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

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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Approved:

Chairperson, Graduate Committee

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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.

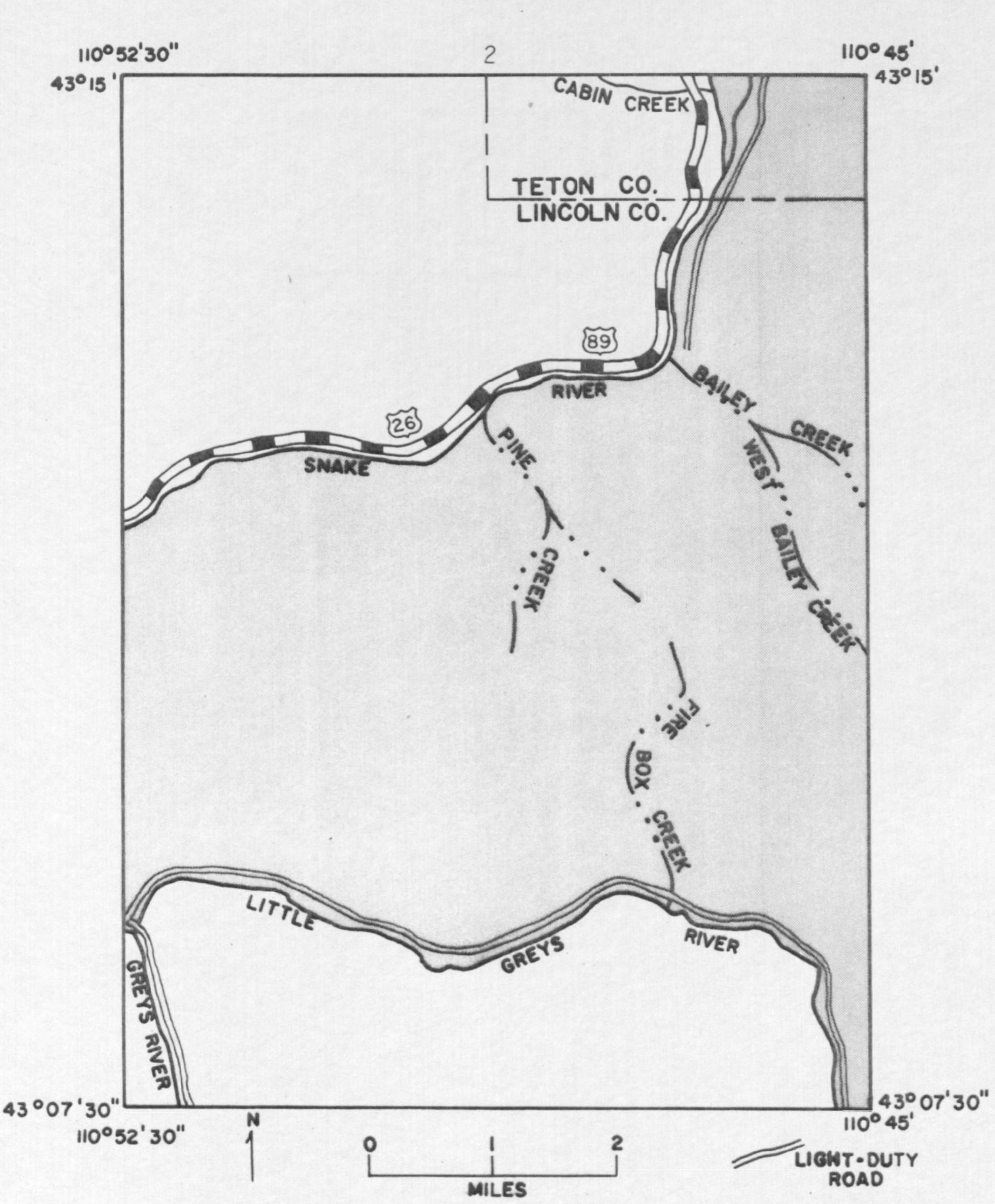
INTRODUCTION

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.



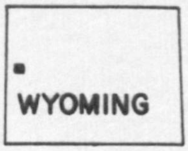


Figure 1. Index Map, Pine Creek Quadrangle.
Map area shaded.

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

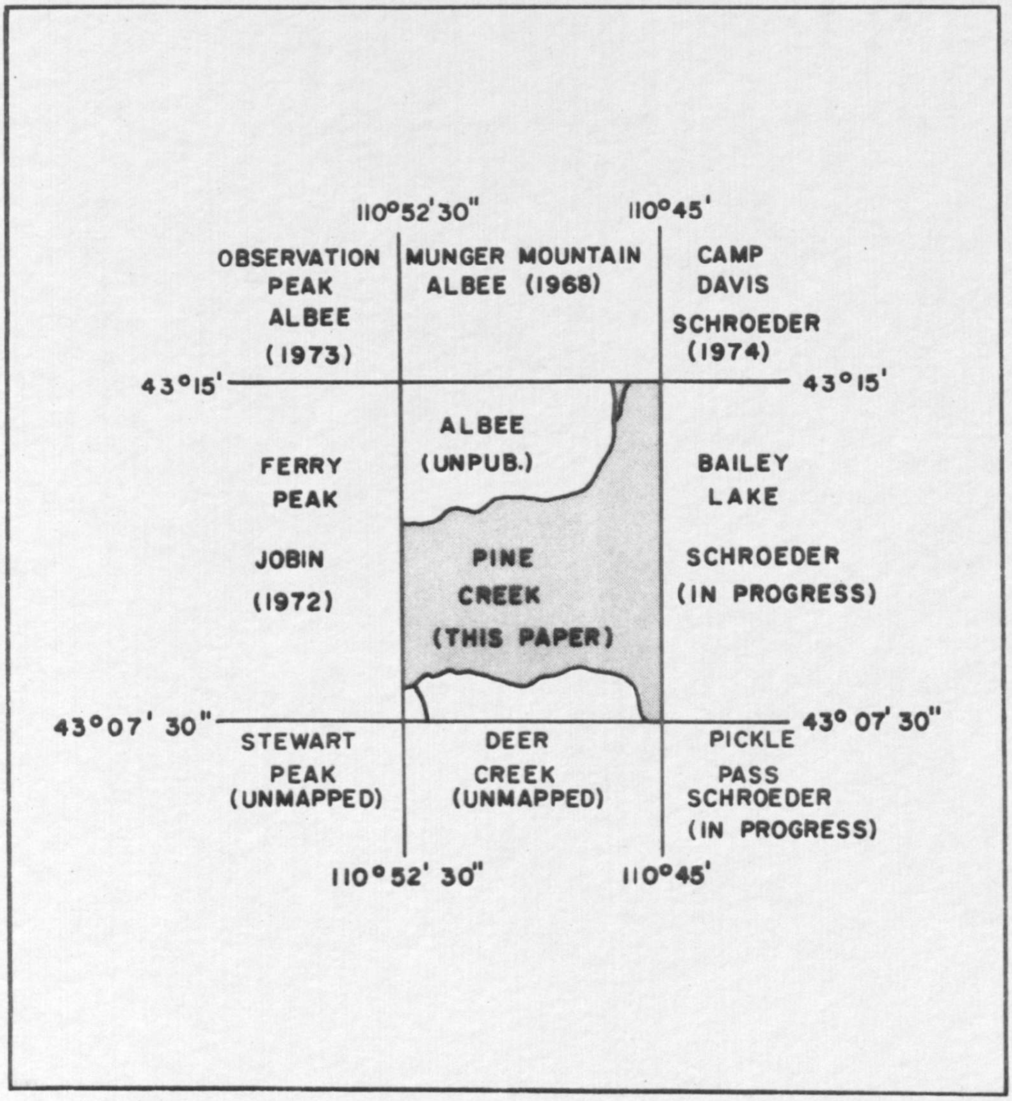


Figure 2. Index map of published and in-progress geologic quadrangles adjacent to Pine Creek Quadrangle. Map area shaded.

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.

GEOMORPHOLOGY

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 1½ 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 7½ 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

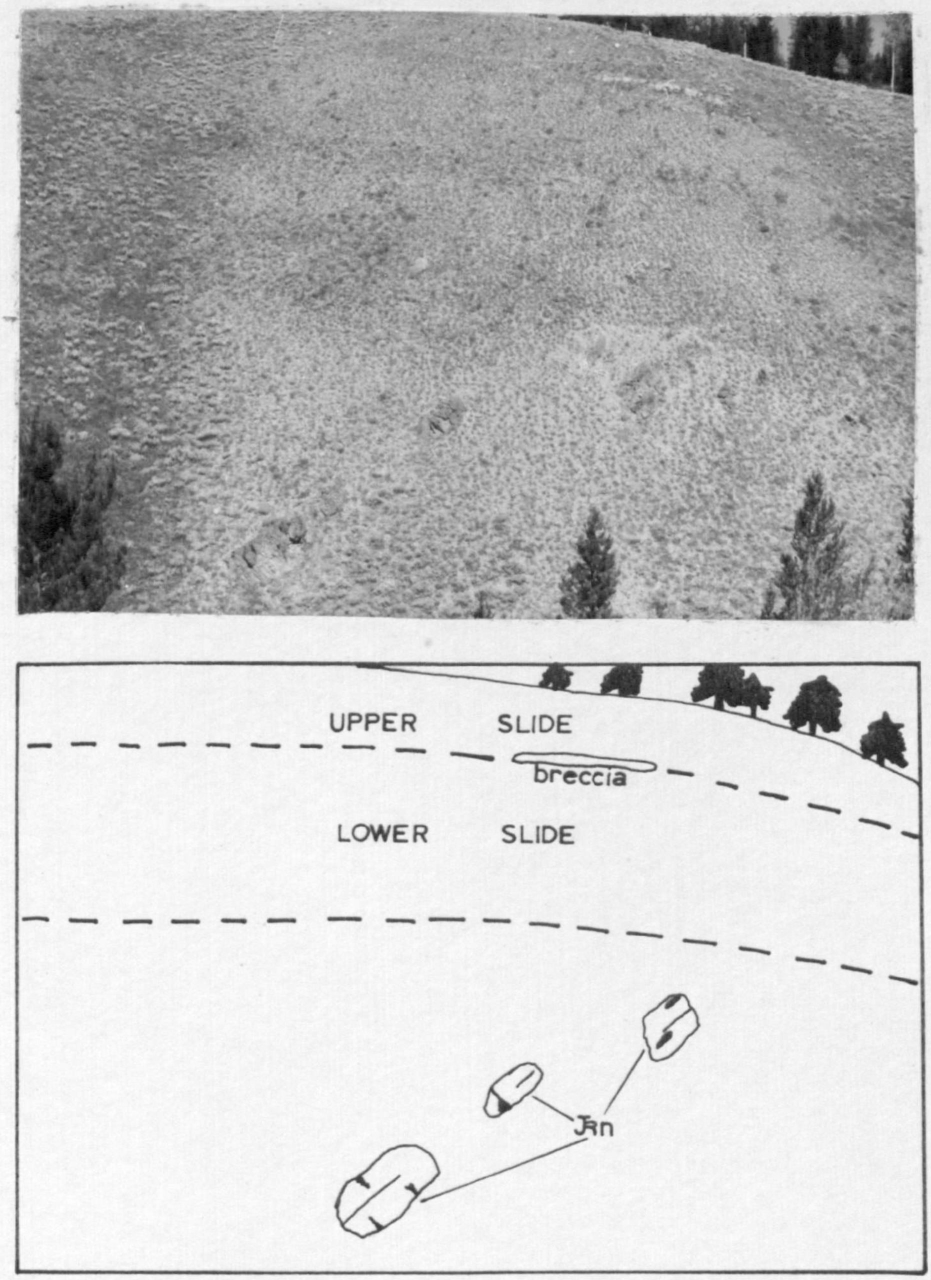


Figure 3. Upper landslide and older lower landslide separated by breccia unit. Note strong lithification of breccia unit compared to adjacent landslide debris. JRn is Nugget Sandstone.

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.

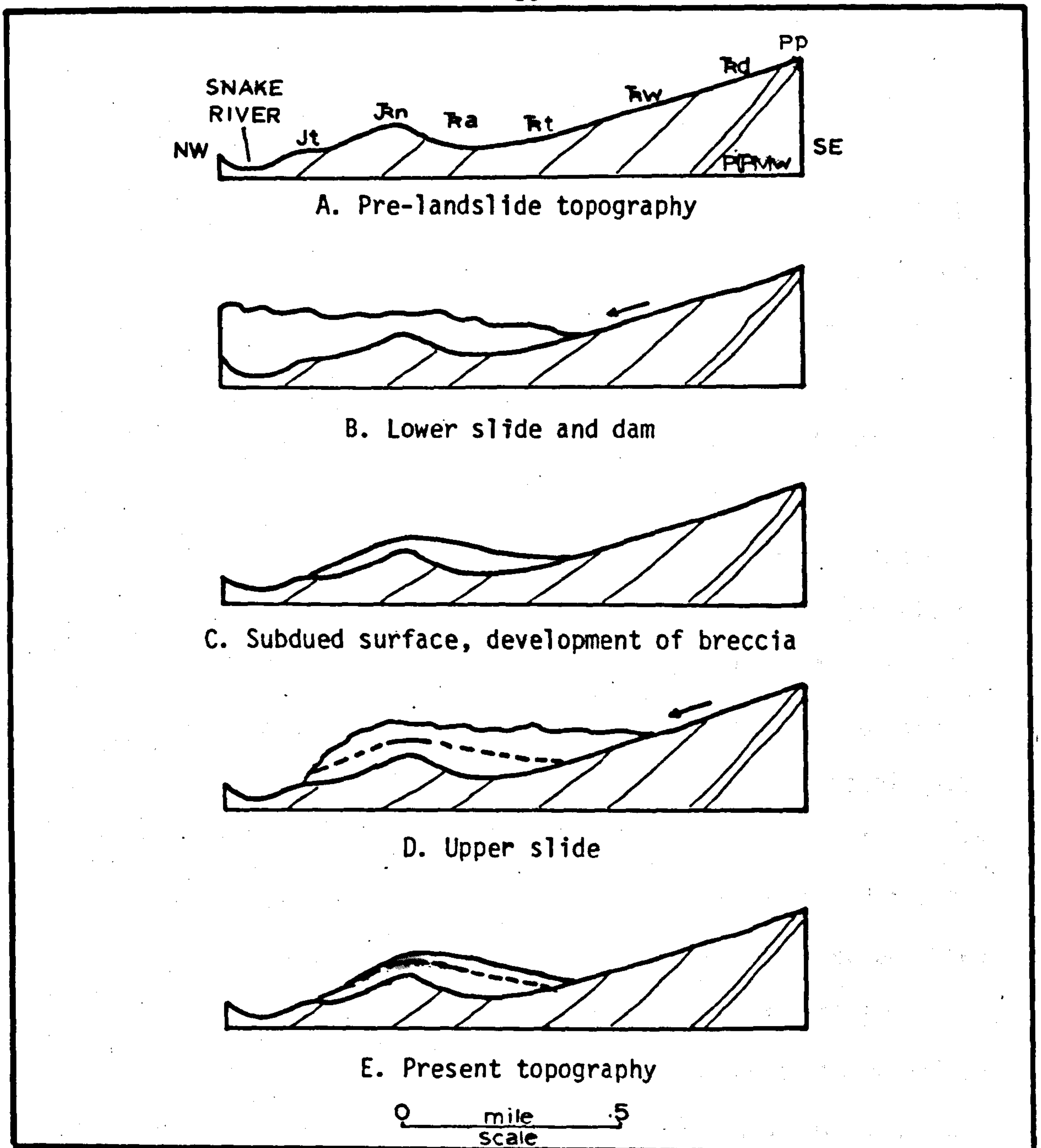


Figure 4. Hypothetical development of Bailey Creek landslide and dam. Formations are (MPPw) Wells Formation, (Pp) Phosphoria Formation, (TRd) Dinwoody Formation, (TRw) Woodside Formation, (TRt) Thaynes Formation, (TRa) Ankareh Formation, (JTRn) Nugget Sandstone, (Jt) Twin Creek Limestone. Scale approximate.

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).

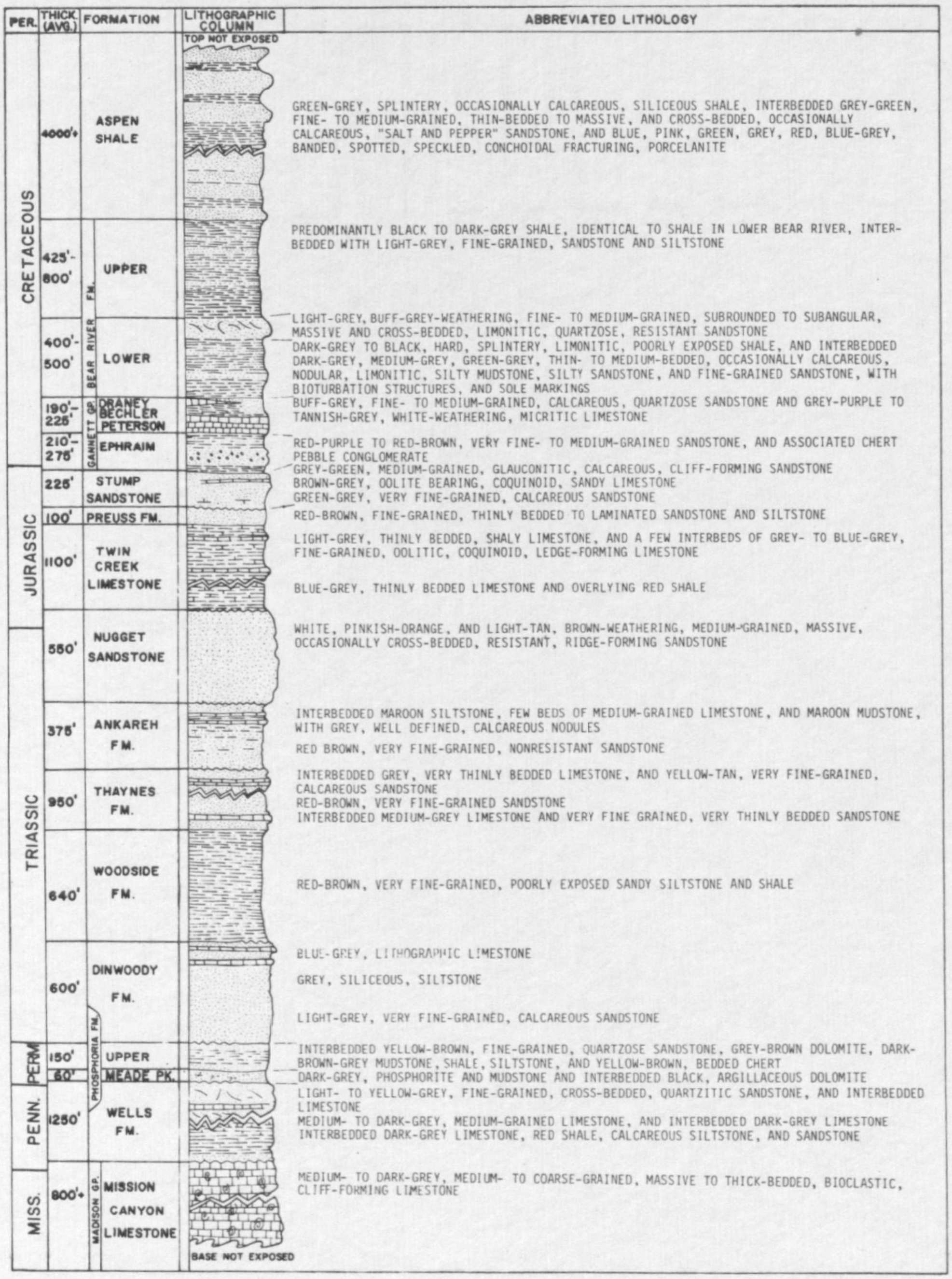


Figure 5. Generalized stratigraphic section, Pine Creek Quadrangle, south of Snake River. Not to scale.

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 north-eastern 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.

<u>Age and Contacts</u>. 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).

<u>Correlations</u>. 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, 1972). 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

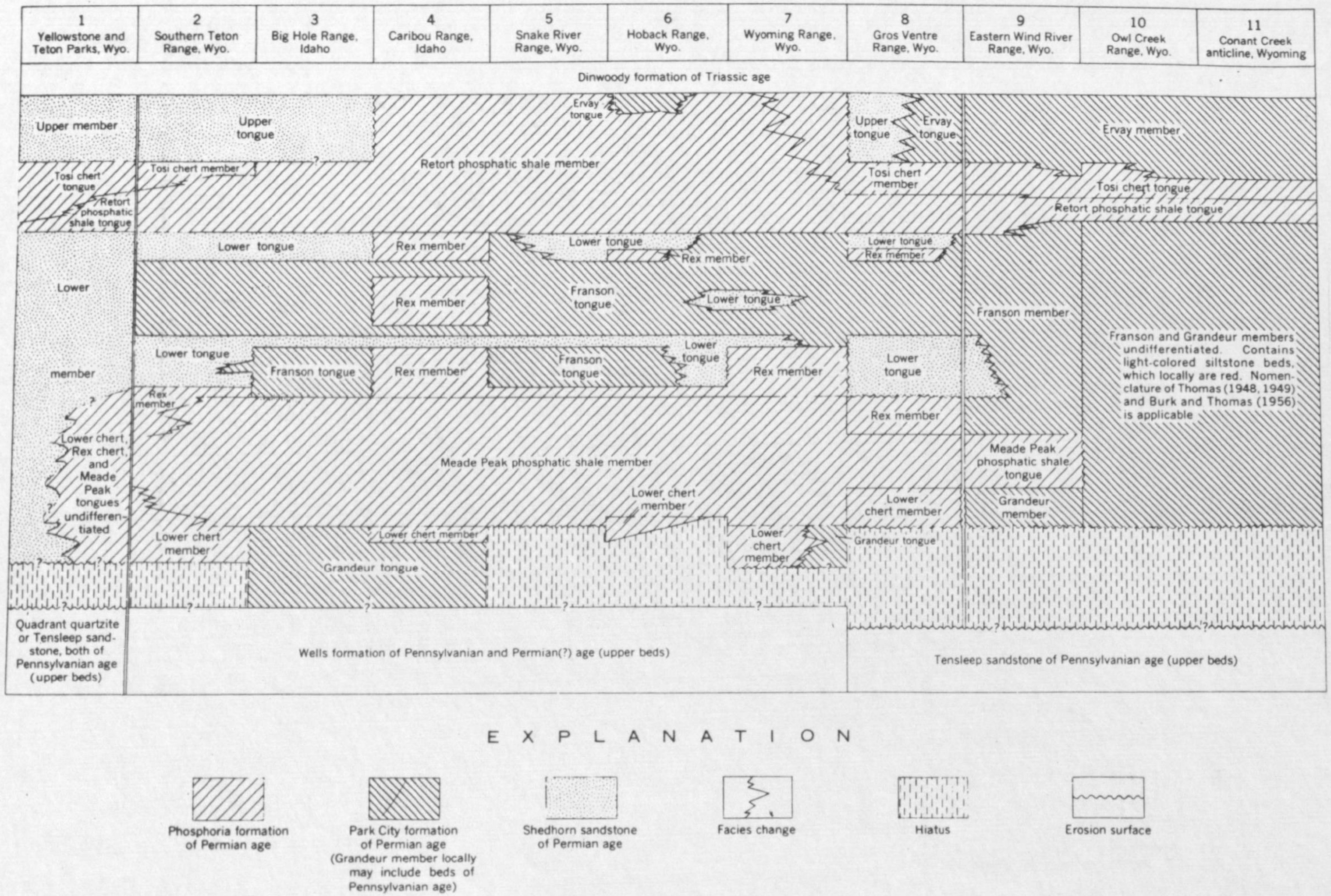


Figure 6. Nomenclature and intertonguing relationships of rocks of Permian age of western Wyoming and southeastern Idaho. Refer to Figure 7 for index map (Sheldon, 1963).

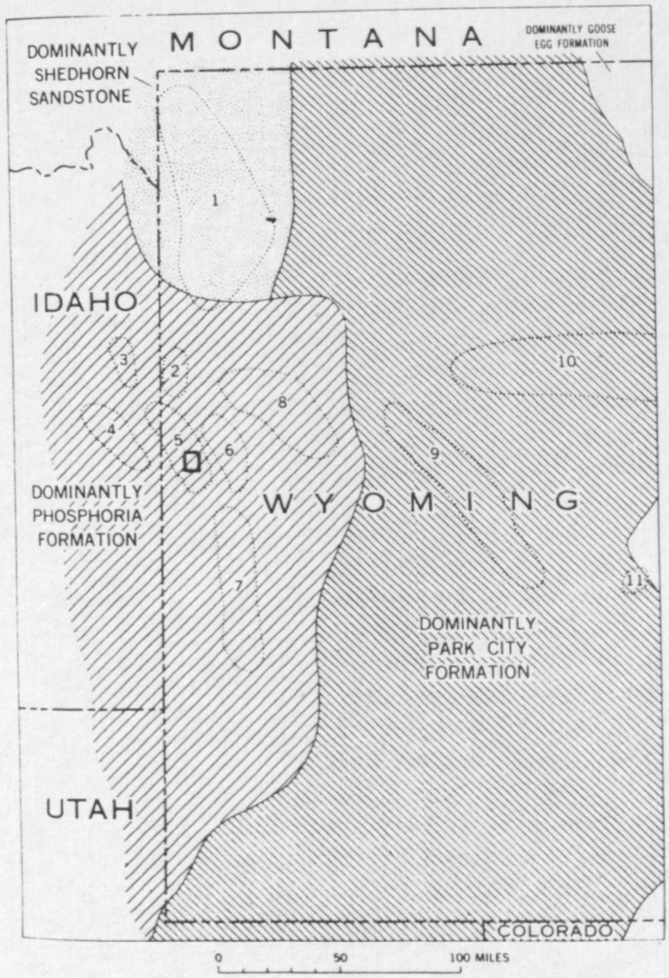


Figure 7. Index map for Figure 6. Symbols and patterns same as for Figure 6 (Sheldon, 1963). Pine Creek Quadrangle outlined.

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).

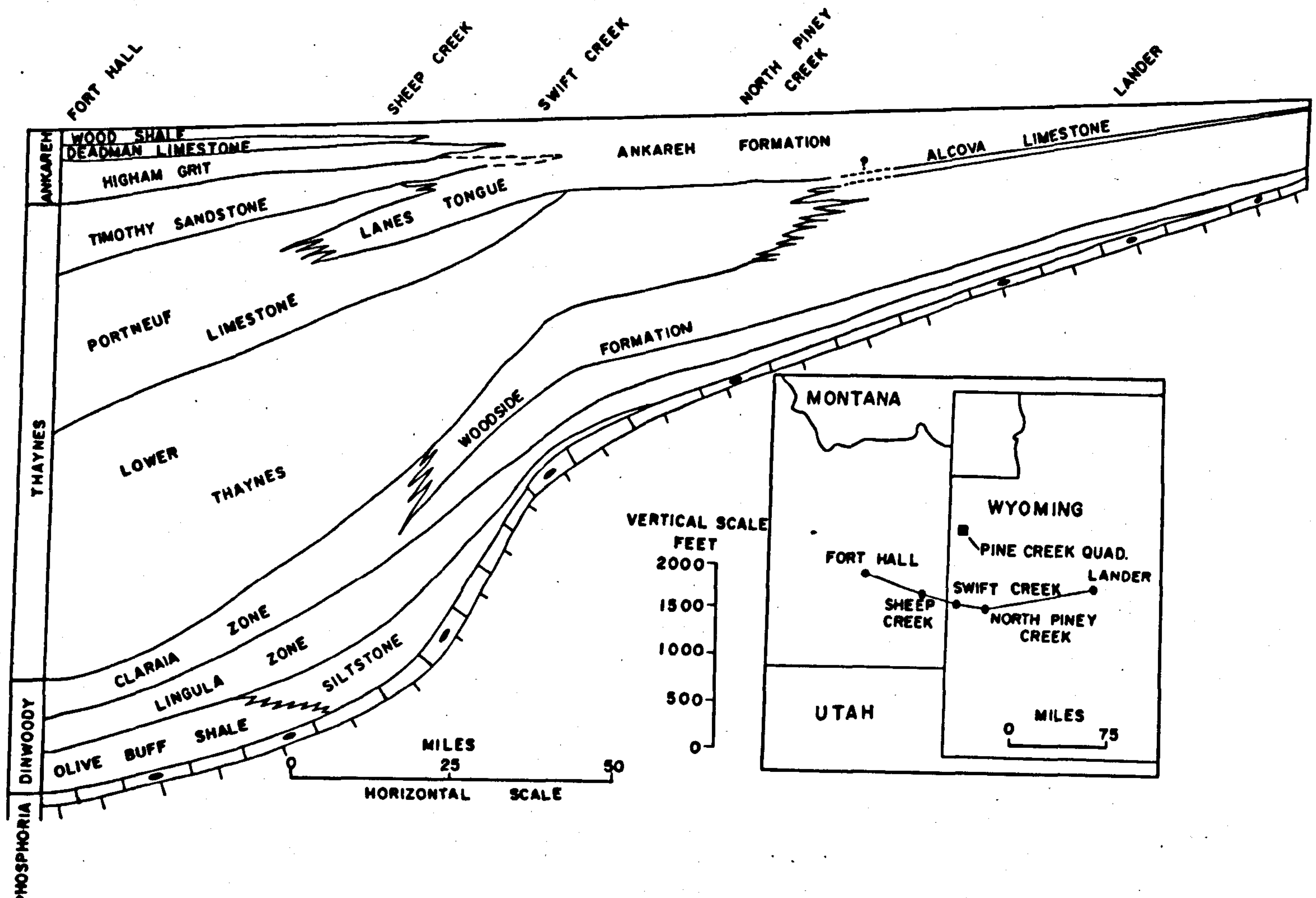


Figure 8. West-east cross-section showing stratigraphic relationships for the Triassic of western Wyoming and southeastern Idaho. Note intertonguing relationships and onlap of Dinwoody over Phosphoria and Thaynes over Woodside (after Kummel, 1954, 1955).

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

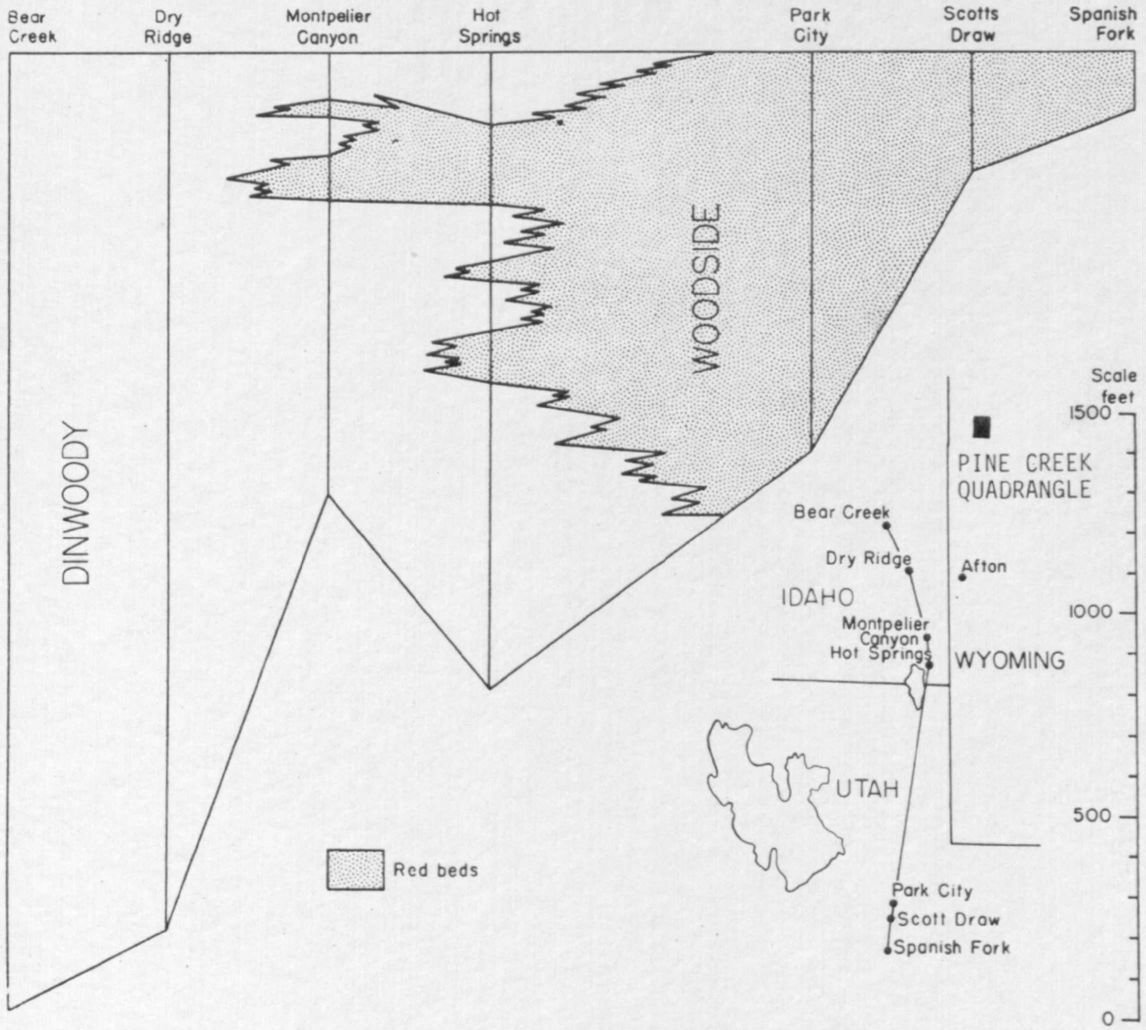


Figure 9. Correlation diagram of Dinwoody and Woodside formations showing intertonguing relationships between Provo, Utah and Henry, Idaho and the resultant time equivalency of the lower part of these units (Kummel, 1953).

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