandstone is considered to be disconformable (Imlay, 1952). A well-exposed, sharp contact occurs on the east flank of the Little Greys anticline along U.S. Highway 26-89 and both north and south banks of the Snake River at this location. For purposes of mapping the contact in the field area was placed at the first, resistant, grey-green, glauconitic sandstone bed.

Correlations. Mansfield and Roundy (1916) named the Stump Sandstone for exposures near Stump Peak in southeastern Idaho. It is found in southeastern Idaho, western Wyoming, and northeastern Utah and is not as widespread as the Preuss and Twin Creek (Staatz and Albee, 1966). The Summerville and Curtis formations of northern

Utah; the Redwater Shale Member of the upper Sundance of central and eastern Wyoming, are temporal and lithic equivalents of the Stump Sandstone (Peterson, 1972).

Lithology. The Stump Sandstone can be subdivided into three lithic units within the study area; a basal unit consisting of a greenish-grey, very fine-grained, calcareous sandstone; a medial unit of brown-grey, oolite-bearing, coquinoïd, sandy limestone; and an upper unit dominated by grey-green, medium-grained, glauconitic, calcareous sandstone. The upper sandstone unit is a prominent cliff former, and the non-resistant basal and medial units are partially obscured by its platy talus.

Throughout its extent the Stump is characterized by coarse-grained sandstone and a constant sand-shale ratio. Eastward, in central Wyoming and Montana, the coarser clastic rocks grade to a grey and green-grey shale facies with limestone and sandstone being minor components. In the southwestern part of central Wyoming, marine limestone is the predominant facies type (Peterson, 1972).

Environment of Deposition. The Stump Sandstone was deposited during the most extensive of the Jurassic transgressions of the Arctic Sea. The oolitic, coquinoïd, sandy limestone is indicative of a shallow depth of water, at least during deposition of these sediments. Brenner and Davies (1973) believed that the bioclastic components were redistributed by intense storms which agitated the shallow water.

The even-bedded character of much of the remainder of the Stump in the study area suggests a slightly greater depth of water where current and wave action was not effective in transporting detritus.

Cretaceous Strata -- Previous Work

Cretaceous age strata exposed within the map area include the Gannett Group, the Bear River Formation, and the Aspen Shale (Fig. 5). Following the precedent of U.S. Geological Survey geologists in the area, the Gannett Group was separated into a lower unit, the Ephraim Conglomerate, and an upper unit including, in ascending order, the Peterson Limestone, Bechler Formation, and Draney Limestone. The Bear River Formation was divided into a lower unit which includes the Muddy Sandstone and underlying dark shale sequence, and an upper unit composed of black shale. The Aspen Shale was not subdivided in the map area as it has been to the north because of the thinness of the porcelanite bed which has been used to separate the lower and upper units.

Previous work on Cretaceous strata includes regional studies in southeastern Idaho and adjacent areas by Mansfield (1920) and Moritz (1953). Stratigraphic studies on Cretaceous strata which include the map area or the region adjacent to it were published by Eyer (1969) on the Gannett Group; by LaRocque and Edwards (1954) on the Bear River and Aspen formations; and by Yen (1952) who discussed

the age of the Bear River. An ongoing investigation of the Aspen and Bear River formations in the area directly adjacent to the Pine Creek Quadrangle is being undertaken by Nazeeh Abraham of the University of Michigan. Wanless et al. (1955) measured several sections of Cretaceous strata adjacent to the map area and at other localities in the Teton, Hoback, and Gros Ventre ranges.

Gannett Group

Age and Contacts. Mansfield (1927) assigned the entire Gannett Group to the Early Cretaceous. On the basis of fossil evidence, Stokes (1944) and Mansfield (1952) placed the lower part of the Ephraim in the Late Jurassic. Peck and Craig (1962) and Eyer (1969) reported species of charophytes that dated the upper part of the Ephraim Conglomerate as Early Cretaceous. Therefore, the evidence indicates that the Jurassic-Cretaceous boundary lies in the Ephraim Conglomerate. The lower contact of the Gannett Group is conformable with the Stump Sandstone and the faunal evidence supports this conclusion (Eyer, 1969). The contact is not exposed in the field area due to a covered shale interval above the last glauconitic sandstone. The Smoot Formation, designated by Eyer (1969) as part of the Gannett Group, but mapped with the overlying Bear River Formation by the writer, contains fauna transitional from the Aptian Gannett Group to the Albian Bear River Formation.

Correlations. The Gannett Group is only recognized within the thrust belt but based on stratigraphic position equivalent strata are recognized in surrounding areas. In the Gros Ventre Range, Love et al. (1948) subdivided the Cloverly Formation into lower and upper units. They considered the boundary between these units to be equivalent to the Gannett-Bear River contact. In support of this correlation, Eyer (1969) considered the upper Cloverly, known as the "rusty beds," to be equivalent to the Smoot Formation. Furthermore, the lower Cloverly, consisting of limestone, mudstone, and shale, is probably equivalent to all but the lowermost part of the Gannett (Eyer, 1969). Furer (1970) suggested that the lower Ephraim, composed of shale and siltstone with minor interbedded sandstone, is temporally and lithologically equivalent to the Upper Jurassic Morrison Formation.

Lithology. Throughout the map area, the Ephraim Conglomerate consists of light-purple to white, medium-grained, quartzitic sandstone ("quartz crystal sandstone" of Wanless et al., 1955) with overlying units of red-purple to red-brown, very fine- to medium-grained sandstone with associated conglomerate lenses. Several covered intervals probably represent shale and claystone units. Conglomerate occurs in the Ephraim over most of the map area but is best exposed along the east flank of the Little Greys anticline where the Gannett Group was measured (see Appendix, page 124). Here

it consists of subrounded- to angular clasts, up to 2 inches in diameter, composed of chert, quartz, and occasionally limestone. These conglomerate beds are not more than 2 feet thick and occur as conglomerate lenses in sandstone 200 feet above the Stump-Ephraim contact. A 22 foot thick bed of purple claystone with grey, calcareous nodules is present at the Ephraim-Peterson Limestone contact.

The measured section of the Gannett Group along the east limb of the Little Greys anticline is 532+ feet thick, including 448 feet of Ephraim. On the northern margin of the map area, along the Snake River, the Ephraim Conglomerate is 275 feet thick and the upper Gannett is 225 feet thick. Wanless et al. (1955) measured 780 feet of Gannett strata at Cabin Creek and this thickness is considerably more than either Albee (1968) (435 feet) or Jobin (1972) (550 feet) measured. The Gannett Group reaches maximum thickness near the type section in southeastern Idaho (Eyer, 1969).

The units exposed in the study area are typical of lithologies found elsewhere in the Ephraim Conglomerate. Generally, grain size decreases to the north, south, and east away from the type section at Red Mountain in southeastern Idaho (Eyer, 1969) evidenced by the lack of conglomerate east and northeast of the Camp Davis area (Wanless et al., 1955). At Cabin Creek on the northeastern boundary of the map area, two conglomerate beds totaling 30 feet, with pebbles to $\frac{1}{2}$ inch in diameter, occur in the Ephraim.

The upper Gannett Group within the map area includes, in ascending order, the Peterson Limestone, Bechler Formation and Draney Limestone. The lithologically similar Draney and Peterson Limestone consist of grey-purple to tannish-grey, white-weathering, micritic limestone with a few chert nodules. The Peterson, the principal limestone in the Gannett Group, is present throughout the map area. The Draney, however, is not present over the entire Pine Creek Quadrangle as indicated by Eyer (1969). Because of extensive forest cover it was difficult to determine the precise location of the Draney, but it is clearly not present in the southeastern third of the map area. In the map area, the Bechler Formation consists of buff-grey, calcareous, fine- to medium-grained, quartzose sandstone which is only occasionally present.

Regionally, throughout the remainder of the overthrust belt, there are interbedded, grey and red, calcareous shales in the Draney and Peterson Limestone. The Bechler consists of red and maroon siltstone and shale, with interbedded, nodular limestone and grey and reddish-grey sandstone. There is also a thin conglomerate bed with clasts up to 2 inches in diameter found locally in the Bechler at the type section (Eyer, 1969). These less-resistant strata are undoubtedly present in the map area but are generally concealed by slumps and mudflows.

Environment of Deposition. The lower part of the Ephraim Conglomerate was deposited under open marine conditions during the Late Jurassic transgression of the Arctic Sea. This environment is indicated for these strata based on marine Jurassic fossils found 50 feet above the base of the Ephraim in southeastern Idaho (Mansfield, 1952, p. 42). The remaining Gannett Group is clearly nonmarine, evidenced by fossil types and lithologic associations such as the thick conglomerate and sandstone units, and red-bed sequence. The change from marine to nonmarine conditions probably resulted from strong tectonic movements in southeastern Idaho that caused the sea to regress (Armstrong and Oriel, 1965), and that created a western sediment source.

The depositional environments of the upper Ephraim and Bechler Formation were similar. Both were deposited in alluvial fans and fluvial systems adjacent to the rising land mass to the west (Eyer, 1969). The angularity of some of the pebbles in the Ephraim Conglomerate in the Pine Creek area suggests that part of the material in these fans was locally derived. In the study area, lower energy conditions prevailed during deposition of the Bechler Formation, evidenced by the lack of conglomerate in this unit. The Draney and Peterson limestones were deposited in fresh water lakes in which the water depth did not exceed 50 feet, based on the presence of charophyte fossils of fresh-water origin (Eyer, 1969).

Bear River Formation

Age and Contacts. The age of the Bear River Formation is an unsettled problem. Previously, the Bear River was assigned to the Late Cretaceous (e.g. Hayden 1869, Stanton 1892). On the basis of the Bear River fauna, Yen (1952) refined this designation, assigning the Bear River to the earliest Late Cretaceous (Cenomanian Stage). However, Cobban and Reeside (1952) and, more recently, Cobban (1972) placed the Bear River in the latest Early Cretaceous (Albian Stage), in agreement with Eyer (1969). The lower contact of the Bear River is considered by Eyer (1969) to be conformable with the underlying Gannett Group on both lithological and paleontologic grounds. The contact in the map area is generally concealed by mudflows and slumps.

Correlations. The Bear River Formation was named by Hayden (1869) for exposures near Old Bear River City, Wyoming. This unit is fairly local in extent and is mainly found in the thrust belt of westernmost Wyoming and in the Snake River Range in Idaho (Staatz and Albee, 1966). The lithic and temporal equivalents of the Bear River are inextricably linked to a nomenclature problem of the Middle Cretaceous rocks of the overthrust belt region and a discussion of this problem is warranted here. The Thermopolis Shale has commonly been considered to consist of three units; a lower dark shale unit; a middle sandstone, widely known as the Muddy Sandstone; and an upper

dark shale unit (Wanless et al., 1955). These correspond to the three stratigraphic units of the Bear River in the Pine Creek area. East of the study area in the Wind River Basin of Wyoming, Love (1948) (1) restricted the term Thermopolis to the lower shale unit, (2) suggested that the muddy Sandstone be viewed as a separate formation, and (3) referred the upper shale unit to the basal part of the overlying Mowry Shale, the lithic and temporal equivalent of the Aspen Shale. The Wyoming Geological Association Stratigraphic Nomenclature Chart (1971) further complicates the nomenclatural picture by equating the Bear River with the Dakota Sandstone, Thermopolis Shale, and Muddy Sandstone. The equivalency of the Bear River Formation with these units, as defined by Love (1948) and the Wyoming Geological Association (1971), is contrary to the U.S. Geological Survey stratigraphic scheme in the map area and the region adjacent to it. They subdivided the Bear River into two units, placing the contact between these units on the top of the Muddy Sandstone as mapped to the east, and included the upper dark shale unit in the Bear River instead of the overlying Aspen Shale. Eicher (1962) in an effort to resolve this conflict, introduced a new term, "Shell Creek Shale" for the interval between the siliceous Mowry (Aspen) and the top of the Muddy Sandstone. These stratigraphic relationships are summarized in Figure 11.

West of the map area, in southeastern Idaho, the Bear River Formation is lithologically and temporally equivalent to the lower

UPPER CRETACEOUS	Moritz (1953), Randall (1960) southeastern Idaho, Freedom area		Prior to Love (1948) Gros Ventre Ra. & east		Love (1948) Gros Ventre Ra. & east		Eicher (1962) east of overthrust belt		WGA Chart (1971) for north and east Green River Basin		This Paper and USGS	
	FRONTIER SANDSTONE											
LOWER CRETACEOUS	WAYAN FORMATION											
	Unit E		MOWRY SHALE		MOWRY SHALE		MOWRY SHALE		MOWRY SHALE		ASPEN SHALE	
	Unit D		THERMOPOLIS SHALE	upper dark shale	upper dark shale	SHELL CREEK SHALE				BEAR RIVER FM.	upper dark shale	
	Unit C			MUDDY SANDSTONE	MUDDY SANDSTONE	MUDDY SANDSTONE		MUDDY SANDSTONE				
	Unit B			dark shale	THERMOPOLIS SHALE	THERMOPOLIS SHALE		THERMOPOLIS SHALE				
	Unit A							"DAKOTA" SANDSTONE				
	TYGEE MEMBER											

Figure 11. Correlation diagram for Lower Cretaceous strata in western Wyoming and adjacent areas.

four units of the Wayan Formation (Fig. 11) as defined by Moritz (1953). The Tygee Member of the Bear River Formation was originally assigned by Mansfield and Roundy (1916) to the Gannett Group. As initially defined, it consisted of only the sandstone unit, but is now considered to include the upper sandstone unit, lithologically and temporally equivalent to the muddy sandstone (Eyer, 1969), and lower dark shale unit. Tygee terminology is used in extreme western Wyoming and in southeastern Idaho (Randall, 1960).

Lithology. In the map area, the dark shale in the lower Bear River is interbedded with silty mudstone, silty sandstone, and fine-grained sandstone. Although these lithologic types are found everywhere in the map area, they are particularly well developed on the west limb of the Little Greys anticline at the southern border. Typically, the siltstone and fine-grained sandstone units are dark-grey, medium-grey, green-grey, thin- to medium-bedded, occasionally calcareous, nodular, and limonitic, with abundant bioturbation structures and sole markings. They are composed of quartz, chert, and volcanic (?) rock fragments. One excellent exposure of this lithology occurs south of the Little Greys River on the west flank of the anticline. Here medium- to buff-grey, massive, cross-bedded, muddy siltstone and fine-grained sandstone forms a prominent 60 foot ledge. Black shale is the predominant rock type in the lower Bear River over much of the remainder of the map area. The shale is

dark-grey- to black, hard, splintery, limonitic on the weathered surfaces, and generally poorly exposed, forming a distinctive black soil.

Sandstone makes up the upper part of the lower Bear River at all localities. Typically this sandstone is light-grey, weathering buff-grey, fine- to medium-grained, subrounded to subangular, massive and crossbedded, limonite stained, quartzose, and resistant. It is an extremely clean sandstone, composed of quartz, chert and volcanic (?) rock fragments (Tbl. 1). This sandstone is best developed in the northwestern part of the map area on the west flank of the Little Greys anticline along Iron Rim Creek (Pl. 1) and to the north along U.S. Highway 26-89 on the border of the map area.

The upper Bear River, which is particularly well exposed in the vicinity of the measured section of the overlying Aspen Shale (see Appendix, page 124), consists predominantly of black- to dark-grey shale, similar in all respects to the shale in the lower Bear River. In the map area, a few poorly exposed beds of light-grey, fine-grained, sandstone and siltstone are interbedded with this shale. A few thin beds of medium-grey, dark-brown-weathering, micritic limestone are present near the contact with the Aspen Shale.

The thickness of the Bear River Formation, especially the upper unit, is variable throughout the map area, increasing to the south and west. Maximum thickness is attained on the southwest limb

Table 1. Volume percentages of grain constituents, cementing agents, and matrix from selected thin sections from sandstone and siltstone of the Bear River and Aspen formations.

		QUARTZ	CHERT	ROCK FRAGS. (Primarily Volcanic)	FELDSPAR	MATRIX	CEMENT
ASPEN	SANDSTONE	55-60	25	5	<1	10-15	CALCITE HEMATITE
	SANDSTONE (assoc. with cong.)	40	35	<10	10	<5	SILICA CALCITE (secondary)
	SILTSTONE	70	←5→		1	25	SILICA CALCITE (secondary)
BEAR RIVER	SILTSTONE (from lower Bear River)	90	←5→		<1	<5	SILICA CALCITE (secondary)
	SANDSTONE (from upper sandstone unit in Tygee Sandstone)	65	20	15			SILICA

of the Little Greys anticline where the lower and upper Bear River are 450 and 800 feet thick respectively. At the north border of the map area, the thickness decreases to 400 and 500 feet, respectively. In the northeast part of the map area the lower Bear River is 400 feet thick and the upper is 425 feet and south of this the thickness increases to 450 and 700 feet for the lower and upper units.

In the area adjacent to the overthrust belt, facies variations in the lithic and temporal equivalents of the Bear River are not significant. In the Big Horn Basin of central Wyoming, the Thermopolis Shale consists of dark-grey shale and interbedded siltstone and sandstone. The Muddy Sandstone here is generally finer grained than that in the map area and is comprised of interbedded siltstone, sandstone and shale (Eicher, 1962). West of the study area in northeastern Idaho, the Wayan Formation is similar to the Bear River in the Pine Creek Quadrangle although red and variegated sandstone and mudstone make up a significant part of the section (Moritz, 1953).

Environment of Deposition. Deposition of the Bear River Formation occurred during the initial stages of the Early Cretaceous transgression that culminated in the open marine conditions of the Mowry-Aspen sea. Fresh and brackish water fauna were collected from the upper Bear River by LaRocque and Edwards (1954) in the Willow Creek area, 2 miles northeast of the Pine Creek Quadrangle. Wanless et al. (1955) collected marine forms from the upper Bear River in

several sections in the area adjacent to the Pine Creek Quadrangle, although the lower Bear River is nearly unfossiliferous in this same area. Eicher (1962) attributed the lack of fauna in the Bear River equivalents in the Big Horn Basin to brackish water conditions.

The environment of deposition of the Bear River within the map area can be broadly characterized as marginal marine, influenced by periods of emergence and submergence. Ripple marks, bioturbation structures, and the lithologic associations such as the black shale, and sandy mudstone and siltstone suggest that the water depth was quite shallow. The environment fluctuated from periods of relative stability during which the more well-sorted siltstone and sandstone beds accumulated to more unstable conditions when arenaceous and argillaceous fractions were mixed. This was, perhaps, due to a variable depth of water resulting from the interaction of transgression and progradation. Euxinic conditions, evidenced by the thick accumulation of black shale, prevailed during deposition of the middle part of the lower Bear River. During the closing stages of lower Bear River deposition, however, open marine conditions were dominant as suggested by the thick, clean, quartzose, mature sandstone in the upper part of the Tygee Sandstone. The sandstone sequence developed as a pro-delta accumulation when progradation was not occurring. Current and wave action, which winnowed out the fine-grained sediment, was effective in transporting and redistributing

the coarser sediment. The environment of deposition of the upper Bear River was much the same as during deposition of the middle sequence of the lower Bear River when the thick black shale unit was deposited.

The general sedimentary-tectonic pattern during deposition of the Bear River is a delta and associated terrestrial environment. Much of the strata accumulated as a flood plain and tidal flat sequence with associated fresh water lakes and lagoons that were periodically barred.

Aspen Shale

Age and Contacts. The age of the Aspen is unsettled because of the controversy surrounding the age of the underlying Bear River. The lithologically and temporally equivalent Mowry Shale of Montana and Wyoming is Early Cretaceous in age on the basis of species of Gastrolites and Neogastrolites (Cobban and Reeside, 1951). The lower contact of the Aspen with the Bear River is considered to be conformable by all workers (e.g. LaRocque and Edwards, 1954, Moritz, 1953). Different workers in the adjacent area have placed this contact at slightly different stratigraphic positions. Moritz (1953) placed the contact at the first siliceous shale bed, and LaRocque and Edwards (1954, p. 320) placed the boundary "above the thick dark splintery shale of Bear River aspect...and below the first salt and

pepper sandstone." The contact was drawn by Staatz and Albee (1966) at the first prominent sandstone ledge below the lowest porcelanite. Within the map area the contact is gradational over 40 to 50 feet and it is placed before the last black shale, above interbeds of grey-green, fine-grained, thin-bedded sandstone, and below the first grey-green sandstone with medium grains of black chert.

Correlations. The Aspen Shale was named by Veatch (1907) for strata exposed near Aspen Station, Uinta County, Utah. Aspen terminology is restricted to the thrust belt between the Absaroka thrust on the west and southwest, and the edge of the overthrust belt on the east and northeast (Staatz and Albee, 1966). The Wayan Formation of extreme western Wyoming and southeastern Idaho is the lithic and partial temporal equivalent of the Aspen (Moritz, 1953). East of the map area over much of central Wyoming and Montana, the Mowry Shale is lithologically and temporally equivalent (Fig. 11) to the Aspen Shale (Cobban and Reeside, 1952).

Lithology. The Aspen Shale, the most widespread unit in the map area, crops out on both flanks of the Little Greys anticline in a broad outcrop band covering the central portion of the Pine Creek Quadrangle, and on the west limb as a wide belt extending to the Absaroka thrust (Fig. 17), (Pl. 1). The Aspen consists of a monotonous sequence of interbedded siliceous shale, sandstone, and porcelanite. In addition, a thin pebbly conglomerate unit occurs

within the upper Aspen in both the central and western outcrop belts. The true thickness of the Aspen Shale in the map area is unknown because structural involvement makes an accurate measurement impossible. The best estimate, however, is that the Aspen is on the order of 4,000 to 4,500 feet thick. This is not unreasonable, when compared to the 3,900 feet thickness measured by Albee (1968) in the Munger Mountain Quadrangle. Wanless et al. (1955) did not measure a complete section of Aspen but the results of their investigation indicate that the Aspen thickens to the south and west.

The sandstone of the Aspen Shale is typically grey-green, fine- to medium-grained, thinly bedded to massive and cross-bedded, occasionally calcareous, and generally more resistant than the interbeds of shale (Fig. 12). Although most are tightly cemented, some of the sandstone is moderately friable. Grain constituents are quartz, chert, and volcanic (?) rock fragments with minor amounts of feldspar, giving some of the sandstone a "salt and pepper" appearance. Most of the grains are subangular to subrounded, although a bimodal distribution is evident with some grains being very well rounded. The percentage of feldspar in the sandstone and siltstone of the Aspen is similar to that of the Bear River strata, although the feldspar content is greatest (10 percent) in the sandstone associated with the conglomerate. Table 1 compares estimated grain constituents, cement types, and matrix volumes for selected samples of the sandstone



Figure 12. Sand-shale contact in Aspen Shale. Note splintery nature of siliceous shale.

and siltstone of the Bear River and Aspen formations generally suggesting that both water depth and volcanic activity increased during deposition of the Aspen Shale. Figure 13 shows comparative photomicrographs of the sandstone from these formations. Interbeds of grey-green, sometimes glauconitic, thinly bedded siltstone, and an occasional thin (1 foot thick) bed of micritic limestone and silty limestone also occur with the sandstone. The siltstone usually grades upward into grey-green shale or fine-grained sandstone.

Shale, which is the most common lithologic type in the map area, is characteristically green-grey, splintery, occasionally calcareous, siliceous, the resistance increasing with the silica content. Dark-grey shale is common near the contact with the Bear River Formation.

Porcelanite is another typical lithology of the Aspen. It is varicolored, occurring in blue, pink, green, grey, red, and blue-grey hues. It is commonly banded, spotted, and speckled, and is either found as single well-developed beds or as thin interbeds within sandstone and siliceous shale. It is composed of cryptocrystalline quartz and breaks with a conchoidal or splintery fracture. The most common and distinctive porcelanite is the spotted type that occurs as amygdules of grey in a white background or vice versa. Just to the north of the map area, the Aspen has been subdivided into lower and upper units by U.S.G.S. geologists on the basis of a thick bed

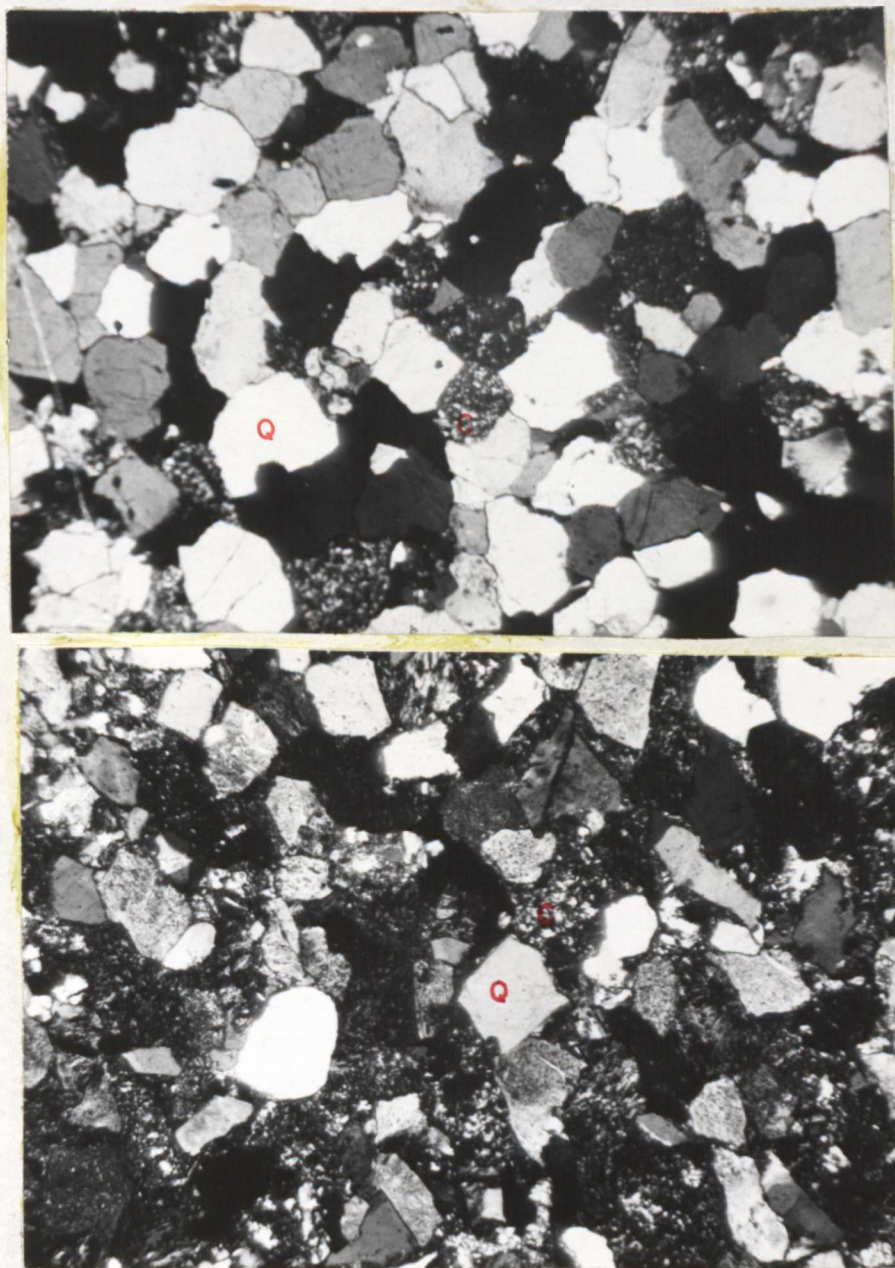


Figure 13. Photomicrographs of sandstone from upper sandstone unit in lower Bear River Formation (upper photograph) and Aspen Shale (lower photograph). Note clean nature of sandstone in Bear River as opposed to sandstone in Aspen Shale. Constituents are (c) chert and (q) quartz. Also see Table 1 for volume analysis of grain constituents of these sandstones.

of the spotted type porcelanite which occurs near the middle of the Aspen there. In the map area, however, this porcelanite bed pinches out and the Aspen has been mapped as a single unit. Although the individual porcelanite beds are thin, several occur together in a "porcelanite zone" about 2,000 feet above the Bear River, that could have been used as a marker horizon in much of the eastern part of the central outcrop belt (Pl. 1). Structural involvement or lateral thinning may have prevented this zone from being observed in the western part of the map area.

An excellent exposure of the conglomerate occurs two-fifths of a mile upstream from the mouth of Fire Box Creek where it is exposed on the eastern wall of the canyon (Pl. 1). It crops out as conglomerate lenses up to 4 feet thick within a conglomerate sandstone, that has a total thickness exceeding 7 feet. The conglomerate is exposed discontinuously along strike and individual beds pinch out within several hundred feet. Exposures are found in both the north and south portions of the map area, on both sides of the Little Greys River in the central outcrop belt, and north of the river in the western outcrop belt. The conglomerate clearly occurs in the upper part of the Aspen. In the map area, on the west side of the Little Greys anticline it is exposed approximately 3,000 feet above the base of the Aspen. Reconnaissance work in the central outcrop belt

suggests that the conglomerate may occur as a series of lenses within a broad horizon from 500 to 1,000 feet thick.

The conglomerate in the hand specimen is identical to the conglomerate within the overlying Frontier Formation which is exposed in the area adjacent to the Pine Creek Quadrangle (Albee, 1975, personal communication). It consists mainly of well-rounded pebbles of grey, brown, and white chert, and white and brown quartzite (Figure 14). No limestone pebbles were noted, which are typical of the Frontier conglomerate in the Garns Mountain Quadrangle north of the map area (Staatz and Albee, 1966). The average pebble is $\frac{1}{2}$ inch in diameter but they range up to $2\frac{1}{2}$ inches. The matrix volume is 20 percent in the tightly packed conglomerate and this increases to 80-90 percent in the conglomeratic sandstone. Sorting of the pebbles ranges from very good to moderate with the largest pebbles occurring in the most poorly sorted conglomerate. The sandstone associated with the conglomerate is grey-buff, medium- to coarse-grained, subangular, occasionally calcareous and cross-bedded, feldspathic (up to 10 percent), and strongly resistant. The sandstone unit is not continuous along strike and is present only where the conglomerate beds are thicker at Fire Box Creek and on the western border of the map area (Pl. 1). At other localities the conglomerate forms a resistant 2 to 4 foot bed between interbedded siliceous shale, porcelanite, and grey-green, "salt and pepper" sandstone.



Figure 14. Chert pebble conglomerate in upper Aspen.

Reconnaissance work by the writer southeast of the study area in the Deer Creek and Pickle Pass quadrangles (Fig. 2) indicates that this conglomerate is most correctly interpreted as a tongue of the Upper Cretaceous Frontier Formation (Fig. 11). The conglomerate can be traced along strike to the Pickle Pass Quadrangle where yellowish-orange sandstone of Frontier character is found both above and below beds of pebbly conglomerate identical to that in the map area. The associated sandstone horizon pinches out northward, approximately $1\frac{1}{2}$ miles south of the Little Greys River. North of the Pine Creek Quadrangle, this intertonguing relationship is less clear. In the Garns Mountain Quadrangle, Staatz and Albee (1966, p. 72) placed the lower contact of the Frontier at the base of a prominent, ridge-forming, feldspathic sandstone which is probably the same as that used by LaRocque and Edwards (1954) in the Willow Creek area two miles northeast of the map area. However, in the Munger Mountain Quadrangle, Albee (1968) called beds above the feldspathic sandstone Aspen Shale and placed the basal contact of the Frontier Formation approximately 2,000 feet higher in the section at a pebbly conglomerate bed associated with the typical yellowish-orange weathering sandstone. This relationship suggests that there may be a facies change between the feldspathic sandstone and the conglomerate or that intertonguing is occurring between Munger Mountain and Garns Mountain. Another example of intertonguing between the Aspen Shale and Frontier

Formation occurs in the vicinity of Cumberland Gap approximately 100 miles south of the Pine Creek Quadrangle. South of Cumberland Gap, the contact between these units is easily discernable where the silver-grey hogbacks of porcelanite and siliceous sandstone of the Aspen Shale are clearly divisible from the nonsiliceous, buff sandstone and medium-grey shale of the Frontier Formation. North of Cumberland Gap, however, porcelanite and porcelanitic siltstone crops out in the basal Frontier and the contact between these formations is much less definitive, suggesting intertonguing.

These relationships suggest, therefore, that intertonguing occurs between the basal part of the Frontier Formation and the top of the Aspen Shale, implying that these units are partial temporal equivalents. Further studies on the fossils and stratigraphy of these formations are needed to substantiate this theory.

The Aspen Shale shows no important facies variations in the region around the map area. In general, it has been described by Rubey (1931) as containing proportionately more unsilicified shale and sandstone than the Mowry Shale and the conspicuous porcelanite beds have less nonvolcanic debris than those in the Mowry. The Aspen in the region adjacent to the Pine Creek Quadrangle contains more sandstone than the Aspen in southwestern Wyoming (Reeside and Cobban, 1960, Fig. 3). West of the map area, the interbedded

sandstone and shale beds of the Wayan Formation are not significantly different than those of the Aspen Shale (Moritz, 1953).

Environment of Deposition. As the Early Cretaceous transgression of the Arctic sea continued, the marginal marine environment, recorded in the Bear River strata changed to more open marine conditions during deposition of the Aspen Shale. Marine, brackish, and fresh water faunas have been collected from the Aspen in the Willow Creek area, 2 miles northeast of the map area (LaRocque and Edwards, 1954).

In the study area, open near-shore marine conditions prevailed and the alternating sequence of sandstone and shale suggests that the base level fluctuated considerably. Argillaceous and arenaceous fractions are not mixed as during deposition of the lower Bear River in the map area, suggesting that wave and bottom currents were probably effective in transporting and redistributing the fine-grained sediment. A series of offshore bars was probably continually being developed and destroyed by the increased wave activity due to fluctuating water depth. Shale was deposited in the quiet water of lagoons and offshore in deeper water. On the shoreline, beach sediment was reworked by currents and wave action. Lakes and lagoons, that were periodically barred, existed marginal to the shoreline. Volcanic activity increased during deposition of the Aspen Shale and volcanic ejecta was intermittently deposited in the basin.

Rubey (1929) attributed the high silica content of the Mowry Shale to volcanic ash but suggested that the shale was enriched in silica by chemical precipitation from sea water in the presence of decaying organic matter. Eicher (1962) suggested that much of the sand and silt supplied to the basin may also be volcanic shards instead of terrigenous clastics.

Gravel was supplied to the map area during the closing stages of Aspen deposition as a consequence of a strong tectonic pulse and resulting progradation. The conglomerate and conglomeratic sandstone suggest a fluvial type deposit in which the gravel accumulated as lag deposits. Part of this conglomerate may have been reworked as strand line deposits evidenced by the sharp lithologic break and lack of channeling associated with some of the conglomerate (see Barrell, 1929).

The sedimentary-tectonic pattern existing during deposition of the Aspen Shale was similar to that of the Bear River, namely that the Aspen accumulated as a delta sequence with marginal terrestrial deposition. It was, however, generally characterized by a slightly greater depth of water and more open marine conditions as well as increased tectonic activity.

Cenozoic Rocks

Cenozoic strata in the map area include Quaternary landslide and terrace deposits, alluvium and colluvium, and a local conglomerate and breccia unit. The landslides are the most spectacular Quaternary feature in the area and are almost without exception confined to the Cretaceous shale of the Bear River and Aspen formations. The conglomerate and breccia are associated with the older Bailey Creek landslide. The terrace, alluvium, and colluvium units are stream- and river-related deposits.

Conglomerate

The Conglomerate is exposed along the east side of Bailey Creek from near the confluence with Dry Wash to approximately 1.2 miles upstream, dropping 350 feet in elevation over its horizontal distance (Pl. 1). It forms a resistant ledge approximately 20 feet thick at its maximum which thins upstream. At the exposure near Dry Wash the lower 6 feet is unsorted and ungraded, and it becomes more sorted and graded in the upper 14 feet. It is composed almost exclusively of subangular to angular blocks of Madison limestone and Wells quartzite. They range in size from pebbles to boulders up to 2 feet in diameter. The more sorted portions are composed of 3 inch cobbles in a calcareous matrix.

Breccia

The breccia unit crops out on the north wall of a small canyon in the middle of the Bailey Creek landslide (Pl. 1). It is composed principally of angular, unsorted clasts of Madison limestone and Wells quartzite although there are also a few cobbles of Nugget and Ankareh sandstone. It is unsorted and unstratified with clasts to 2 feet in diameter (Fig. 15). The matrix content, which approaches 30 percent in volume, is composed of salmon colored, calcareous mudstone. The deposit is not over 3 feet thick and has an apparent dip of 5 degrees to the east (Fig. 3).

Colluvium

Colluvium as shown on Plate 1 includes several different types of unconsolidated sediments from soil to gravel and talus deposits that cover the lower slopes of the hills and mountains along stream courses. Much of the colluvium is deposited along the Little Greys River, formed from the disintegration of sandstone and shale of the Aspen and Bear River formations.

Alluvium

Alluvium in the map area includes clay- to boulder-sized detritus deposited in the Holocene as bars along stream courses.



Figure 15. Breccia unit exposed in canyon within Bailey Creek landslide deposits. Also see Figure 3.

Terrace Deposits

Terrace deposits as mapped along flat lying areas adjacent to the Snake River are of two different ages (see Geomorphology Section, page 6) but include boulder to silt sized fragments. The well-rounded boulders consist of durable Paleozoic and Mesozoic quartzite and sandstone.

STRUCTURAL GEOLOGY

Regional Structure

The study area lies in the western Wyoming salient of the Cordilleran overthrust belt. The rocks of this area are unlike many in other well known thrust belts in that they have undergone little metamorphism of even the lowest grade (Rubey and Hubbert, 1959). In addition, crystalline basement rock has played a passive role and is not involved in any of the thrusts. The overthrust belt emerges from beneath the basalts of the Snake River Plain, trends south of the Teton Range to the latitude of Jackson, and follows southward along both sides of the Idaho-Wyoming state line to LaBarge, Wyoming where it turns southwestward and enters Utah east of the southwestern corner of Wyoming and north of the Uinta Range. This arcuate belt is about 60 miles in width and 250 miles in length along a curving arc of 120 degrees (Rubey and Hubbert, 1959). It is indistinctly bounded on the west but is bordered on the east by the Green River Basin. The thrust belt is composed of subparallel mountain ranges that are generally bordered on the east by major thrust faults and on the west by high-angle normal or reverse faults. Between these major bordering faults, the strata are deformed by minor thrusts, large and small folds, and diagonal transverse faults (Rubey and Hubbert, 1959).

Major overthrust faults in the overthrust belt are, from west to east, the Paris, Meade, Crawford, Absaroka, Darby, Prospect, and Hogsback (Fig. 16), in apparent age sequence with the older thrusts on the west (Armstrong and Oriel, 1965). The principal movement on these thrusts ranges from latest Jurassic to mid-Early Eocene (Armstrong and Oriel, 1965). Stratigraphic throw on each of the major thrusts is about 20,000-25,000 feet (Crosby, 1968) and they involve successively younger strata to the east (Armstrong and Oriel, 1965). Rubey and Hubbert (1959, p. 187) have estimated horizontal movement to be on the order of 10-15 miles, based on carefully drawn structure sections. Alternative interpretations by them suggest that minimum movement may be about 5-8 miles and maximum displacement may be as great as 20-30 miles. Although they commonly intersect the surface at higher angles, the overthrusts are bedding plane thrusts, evidenced by the parallelism of fault and stratigraphic surfaces across extensive areas (Crosby, 1968).

Stresses responsible for the deformation of the overthrust belt may be categorized as either boundary forces or body forces (Crosby, 1969). Boundary forces may be equated to regional compression, a "push from the rear" (Crosby, 1969), and body forces to gravitational sliding. Rubey and Hubbert (1959) rejected a purely gravitational gliding or regional compression origin for faults in the overthrust belt, as untenable, based on apparent absence of

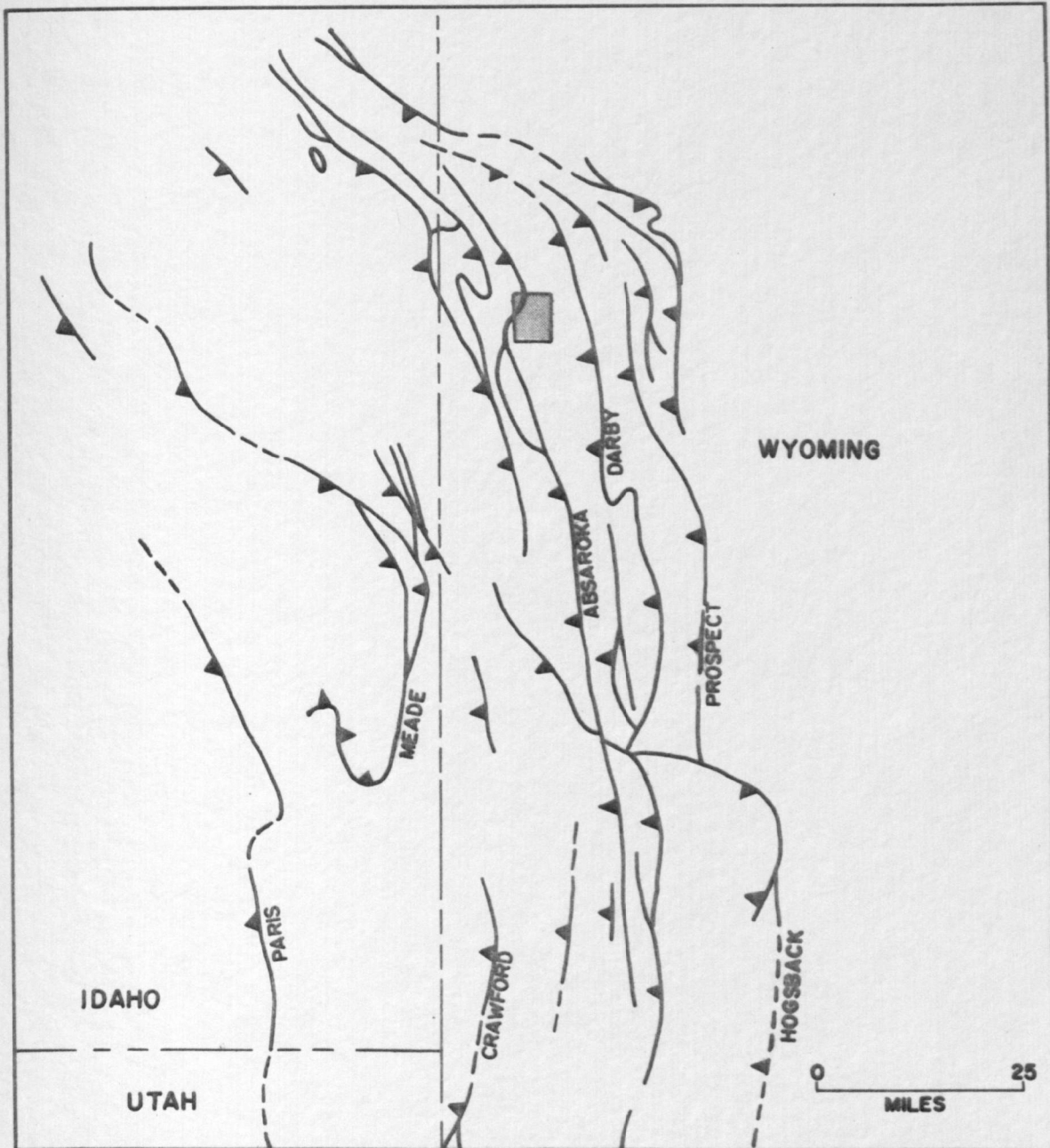


Figure 16. Tectonic map of north end of the overthrust belt. Principal thrusts are labeled; sawteeth on upper plate (after Armstrong and Oriel, 1965, Crosby, 1968). Pine Creek area shaded.

pull-apart rifts that should be developed in gravity slides and the nonexistence of any root that could have produced the required shallow compressive stress. They concluded that the most likely mechanism may have been a combination of the two forces. Crosby (1969) likewise repudiated a boundary force origin mostly on the same lack of any physical boundary at the back of the salient. Instead, Crosby (1968) proposed that gravitational gliding was the mechanism of deformation. He postulated the presence of an uplift with an apex that roughly coincided with the depocenter of the maximum thicknesses of Paleozoic and Mesozoic strata in southeastern Idaho. This area, according to him, rose in response to isostatic readjustment. High pore pressures, developed during the earlier depositional phase, enabled the sedimentary pack to move away from the high in a radial and diverging pattern (Crosby, 1969) under a purely gravitational influence. Later erosion of the high would effectively remove the pull-apart gaps or rifts, the lack of which Rubey and Hubbert (1959) used to disqualify the gravity gliding mechanism.

The early depositional phase in which the sediments accumulated in the miogeosynclinal portion of the geosyncline was followed by the two part destructional phase known as the Laramide Orogeny. Early thrusting and folding was succeeded by block faulting which began in the Eocene and has continued to the Recent. Recent movement, on both north and east-trending fault sets, is indicated by

broken alluvial fans, displaced basalt flows less than 27,000 years old, and earthquakes (Armstrong and Oriel, 1965).

Local Structure

Introduction

The map area lies on the upper plate of the Darby thrust and the lower plate of the Absaroka thrust (Fig. 17). The Absaroka thrust, within 1 mile of the western margin of the map area, places Madison limestone on the Aspen Shale. Jobin (1972) showed this fault to be an extremely flat thrust, dipping a few degrees to the west. The Darby thrust, approximately 1-2 miles east of the map area, has moved Bighorn Dolomite over Aspen and Bear River strata. Ross and St. John (1960) indicated that the dip of the Darby overthrust is 30° to 35° in the region adjacent to the map area, although this probably represents a near-surface phenomenon as the thrust undoubtedly flattens at depth. Both of these thrusts can be traced tens of miles north and south of the map area (Fig. 16).

Within the map area, there is one large fold, two small folds, and a large reverse fault, all of which are related to the earlier compressional phase of the Laramide Orogeny. These structures follow the regional northwest trend and, as found elsewhere in the overthrust belt, the folds are moderately to strongly overturned to the east. Three small cross faults are also found in the map area

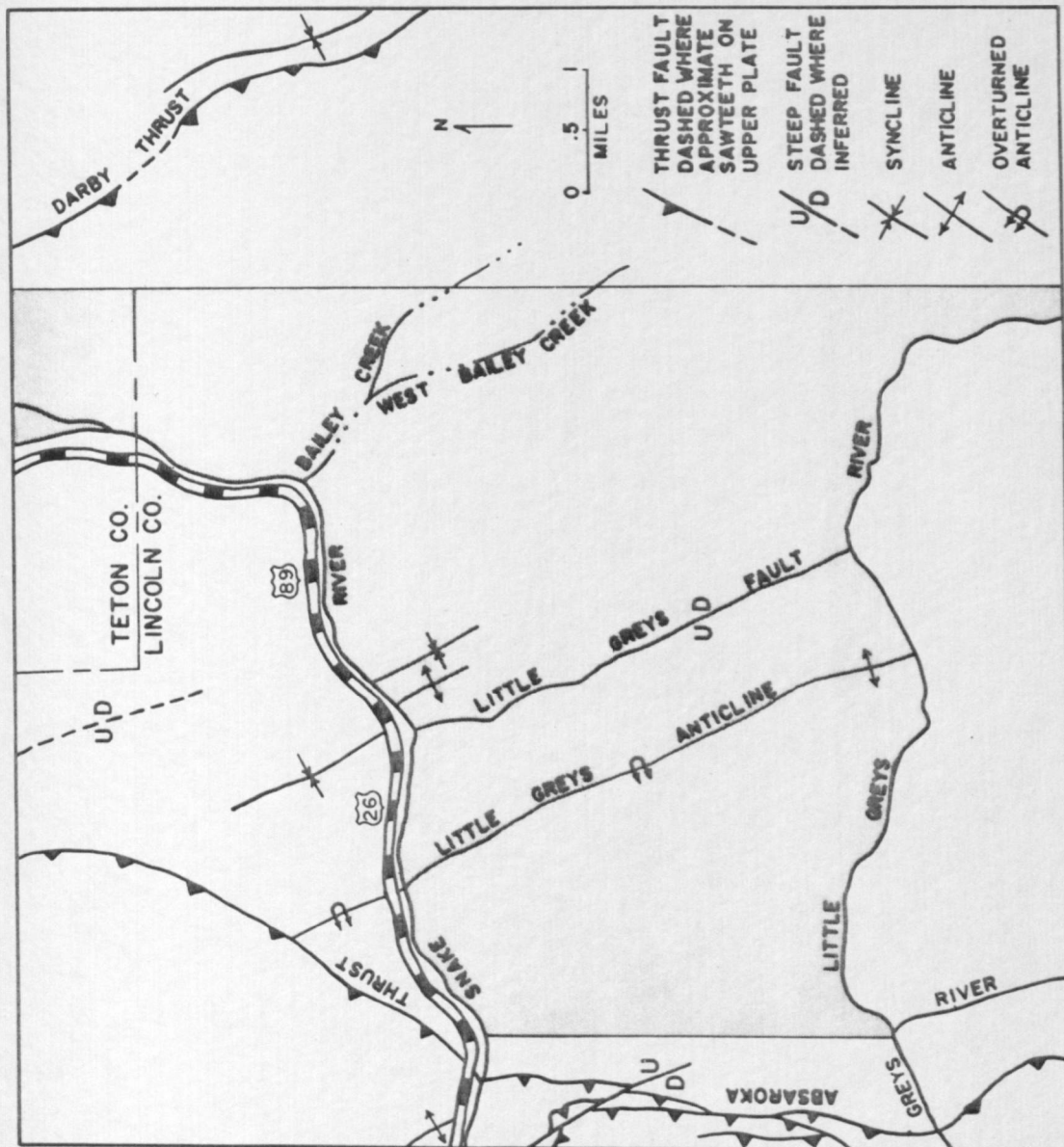


Figure 17. Structure map of Pine Creek Quadrangle and adjacent area. Map area shaded. Geology by Jobin (1972) on west; Ross and St. John (1960), east; Albee (unpub.), north.

which are contemporaneous with or post date the folding-thrusting phase.

In addition to these structures, folds are probably present in the south-central part of the map area where the Aspen Shale is exposed. The Aspen here is nearly 7,000 feet thick when measured from the eastern contact with the Bear River to the trace of the Little Greys fault (Pl. 1). Albee (1968) approximated the thickness of Aspen Shale at 4,000 feet in the Munger Mountain Quadrangle to the north, indicating that roughly 3,000 feet of section is repeated in the south-central part of the map area. This discrepancy may partly be due to faulting. However, the evidence in the adjacent areas suggests that overturned folding is probably responsible for the excessive thickness of Aspen. One evidence of folding may be the two small-amplitude folds mapped along the Snake River (Fig. 17) which could extend to the south-central part of the map area. This implies that these folds become strongly overturned in the approximate middle of the Pine Creek Quadrangle. Alternately, Schroeder (1975, personal communication) mapped a large overturned syncline in the Pickle Pass Quadrangle to the southeast (Fig. 2) which may continue to the south-central part of the map area.

Unfortunately, there is no strong field evidence such as folding or overturned bedding in the south-central part of the map area to support this theory. It is likely, however, that crumpling

and deformation has occurred in the incompetent sandstone and shale of the Aspen which resulted from deformation of the adjacent Little Greys anticline and related fault.

Faulting

Normal Faults. Three small tear faults occur in the map area, two of which are located on the west flank of the Little Greys anticline. These faults trend approximately N 35° to 65° W and the strike slip offset has been on the order of 100 to 200 feet. Neither are over 1,200 feet in length. They appear to be closely related in both time and in the mechanics of their formation and I suggest that they are contemporaneous with the fold, forming on the flank of the Little Greys anticline from simple stress release as the fold developed. The third fault, visible from U.S. Highway 26-89, lies near the northeastern corner of the map area. This fault trends N 40° E and the dip-slip movement offset the Draney and Peterson limestones approximately 50-75 feet.

Reverse Faults -- Little Greys Fault. The fault that runs east of the axis of the Little Greys anticline (Fig. 17) is here named the Little Greys fault. It trends approximately N 20° W and its trace is parallel to the overall structural grain of the area. The length of the fault is in excess of 4 miles within the map area and it extends at least 3 miles south of the Little Greys River.

Northward, this fault may connect with one mapped by Albee (1975, personal communication) that continues into the Munger Mountain Quadrangle (Fig. 17). More definitive detail is not possible as the fault lies entirely within the Aspen Shale which is not separated into lower and upper units in the map area as it has been to the north (see section on Aspen Shale, page 74).

Structural deformation in the beds adjacent to the trace of the fault imply its existence. Erratic dips are common in the strata next to the fault. Two miles south of the Little Greys River, over a 150 foot horizontal distance, the strike of the beds is consistent but the dips are 55° W, 22° W, 65° W, vertical, and 55° W from west to east, respectively. In addition, vertical to overturned beds occur along the fault trace in the ridge just to the east of the mouth of Cow Camp Creek with the Little Greys River (Pl. 1). Vertical to overturned bedding is apparent north of this locality as well (Pl. 1). The fault is also suggested by the apparent truncation of a syncline mapped by Albee (1975, personal communication) directly east of Station Creek, north of the Snake River (Fig. 17). This syncline trends directly into the small anticline west of Pine Creek in the map area. The syncline mapped by Albee is apparently the same syncline mapped south of the Snake River (Fig. 17) and the offset is a result of erosion of the upthrown side of the fault. Additional evidence for the fault was noted by Wiger (1956) who mentioned that

in a test drilled at the southern end of the Little Greys anticline just to the north of the Little Greys River, the hole bottomed in the Woodside Formation after faulting out of what was interpreted to be the Phosphoria Formation.

Stratigraphic evidence also supports the existence of the fault. The thickness of Aspen Shale is approximately 8,500 feet when measured across the southern end of the central outcrop belt, exceeding twice the thickness of Aspen (4,000 feet) in the Munger Mountain Quadrangle (Albee, 1968) to the north. If it can be assumed that a fold repeats 3,000 feet of section east of the Little Greys fault (see Local Structure, Introduction, page 95) then the throw is conservatively estimated at 1,500 feet.

The dip of the Little Greys fault increases to the south. Bedding dips indicate that the fault plane dips 40° to 60° in the north and 60° to 80° in the south. These amounts are not representative of the steeper intersection at the surface particularly in the south where the fault plane is vertical. It is suggested that the difference in the dip of the fault along the trace is due primarily to its proximity to the Absaroka thrust where overturning increases on the adjacent Little Greys anticline at the north end of the map area (Fig. 16).

The Little Greys fault probably developed as a "stretch thrust" (Badgley, 1965, p. 194) resulting from weakening of the

forelimb in the incompetent Aspen Shale (Fig. 18). This would imply, therefore, that the folding of Little Greys anticline slightly pre-dates the faulting.

Folding

Little Greys Anticline. The Little Greys anticline was first mapped by Schultz (1914) and later by Boeckerman and Eardley (1956). The axial trace trends approximately N 20 W and is exposed over the entire length of the map area. Just to the north of the map area the fold is cut off by the Absaroka thrust, and the fold flattens approximately 5 miles south of the map area (Wiger, 1956). Structural closure on this structure has been estimated to be on the order of 1,500-2,000 feet (Wiger, 1956).

The Little Greys anticline is complex throughout its length of exposure within the map area. In the southern part of the map area, small flexures are present on both limbs (Fig. 20). At the southern border of the map area along the Little Greys road, a small, tightly folded syncline developed on the eastern limb within 300 feet of nearly horizontal beds (Fig. 19). One mile northwest of this locality, gently dipping Stump and Preuss sandstone and lower Gannett strata are exposed on the western limb where slope angles exceed the dip (Pl. 1). Boeckerman and Eardley (1956, p. 182) suggested that

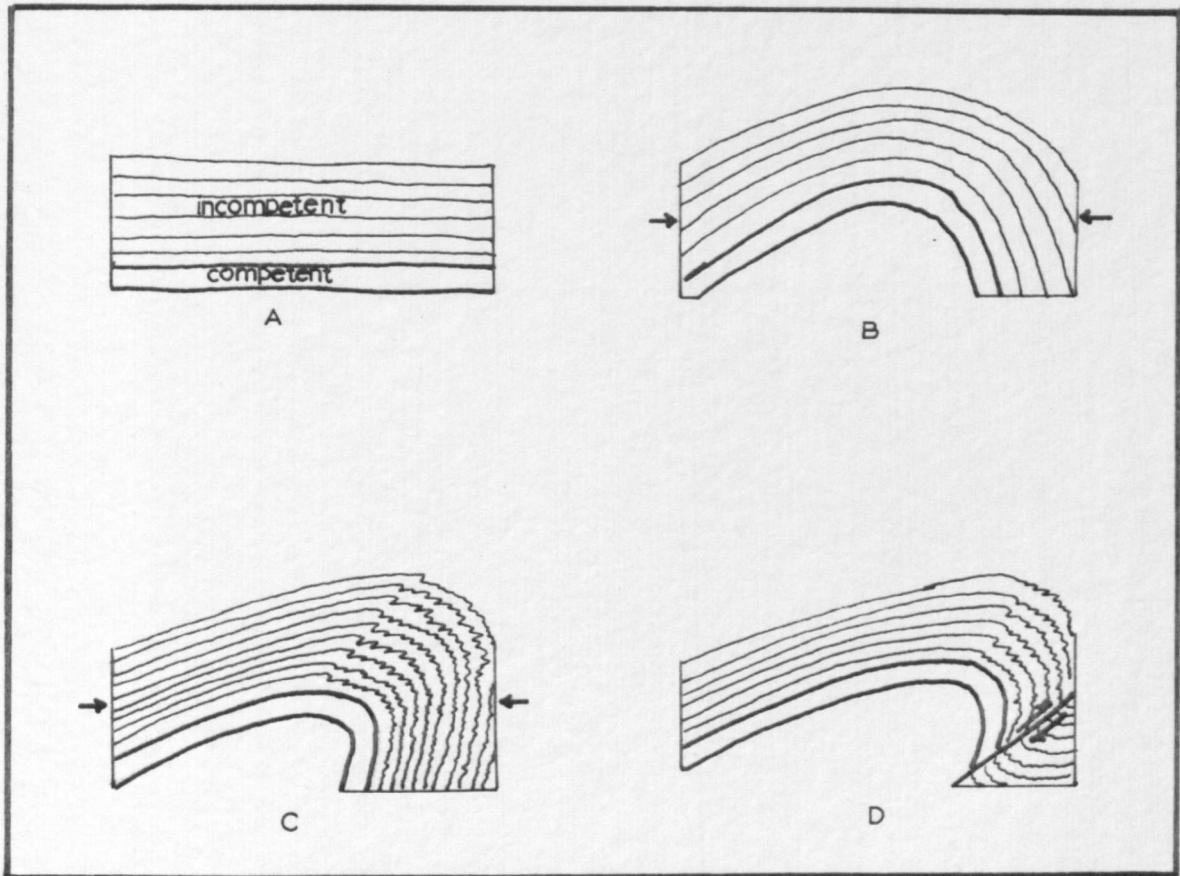


Figure 18. Development of the Little Greys anticline and associated fault. As stress ($\Rightarrow$) was applied, the competent sandstone in the lower Bear River Formation, and the overlying incompetent shale of the upper Bear River and Aspen Shale (A) were broadly folded (B). As stress continued, the strata became overturned and stretching occurred in the shale sequence (C). Note that very little stretching occurs in the competent sandstone. Eventually the sandstone failed and the fault developed (D) (after Badgley, 1964).



Figure 19. Little Greys anticline, view towards the north. Bedding planes are accentuated. Note small syncline on eastern limb and landslide in core (outlined). Formations are (Jt) Twin Creek Limestone, (Jsp) Stump and Preuss sandstones, and (KGI) lower Gannett Group.

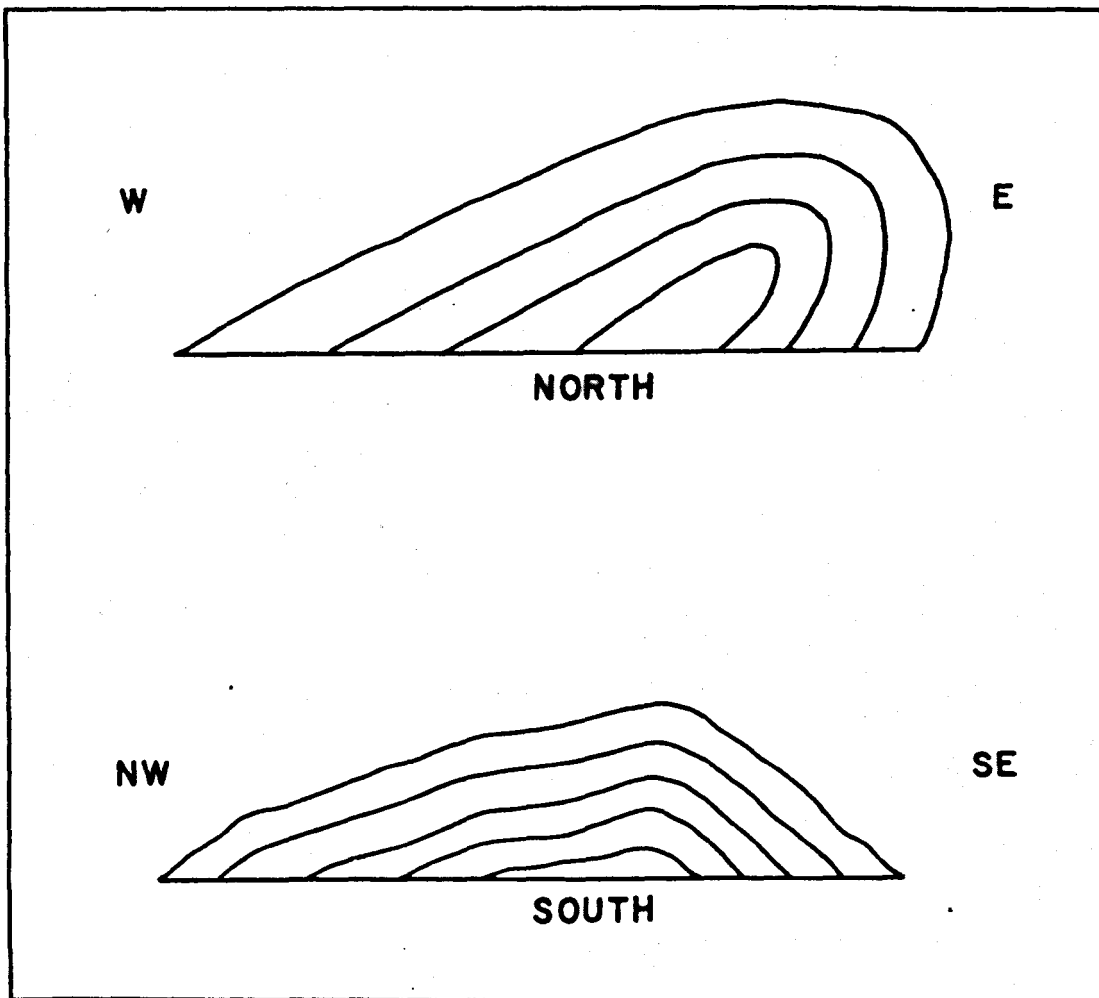


Figure 20. Composite of dips taken across Little Greys anticline at north end along Snake River, and south along northwestern trend near top of Elk Mountain. Anticline overturned at north, reflecting its proximity to Absaroka thrust. Not to scale.

this flexure is part of the Middle Ridge syncline which increases in magnitude to the south.

The anticline is moderately asymmetric in the south with dips on the western limb averaging 45° and those on the east limb averaging 60° . In the middle of the map area, the anticline becomes strongly overturned to the east where both eastern and western limbs dip 40° to the west. Northward, the overturning is somewhat less with dips on the eastern limb on the order of 40° to 60° W. Those on the western limb do not exceed 25° to 30° W. One-half mile north of the study area, the amplitude of the fold greatly diminishes as it gently plunges beneath the hanging wall of the Absaroka thrust.

Small Folds. A small anticline and syncline repeat the Aspen section at the north-central margin of the map area (Fig. 17). They trend N 30° W and both are not apparent a mile to the south. They plunge approximately 14° to the north, determined by a measurement of the axial crest where the anticline is exposed along the Snake River. These folds are strongly asymmetric with dips on the western limb averaging 35° , and 70° on the eastern limb.

ECONOMIC GEOLOGY

Economic resources of the Pine Creek Quadrangle include phosphate rock, gravel, riprap, road metal, limestone, placer gold, and potential petroleum.

The phosphate is concentrated in the Meade Peak and Retort Phosphatic Shale members near the base and top of the Phosphoria Formation. These poorly exposed phosphate beds crop out on the west flank of Grayback Ridge in the extreme northeastern corner of the map area. The Meade Peak Member is approximately 50 feet thick and is principally comprised of intercalated thin beds of phosphorite, phosphatic shale, mudstone, siltstone, and carbonate (Jobin, 1972). The phosphorite occurs as oolites, pisolites, pellets, and as dense structureless types. The phosphate rich beds in the Retort Phosphatic Shale Member are very thin due to post-depositional erosion (Jobin, 1972). The true thickness of this unit within the Pine Creek Quadrangle is unknown but to the west in the Ferry Peak Quadrangle it ranges from 1-6 feet. Refer to Sheldon (1963), Albee (1963), and Jobin (1972) for a complete analysis of P_2O_5 concentrations in these members in the area directly adjacent to the Pine Creek Quadrangle. These members are too thin for economic development under current conditions.

Deposits of gravel, riprap, road metal, and limestone are abundant within the map area. The Mission Canyon Limestone and lower

part of the Wells Formation provide relatively pure Limestone (Jobin, 1972) although these formations are confined only to the northeastern corner of the map area. Magnesium rich limestone can be quarried from the Draney and Peterson limestones along the Little Greys River.

Gold bearing gravel from the terraces along the Snake River have been placered intermittently for more than 100 years. Values averaged 10 to 14 cents a cubic yard (Albee et al., 1975).

Oil potential within the area is unknown. The Little Greys anticline along the Little Greys River has been drilled at least three times, two of which are on record. Wiger (1955) reported on these tests both of which occurred prior to 1951. The first test bottomed in the Thaynes Formation at 2,752 feet and no oil shows were reported. The second test was drilled to 4,699 feet to the Woodside Formation after faulting out of what was interpreted to be the Phosphoria Formation. This second test had dead oil stain in the Phosphoria (?) at 4,400 feet in a slightly vuggy, sucrosic dolomite. It is important to note that a fault, probably the Little Greys, was intersected in this second test. Therefore, the Little Greys anticline is probably a smaller structural trap than was previously thought. The probable overturned folds occurring in the central part of the Pine Creek area (see Local Structure, Introduction, page 95) may provide potential petroleum traps.

SUMMARY

Three stages are evident in the geologic development of the map area. First, there was an early depositional phase in which sediment accumulated in the transitional area between the miogeosyncline on the west and the continental platform on the east; second, large northward-trending thrusts and associated folds were developed; and third, the geomorphic development of the area in which several processes interacted to alter the landforms produced during the first two phases.

Mississippian -- Marine limestone was deposited in the miogeosynclinal and shelf areas during the Early Mississippian advance of the sea (Haun and Kent, 1965). Regression of the sea in late Mississippian time resulted in the development of a karst surface on the exposed Mission Canyon Limestone.

Pennsylvanian -- Detritus was derived from eastern and western sources and deposited in a marginal basinal area in southeastern Idaho which was appreciably more calcareous than its margins. Epeirogenic uplift gradually gave way to a partial withdrawal of the sea in Late Pennsylvanian time (Mallory, 1972).

Permian -- Due to tectonic movements the Phosphoria sea twice transgressed and regressed across western Wyoming, and minor fluctuations of climatic and oceanographic conditions produced intricate interbedding (McKelvey et al., 1959).

Triassic -- Two marine advances during the Early and Middle Triassic resulted in the deposition of clastic and carbonate strata of the Dinwoody and Thaynes formations. Between marine advances deltas were prograding westward and northward producing intertonguing of marine and continental deposits. West of the basin, in south-central Idaho, a large northeast trending ridge rose in early Late Triassic time shedding detritus eastward.

Jurassic -- The shallow marine environment of the Twin Creek Limestone gradually gave way to open marine conditions during deposition of the Upper Jurassic Stump sandstone as the marine incursions of the Arctic sea spread successively farther across Wyoming. The high area in south-central Idaho again rose in early Late Jurassic time spreading alluvial detritus across the study area.

Cretaceous -- The alluvial fans which developed in the study area were gradually inundated by another marine incursion in middle Early Cretaceous time. Although both the Bear River and Aspen formations were deposited in deltaic and associated terrestrial environments the water depth and volcanic activity increased during deposition of the Aspen Shale.

Late Cretaceous - Early Tertiary -- Structural deformation in the area resulted from large eastward moving thrust plates which emanated from a high area in southeastern Idaho. A large fold developed within the map area from movement on the adjacent Absaroka

Thrust. As deformation continued the fold became overturned and the shales of the Bear River and Aspen formations were stretched. Movement on the Little Greys fault occurred as the sandstone bed in the upper part of the lower Bear River Formation failed.

Late Tertiary - Quarternary -- During Middle Pliocene time a large lake in which fine grained detritus was deposited may have occupied the study area. The Snake and Little Greys Rivers could have developed on this basin fill or lake level and eroded through the underlying topography by superposition. During the Pleistocene a large landslide originated on the west flank of Grayback Ridge and moved water-saturated material down Bailey Creek damming it and the Snake River causing the bed loads to be deposited upstream. This slide surface was modified over time and then covered by a second landslide that also originated on the flank of the ridge.

NEW CONCEPTS

Several notable conclusions regarding the geomorphology, stratigraphy, and structure of the Pine Creek area have resulted from this study. It is hoped that these will contribute to the general understanding of the geology of the northern part of the Wyoming overthrust belt.

Geomorphology

The Bailey Creek landslide originated on the west flank of Grayback Ridge within the Madison and Wells formations, moving debris down Bailey Creek. This resulted in the damming of Bailey Creek and the Snake River causing the bed loads to be deposited upstream. The surface of the slide debris was modified over time which allowed for some of the detritus to become lithified. This surface was later covered by a second landslide that also originated within the Madison limestone and Wells quartzite.

Stratigraphy

1. A basal breccia was found within the Thaynes Formation which may indicate that a local shoal existed in the Pine Creek area during deposition of the lower part of this unit.

2. The Draney Limestone of the Gannett Group is present in the northwestern part of the map area and is absent to the southeast, contrary to conclusions reached by Eyer (1969) who indicated that the Draney was present over the entire map area.

3. The lower Bear River sequence, consisting of siltstone, sandstone, mudstone, and black shale is anomalously thick and well developed in the southwestern part of the map area on the west limb of the Little Greys anticline. The total thickness (1,250 feet) of the Bear River here is the greatest in the Pine Creek Quadrangle and adjacent area.

4. A pebbly conglomerate unit was found within the upper Aspen Shale in the central and western outcrop belts and south of the Little Greys River. The conglomerate is most correctly interpreted as a tongue of the overlying Frontier Formation to which the conglomerate can be traced along strike to the south.

Structure

The Little Greys reverse fault runs east of the axis of the Little Greys anticline and repeats part of the Aspen section. It is likely, however, that the south-central part of the map area is further complicated by overturned folding not evident in the outcrop.

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APPENDIX

GANNETT GROUP SECTIONS

This partial section of the Gannett Group is located on the south facing hill just to the east of the axis of the Little Greys anticline, directly north of the Little Greys Road, and 1,000 feet northwest of the point where the road crosses the first creek west of Cow Camp Creek at 43° 8' 55" latitude and 110° 43' 45" longitude.

GANNETT GROUP:

	Unit Thick. (feet)	Cumul. Thick (feet)
Bechler Conglomerate:		
18. Concealed - - - - -	40+	572+
Peterson Limestone:		
17. Limestone -- medium-grey, weathers grey-purple at base, becomes light-cream-grey, weathering white-grey near middle, micritic, sparite crystals apparent, massive, chert nodules - - - - -	84	532
Ephraim Conglomerate:		
16. Calcareous claystone -- brown-purple, weathers same, a few coarse grains of sand, limestone nodules, calcite filling of vugs, massive, becomes brecciated near top, and very nodular with straight contact with unit 17 above - - - - -	22	448
15. Concealed - - - - -	34	426
14. Sandstone -- medium purple, weathers brown purple, fine- to very fine-grained, very thinly bedded - - - - -	5	392

GANNETT GROUP continued

	Unit Thick (feet)	Cum. l. Thick (feet)
13. Concealed - - - - -	103	387
12. Sandstone -- purple-grey, weathers medium-purple, fine- to very fine- grained, a few grey limestone nodules, becomes grey limestone at top - - - - -	12	284
11. Concealed - - - - -	42	272
10. Sandstone -- as unit 12 above - - - - -	2	230
9. Concealed - - - - -	18	228
8. Sandstone -- medium-purple, weathers same, fine- to very fine-grained, massive, a few $\frac{1}{4}$ inch, subrounded, chert pebbles at base - - - - -	10	210
7. Sandstone and conglomeratic sandstone -- sandstone, brown-red, weathers white, medium- to coarse-grained, "clean," quartzose, grades to sandstone, very fine-grained, laminated, near top, conglomerate, brown-red, weathers same, matrix 20%, clasts are brown chert, subangular to subrounded, $\frac{1}{4}$ inch to 2 inches, sorting in matrix good to poor, sandstone grades to conglomeratic sandstone to conglomerate lenticular - - - - -	19	200
6. Concealed - - - - -	33	181
5. Sandstone -- purple, weathers purple- red, very fine-grained, very thinly bedded - - - - -	11	148

GANNETT GROUP continued

	<u>Unit Thick (feet)</u>	<u>Cumul. Thick (feet)</u>
4. Sandstone -- light-purple, weathers same, fine-grained, well sorted, cross-bedded - - - - -	3	137
3. Concealed - - - - -	41	134
2. Sandstone -- very light-purple, weathers same, medium-grained, laminated- to thinly bedded, "clean," quartzose - - - - -	22	93
1. Concealed - - - - -	71	71

STUMP SANDSTONE

1. Sandstone -- medium grey, weathers brown-grey fine-grained, massive, glauconitic - - - - -	10+	10+
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The second partial section of the Gannett Group occurs on the hill, 200 feet above U.S. Highway 26-89, directly adjacent to Elbow Campground at 43° 12' 45" latitude and 110° 47' 22" longitude.

GANNETT GROUP:

	Unit Thick (feet)	Cumul. Thick (feet)
6. Concealed - - - - -	35+	318+
Draney Limestone:		
5. Limestone -- medium-grey, weathers white, micritic, massive, few coarse crystals of sparite as vein filling - - - - -	70	283
Bechler Conglomerate:		
4. Concealed -- soil light-red-purple - -	87	213
3. Sandstone -- buff-grey, weathers same, very fine grained, thinly bedded to laminated, quartzose - - - -	4	129
Peterson Limestone:		
2. Limestone -- as Draney Limestone above - - - - -	100	125
Ephraim Conglomerate:		
1. Concealed - - - - -	25+	25+

ASPEN SHALE SECTION

This partial section of Aspen Shale occurs in the west-central part of the quadrangle just to the south of the Little Greys River on the east facing slope. It begins 2,500 feet southwest of the point where the Little Greys Road crosses Squirrel Creek and 2,000 feet northeast of the 7,449 foot peak, at 43° 8' 55" latitude and 110° 50' 45" longitude.

	<u>Unit Thick (feet)</u>	<u>Cumul. Thick (feet)</u>
ASPEN FORMATION:		
74. Porcelanite -- grey-green, white spots, thinly bedded - - - - -	1	864+
73. Concealed - - - - -	1	863
72. Porcelanite -- grey-green, massive - -	1.5	862
71. Concealed - - - - -	185	860.5
70. Sandstone--grey-green, weathers same silt- to fine-grained, argillaceous, massive - - - - -	10	675.5
69. Sandstone -- grey-green, weathers same, medium-grained, "salt and Pepper," cross-bedded - - - - -	5	665.5
68. Concealed - - - - -	14	660.5
67. Sandstone -- as unit 69 above - - - - -	3	646.5
66. Concealed - - - - -	11	663.5

ASPEN SHALE continued

	<u>Unit Thick (feet)</u>	<u>Cumul. Thick (feet)</u>
65. Silty claystone -- grey-green, weathers same, poorly exposed - - - - -	1	632.5
64. Concealed - - - - -	9.5	631.5
63. Sandstone -- grey-green, weathers same, silt- to fine-grained in argillaceous matrix, poorly sorted, massive, becomes silty claystone, grey-green, weathers same, in last few feet - - - - -	13.5	622
62. Sandstone -- light-grey, weathers same, medium-grained, "salt and pepper," simonitic, massive - - - - -	11	608.5
61. Siltstone -- grey-green, weathers light-grey - - - - -	75	597.5
60. Sandstone -- as unit 70 above - - - - -	1.5	590
59. Sandstone -- grey-green, weathers same, very-fine-grained- to silt, thickly bedded to massive - - - - -	9.5	582.5
58. Sandstone -- light grey, weathers grey-green, medium grained, massive - -	1	579
57. Concealed - - - - -	1	578
56. Claystone -- medium-grey, weathers grey-green, blocky - - - - -	12	577
55. Concealed - - - - -	10	565
54. Sandstone -- grey-green, weathers same, fine- to very-fine-grained, argillaceous matrix, becomes medium-grained near top - - - - -	6	555

ASPEN SHALE continued

		Unit Thick (feet)	Cumul. Thick (feet)
53.	Concealed - - - - -	39	549
52.	Siltstone -- grey-green, weathers same, blocky - - - - -	3.5	510
51.	Sandstone -- light-grey-green, weathers grey-green, medium-grained, massive - - - - -	3.5	506.5
50.	Concealed - - - - -	71	503
49.	Sandstone and Siltstone, interbedded -- 1 foot to 2 foot beds, sandstone, medium-grey, weathers grey-green, very fine-grained, massive, siltstone, grey- green, weathers same, blocky - - - - -	10	432
48.	Concealed -- a little dark grey-green shale near top - - - - -	15.5	422
47.	Sandstone -- grey-green, weathers same, medium-grained, "salt and pepper", massive - - - - -	2.5	406.5
46.	Concealed - - - - -	8.5	404
45.	Sandstone -- grey-green, weathers same, fine- to medium-grained, poorly cemented - - - - -	3.5	395.5
44.	Concealed - - - - -	5	392
43.	Sandstone -- grey-green, weathers same, medium-grained with some fine grains, "salt and pepper", thinly bedded and cross-bedded - - - - -	4	387
42.	Sandstone -- grey-green, weathers same, very fine-grained, thinly bedded - - -	2	383

ASPEN SHALE continued

	Unit Thick (feet)	Cumul. Thick (feet)
41. Concealed - - - - -	4	381
40. Sandstone -- light grey, weathers grey-green, medium-grained, "salt and pepper", massive - - - - -	4	387
39. Concealed -- a little olive-grey shale present - - - - -	46	383
38. Claystone and siltstone, interbedded -- grey-green, weathers same, mottled, blocky, in 4 inch to 6 inch beds - - -	9	337
37. Sandstone -- grey-green, weathers same, fine-grained, massive - - - - -	3	328
36. Claystone -- grey-green, weathers same - - - - -	9	325
35. Limestone -- green-grey, weathers medium-brown, micritic, massive - - - -	1	316
34. Concealed - - - - -	2	315
33. Sandstone -- light-grey, weathers grey-green, medium-grained, "salt and pepper", massive, becomes finer grained last 15 feet and cross- bedded 3 feet - - - - -	45	313
32. Concealed -- a little shale, grey- green present - - - - -	49	268
31. Siltstone -- dark green-grey, weathers same, few plant fragments, blocky - - -	2	219
30. Concealed - - - - -	2	217

ASPEN SHALE continued

	<u>Unit Thick (feet)</u>	<u>Cumul. Thick (feet)</u>
29. Sandstone -- light grey, weathers same, medium grained to fine grained, massive, occurs as lenses - - - - -	2	215
28. Concealed - - - - -	9	213
27. Shale -- medium grey, weathers same, fissile, becomes blocky up section - -	6.5	204
26. Sandstone -- grey-buff, weathers brown-grey, medium-grained, thickly bedded - - - - -	1	197.5
25. Siltstone -- grey-green, weathers same, very thinly bedded- to shaly, grading to very fine-grained sandstone at top - - - - -	14	196.5
24. Sandstone -- grey-green, weathers same, fine- to medium-grained, limontic, massive - - - - -	3	182.5
23. Concealed - - - - -	4	179.5
22. Claystone -- green-grey, weathers medium-brown, blocky - - - - -	1	175.5
21. Concealed - - - - -	7.5	174.5
20. Sandstone -- green-grey, weathers same, fine-grained, cross-bedded - - -	4.5	167
19. Concealed - - - - -	8	162.5
18. Sandstone -- grey-green, weathers same, very fine-grained, thinly bedded, occurs as lenses - - - - -	1	154.5

ASPEN SHALE continued

	<u>Unit Thick (feet)</u>	<u>Cumul. Thick (feet)</u>
17. Shale -- medium grey, weathers same, fissile - - - - -	7	153.5
16. Sandstone -- light grey, weathers grey-green, medium-grained, "salt and pepper", massive, becomes thinly bedded at top - - - - -	3.5	146.5
15. Shale -- dark-grey, weathers same, fissile - - - - -	3.5	143
14. Sandstone -- grey-green, weathers same, fine- to medium-grained, "salt and pepper", limonitic, massive - - - -	2.5	139.5
13. Shale -- grey-green, weathers same, fissile, becomes blocky up section - -	6	137
12. Concealed -- a little shale, grey- green present - - - - -	17	131
11. Sandstone -- grey-green, weathers same, medium-grained, "salt and pepper", wispy, lenticular, limonitic - - - - -	2	114
10. Concealed - - - - -	21	112
9. Silty limestone -- grey, weathers brown, uneven bedding, lenticular - - -	3	91
8. Sandstone -- grey-green, weathers same, medium-grained, thinly bedded - - - - -	2	88
7. Siltstone -- grey-green, weathers same, thinly bedded, glauconitic, grades to shale, dark-grey, near top - - - - -	11	86

ASPEN SHALE continued

	<u>Unit Thick (feet)</u>	<u>Cumul. Thick (feet)</u>
6. Sandstone -- very light-grey, weathers grey-green, medium-grained, "salt and pepper"; poorly cemented - - - - -	1	75
5. Concealed - - - - -	19	74
4. Siltstone -- grey-green, weathers same, thinly bedded, glauconitic, grades to sandstone, grey-green, very fine-grained, thinly bedded to very thinly-bedded near top - - - -	12.5	55
3. Concealed - - - - -	28	42.5
2. Shale -- black, weathers dark-grey, fissile - - - - -	5	14.5
1. Sandstone -- grey, weathers grey-green, medium-grained, "salt and pepper", thinly bedded, becomes thickly bedded near top - - - - -	9.5	9.5

BEAR RIVER FORMATION:

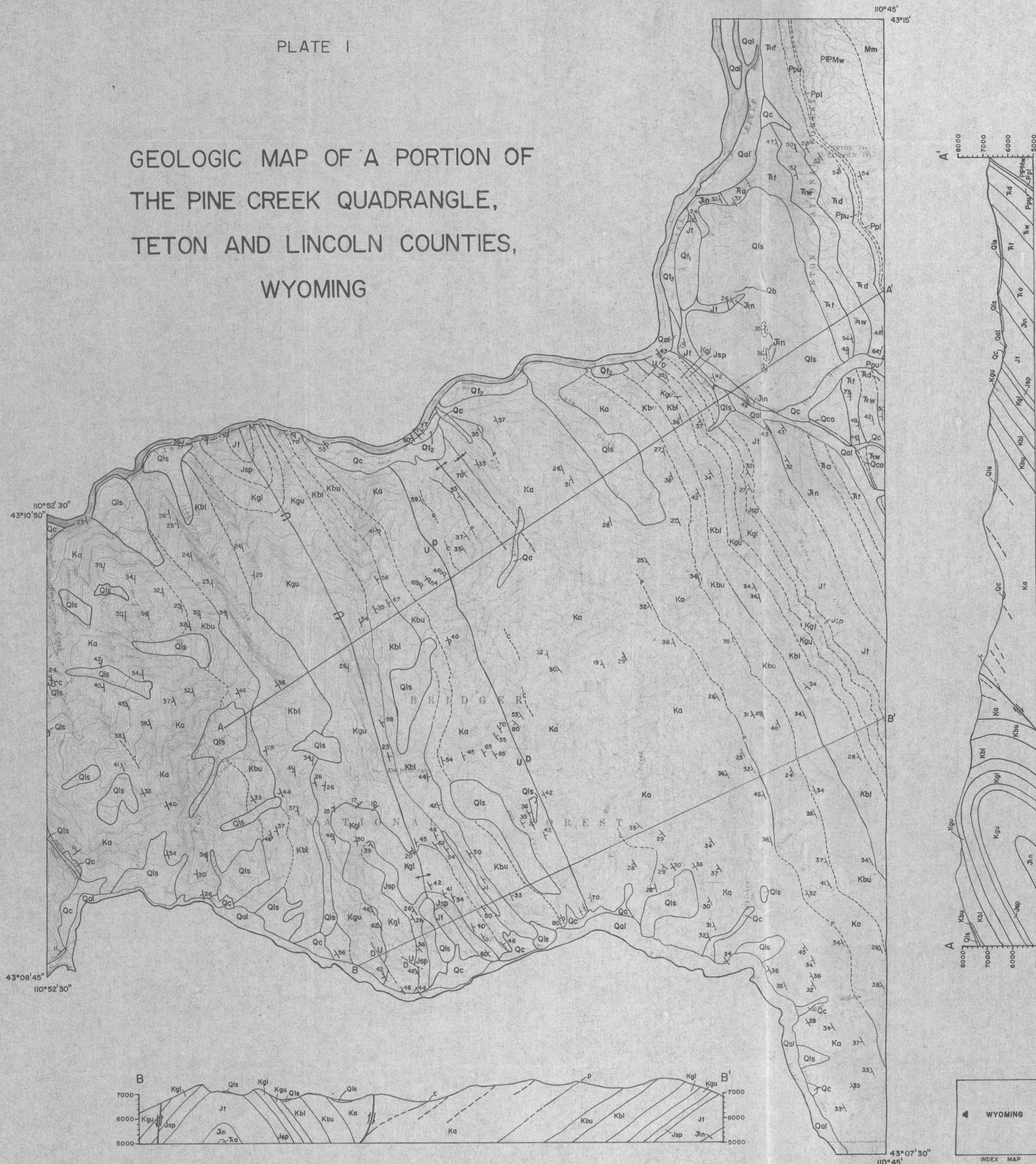
5. Shale -- dark-grey, weathers black, silty, fissile - - - - -	13	60+
4. Shale -- as above but with fossiliferous bed 6 inches from base -	14	47
3. Sandstone -- grey-green, weathers same, fine-grained, plant fragments, thinly bedded, becomes thickly bedded near top - - - - -	11	33

ASPEN SHALE continued

	<u>Unit Thick (feet)</u>	<u>Cumul. Thick (feet)</u>
2. Shale -- black, weathers same, with coquina float - - - - -	16	22
1. Sandstone -- as unit 3 above - - - - -	6+	6

PLATE I

GEOLOGIC MAP OF A PORTION OF THE PINE CREEK QUADRANGLE, TETON AND LINCOLN COUNTIES, WYOMING

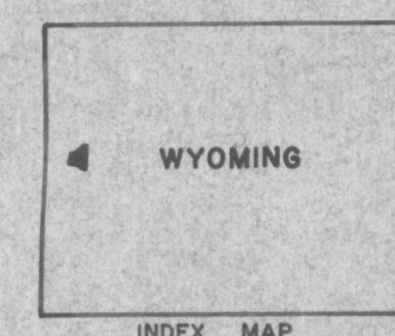


EXPLANATION

QUATERNARY	Qal	ALLUVIUM
	Qc	COLLUVIUM
	Qf ₂	TERRACE DEPOSITS
	Qf ₁	
	Qls	LANDSLIDE DEPOSITS
	Qb	BRECCIA
CRETACEOUS	Qco	CONGLOMERATE
	DERIVED FROM BAILEY CREEK LANDSLIDE	
	Ka	ASPEN SHALE
	Kp	PORCELANITE, C CONGLOMERATE
	Kbu	UPPER BEAR RIVER FORMATION
	Kbl	
	Kgu	UPPER GANNETT GROUP
	Kgl	
	Jsp	STUMP SANDSTONE
	Jt	PREUSS SANDSTONE
JURASSIC	Jn	TWIN CREEK LIMESTONE
	Ja	NUGGET SANDSTONE
	Ra	ANKAREH FORMATION
	Rt	THAYNES FORMATION
TRIASSIC	Rw	WOODSIDE FORMATION
	Rd	DINWOODY FORMATION
PERMIAN	Ppu	UPPER PHOSPHORIA FORMATION AND ASSOCIATED ROCKS
	Ppl	
PENNSYLVANIAN	PPMw	WELLS FORMATION
MISSISSIPPIAN	Mm	MISSION CANYON LIMESTONE

- CONTACT, DASHED WHERE APPROXIMATELY LOCATED
- FAULT, DASHED WHERE APPROXIMATELY LOCATED
- U UP THROWN SIDE
- D DOWN THROWN SIDE
- ANTICLINE
- OVERTURED ANTICLINE
- SYNCLINE
- STRIKE AND DIP OF BEDS
- INCLINED
- OVERTURNED
- VERTICAL

GEOLOGY BY ROBERT A. LUNCEFORD
SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE
OF MASTER OF SCIENCE IN EARTH
SCIENCES AT MONTANA STATE
UNIVERSITY 1976



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