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GEOLOGY OF THE PHIL PICO MOUNTAIN QUADRANGLE, DAGGETT COUNTY, UTAH AND SWEETWATER COUNTY, WYOMING

by

Alvin D. Anderson

A thesis submitted to the faculty of
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in
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BRIGHAM YOUNG UNIVERSITY

GRADUATE COMMITTEE APPROVAL

of a thesis submitted by

Alvin D. Anderson

This thesis has been read by each member of the following graduate committee and by majority vote has been found to be satisfactory.

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BRIGHAM YOUNG UNIVERSITY

As chair of the candidate's graduate committee, I have read the thesis of Alvin D. Anderson in its final form and have found that (1) its format, citations, and bibliographical style are consistent and acceptable and fulfill university and department style requirements; (2) its illustrative materials including figures, tables, and charts are in place; and (3) the final manuscript is satisfactory to the graduate committee and is ready for submission to the university library.

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TABLE OF CONTENTS

ABSTRACT

Geologic mapping in the Phil Pico Mountain quadrangle and analysis of the Carter Oil Company Carson Peak Unit 1 well have provided additional constraints on the erosional and uplift history of this section of the north flank of the Uinta Mountains. Phil Pico Mountain is largely composed of the conglomeratic facies of the early Eocene Wasatch and middle to late Eocene Bridger Formations. These formations are separated by the Henrys Fork fault which has thrust Wasatch Formation next to Bridger Formation. The Wasatch Formation is clearly synorogenic and contains an unroofing succession from the adjacent Uinta Mountains. On Phil Pico Mountain, the Wasatch Formation contains clasts eroded sequentially from the Permian Park City Formation, Permian Pennsylvanian Weber Sandstone, Pennsylvanian Morgan Formation, and the Pennsylvanian Round Valley and Mississippian Madison Limestones. Renewed uplift in the middle and late Eocene led to the erosion of Wasatch Formation and its redeposition as Bridger Formation on the down-thrown footwall of the Henrys Fork fault.

Field observations and analysis of the cuttings and lithology log from Carson Peak Unit 1 well suggest that initial uplift along the Henrys Fork Fault occurred in the late early or early middle Eocene with the most active periods of uplift in the middle and late Eocene (Figure 8, Figure 24, Appendix 1). The approximate post-Paleocene throw of the Henrys Fork fault at Phil Pico Mountain is 2070 m (6800 ft).

The Carson Peak Unit 1 well also reveals that just north of the Henrys Fork fault at Phil Pico Mountain the Bridger Formation (middle to late Eocene) is 520 m (1710 ft) thick; an additional 460 m (1500 ft) of Bridger Formation lies above the well on Phil Pico Mountain. Beneath the Bridger Formation are 400 m (1180 ft) of Green River Formation (early to middle Eocene), 1520 m (5010 ft) of Wasatch Formation (early Eocene), and 850 m (2800 ft) of the Fort Union Formation (Paleocene).

Stratigraphic data from three sections located east to west across the Phil Pico Mountain quadrangle show that the Proterozoic Red Pine Shale has substantially more sandstone and less shale in the eastern section of the quadrangle. Field observations suggest that the Red Pine Shale undergoes a facies change across the quadrangle. However, due to the lack of continuous stratigraphic exposures, the cause of this change is not known.

INTRODUCTION

The Phil Pico Mountain quadrangle is located along the north flank of the Uinta Mountains in northeastern Utah and southwestern Wyoming (Figure 1). Several kilometers of sedimentary strata are exposed within the quadrangle. They consist of a north-dipping succession of Paleozoic, Mesozoic, and Eocene strata deposited on a thick package of Proterozoic sedimentary rocks that make up the core of the range. A third of the quadrangle is heavily forested and most of the siliciclastic Precambrian rocks in the southern part of the quadrangle are poorly exposed. Much of the Eocene fluviatile strata deposited during and after the uplift of the Uinta Mountain range in the northern section of the quadrangle are also poorly exposed. However, the steeply dipping Paleozoic rocks in the center of the quadrangle are generally well-exposed.

The principle aims of this study were 1) to produce an accurate geologic map and cross-section of the Phil Pico Mountain quadrangle at a 1:24,000 scale, 2) determine the composition and age of the Paleogene conglomeratic/fluviatile units that make up Phil Pico Mountain, 3) better resolve the age, location, and amount and style of offset the Henrys Fork fault zone across the Phil Pico Mountain quadrangle, and 4) understand the nature of the lithologic changes occurring across the quadrangle in the late Proterozoic Red Pine Shale.

Existing regional maps provide conflicting reports on the identity and age of the Eocene conglomeratic units that make up most of Phil Pico Mountain. The detailed mapping and analysis of this study have allowed for the identification and correlation of these units and have provided data and important constraints on the structural and erosional history of the north flank of the Uinta Mountains.

The trace of the Henrys Fork fault across Phil Pico Mountain, the eastern trace of the Uinta thrust, and the location of other faults within the quadrangle were previously not well understood. There have been conflicting estimates of the amount of offset along the Henrys Fork fault. Now, measurements along the fault and detailed mapping of the conglomeratic units on Phil Pico Mountain have produced better constraints on the location and character of the Henrys Fork fault across the quadrangle. An analysis of the cuttings from the Carter Oil Company Carson Peak Unit 1 well, 1 km (0.6 mi) north of the Henrys Fork fault, has provided an estimate of the age, periods of activity, and the amount of offset along the fault. Mapping of other faults across the quadrangle has also provided useful structural data.

The nature of the Proterozoic Red Pine Shale at Phil Pico Mountain was not clearly known prior to this report. A thick sequence of the Red Pine Shale outcrops 10 km west at Hoop Lake (Dehler et al., 2005), but it is absent or significantly sandier 6 km (3.7 mi) east in the Sheep Creek Geological area (Sprinkel, 2006). Is the Red Pine Shale pinching out along the unconformable contact with the Madison Limestone, is there a facies change across the quadrangle, or is the Red Pine Shale simply faulted out in this area? A detailed description of the lithology of the Late Proterozoic Red Pine Shale in the Phil Pico Mountain quadrangle answers these questions.

Geologic Setting

The Phil Pico Mountain quadrangle lies on the north flank of the Uinta Mountains (Figure 1). The Uinta Mountains form a large compound anticline bounded on the north and south by thrust faults along which the mountains have been uplifted (Hansen, 1986; Bradley, 1995). Along the north flank, from west to east, these faults are the North flank thrust, the Henrys Fork fault, the Uinta thrust, and the Sparks fault (Bradley 1988) (Figure 2). The Henrys Fork fault cuts through the northern section of Phil Pico Mountain. East of the Phil Pico Mountain quadrangle, the Henrys Fork fault overlaps with the Uinta thrust fault some distance before dying out near the Flaming Gorge Reservoir (Figure 2). The western trace of the Uinta thrust fault evidently terminates in the neighboring Jessen Butte quadrangle to the east (Bradley, 1995) (Figure 3).

The Uinta Mountain uplift, due to Laramide compression, began in the latest Cretaceous to early Paleocene (Bradley, 1995) and likely ended in the Oligocene, approximately 30 Ma (Hansen, 1986; Piety and Vetter, 1999). The uplift and dissection of the range are responsible for the removal of nearly 20 km (12.4 mi) of Mesozoic, Paleozoic, and Proterozoic sedimentary rocks. During this uplift the Paleozoic and Mesozoic rocks of the range were folded, tilted steeply northward, and faulted. Several kilometers of strata were eroded from the growing mountains and deposited as a thick package of clastic material (mudstone, sandstone, and conglomerate) in the developing Green River Basin to the north. This package of clastic material is made up of the fluviatile Paleocene Fort Union, early Eocene Wasatch, and middle to late Eocene Bridger Formations. The early to middle Eocene Green River Formation was also deposited in the Green River Basin to the north. However, the Green River Formation was deposited within of a large lake (Lake Gosiute) which lapped onto the north flank of the Uinta Mountains.

Previous Work

The area has been mapped regionally by Anderman (1955) (scale 1:40,000), Rowley et al.

(1985) (scale 1:250,000), and Bradley (1988) (1:24,000). Sprinkel (2006) mapped the Dutch John 30'x 60' quadrangle (scale 1:100,000), which includes this area. Hansen (1965) discussed the geology of the Flaming Gorge area. Anderman (1955), Hansen (1984, 1986), Bradley (1988), and Bradley (1995) worked on the Cenozoic structural evolution of the area. Thomas and Krueger (1946) measured and described the Late Paleozoic and early Mesozoic stratigraphy of Uinta Mountains. Bradley (1964) discussed the geology of the Green River Formation, and Smith et al. (2008) reconstructed its depositional history. Hansen (1984, 1986), Roehler (1992), and Boyd (1995) described and discussed the Eocene stratigraphic units of the area. Dehler et al. (2005) described the stratigraphy of the Neoproterozoic Uinta Mountain Group and Red Pine Shale in the eastern Uinta Mountains.

METHODS

Field Work

Over 70 days were spent in the Phil Pico Mountain quadrangle collecting data and mapping the geology. Geologic contacts and faults were located and drawn in stereo on aerial photographs available from the United States Geological Survey. Lithology, sedimentary structures, erosional character, and color of several formations within the quadrangle were observed and described in the field. The attitude of bedding at 127 locations was measured and recorded. Organic-rich shale samples were collected from the Bridger Formation and Uinta Mountain Group and submitted to Gerald Waanders a consulting palynologist for palynomorph analysis. Glacial, mass-movement, and other Quaternary deposits were also investigated.

Computer Work

After collecting data in the field, contacts, faults, and other geologic data from field notes and air photos were transferred to stereo computer models. A Computer Aided Design (CAD) -based software program (VR Orientation) was used to create geo-referenced 3D models from air photos within the quadrangle. Field-collected geologic contacts and faults were then drawn within these models (detailed stereo projections of the air photos). The contacts, faults and other geologic data were drawn using another CAD-based software program (VRTwo), and were verified in the field when necessary. In some locations, 3-point elevation analysis from the stereo air photos added strike and dip data. After adding sample location symbols, the contact lines were smoothed and other final edits were made in VROne. These data were then exported as a .dxf file to ArcMap. In ArcMap, polygons were created, colors were added, and the map was finalized. These data were overlaid in ArcMap on a digital version of the 7 ½'/1:24000 topographic and shaded relief map of the Phil Pico Mountain quadrangle.

The geologic cross-section was created using Global Mapper and Adobe Illustrator. The topographic profile was created in Global Mapper from a 10 m digital elevation model (DEM) and imported into Adobe Illustrator where the remainder of the cross-section was drawn. The stratigraphic columns and other figures were drawn using Adobe Illustrator.

UGS Core Research Center

Two days were spent examining the cuttings from the Carter Oil Company Carson Peak Unit 1 well stored at the Utah Geological Survey's (UGS) Utah Core Research Center. Cuttings from the well are catalogued and stored in envelopes. Each envelope represents a 10 ft (3 m) interval and contains a small amount of cuttings from that interval. Nearly all of the intervals are represented. The cuttings from several dozen intervals were examined and classified under a binocular microscope and the composition and proportion of the conglomeratic material was determined for several intervals. These data were used to estimate the percentage of different clast types and determine changes in the overall clast composition in the well. The author also determined that the lithology log of the well was generally consistent with our analysis of the proportion and composition of the well cuttings.

STRATIGRAPHY

Overview

Several kilometers of strata are exposed within the Phil Pico Mountain quadrangle (Appendix 1, Plate I). These strata consist of a north-dipping succession of Paleozoic, Mesozoic, and Eocene rocks deposited on the thick Proterozoic sedimentary rocks of the Uinta Mountain Group and Red Pine Shale (Figure 4). Descriptions of these formations are included below and on the geologic map of the quadrangle (Appendix 1, Plate II). The Uinta Mountain Group makes up the core of the Uinta Mountains and covers the southern third of the quadrangle. The resistant Paleozoic rocks are geomorphically expressed as north-dipping hogbacks across middle third of the quadrangle. The Mesozoic rocks of the quadrangle are generally less resistant and are commonly covered by the Eocene rocks which cover much of the northern third of the quadrangle. The Eocene rocks in the quadrangle are syndepositional with the uplift of the range and are generally conglomeratic. This thesis specifically addresses questions regarding the Eocene conglomerates and the Precambrian Red Pine Shale.

Proterozoic Strata

The Proterozoic rocks consist of the Uinta Mountain Group and the Red Pine Shale. The Uinta Mountain Group (Middle Upper Proterozoic) in the quadrangle is over 1400 m (4600 ft) of light orange and light purple, medium- to very coarse-grained, feldspar-rich sandstone interbedded with light green, green-gray, maroon, and dark gray shale; sandstone is thick to medium bedded with cross-bedding in places. Sandstone thickness increases and shale interbeds decrease toward base with shale interbeds up to 60 m (200 ft) thick. The Uinta Mountain Group has been interpreted as principally a braided river system (Dehler et al., 2005).

The Red Pine Shale (Middle Upper Proterozoic) is 553 m (1810 ft) thick near western quadrangle boundary; however, the thickness toward the east is unknown because it is poorly exposed. The exposed section of Red Pine Shale near the western quadrangle boundary is maroon, green and green-gray shale interbedded with fine-grained light-green sandstone and siltstone and fine- to very coarse-grained light purple and buff to orange feldspar-rich sandstone; the sandstone is thick- to thin-bedded, cross-bedded, and siliceous. Sand interbeds increase toward the base and are up to 20 m (65 ft) thick. The Red Pine Shale becomes more sand-rich toward the east across the quadrangle. The Red Pine Shale records a period of fluvio-deltaic deposition.

Paleozoic Strata

The Paleozoic rocks are generally resistant to erosion and range in age from lower Mississippian to lower Permian. Marine conditions dominated much of the Paleozoic. However, during the Late Pennsylvanian to Early Permian time the thick eolian Weber Sandstone was deposited. The Madison Limestone (Lower Mississippian) represents a period of marine deposition and is about 300 m (1000 ft) of gray limestone; with light gray chert abundant in some layers. The Humbug Formation (Upper Mississippian) is about 100 m (330 ft) of light gray to yellow to red fine-grained sandstone interbedded with purple, gray, and light tan muddy limestone, light gray micritic limestone and red to light gray mudstone and shale; sandstone is red near the top of the formation. The Humbug Formation is slope-forming and poorly exposed. The Doughnut Shale (Upper Mississippian) is about 65 m (215 ft) of dark gray marine shale, and a few thin beds of limestone and sandstone with red shale in the lower section. The Doughnut Shale is slope-forming and generally poorly exposed. The Round Valley Limestone (Lower Pennsylvanian) is 85 to 136 m (280-340 ft) of light gray limestone with some interbeds of red shale; limestone is fossiliferous and cherty in places; chert is gray, yellowish, and red. The Round Valley Limestone forms ledges and cliffs and also represents a period of marine deposition. The Morgan Formation (Middle Pennsylvanian) is 152 to 295 m

(615-970 ft) of red, light gray and purple fine-grained sandstone, red, gray, and light tan shale and siltstone, and gray to lavender limestone; limestone is fossiliferous and cherty in places. The Morgan Formation is mostly slope-forming. The Weber Sandstone (Lower Permian to Middle Pennsylvanian) is 309 to 365 m (1015-1200 ft) of yellowish-gray fine- to medium-grained sandstone with a few thin limestone and dolomite beds occurring in the lower section. The sandstone is thick-bedded to massive and commonly cross-bedded. The upper section of the Weber has cross-beds indicative of eolian transportation. The Weber Sandstone is cliff-forming in places. The Grandeur Member of Park City Formation (Lower Permian) is 64 to 78 m (210-255 ft) of light-gray, light tan and brownish-gray limestone, dolomite, and sandstone. The Grandeur Member of Park City Formation forms ledges and cliffs. The Meade Peak Phosphatic Shale Member of the Phosphoria Formation (Lower Permian) is 34 to 48 m (110-160 ft) of slope-forming, dark-gray phosphatic and red to ochre shale with interbeds of sandstone and limestone. The Franson Member of Park City Formation (Lower Permian) is 52 to 64 m (170-210 ft) of ledge-forming gray cherty limestone and gray dolomite interbedded with fine-grained light tan-gray sandstone and minor amounts of gray, green, and red shale. Silica-rich fossil hash interbedded with sandy dolomitic layers occurs near the top of this member.

Mesozoic Strata

The Mesozoic rocks in the quadrangle are generally slope-forming, consist of lower Triassic through upper Jurassic aged clastic rocks, and contain several unconformities. The depositional environment generally alternated between shallow marine and continental (i.e. fluvial, eolian).

The Dinwoody Formation (Lower Triassic) is 90 to 182 m (300-600 ft) of mostly soft, slope-forming light gray to light brown and greenish-gray, shale, siltstone, and fine-grained thinly bedded micaceous sandstone with minor amounts of limestone. The Moenkopi Formation (Lower Triassic) is 230 to 254 m (750-830 ft) of mostly slope-forming medium to dark red, and dark reddish-orange interbedded siltstone, mudstone, and thinly bedded fine-grained sandstone with some ripple laminations and rip up clasts. The depositional environment was apparently intertidal to shallow marine with some fluvial influence. The Chinle Formation (Upper Triassic) is about 70 m (230 ft) of slope-forming red, purple, yellow, and orange mudstone and silty mudstone. The depositional environment was shallow marine. The base is a resistant 0.5 to 3 m medium- to very coarse-grained poorly-sorted purplish channelized sandstone, possibly correlative with the Gartra Member. This basal sandstone was likely deposited as part of a braided stream. The Upper Chinle Formation (Upper Triassic) is 51 to 60 m (170-200 ft) of ledge- to slope-forming light tan and green, fine-grained sandstone interbedded with red, light green, pink, and purple siltstone and greenish brown limey siltstone, blocky reddish orange silty mudstone, and purple and green mudstone, sandstone is ripple laminated in places. The Nugget Sandstone (Lower Jurassic) is 234 to 270 m (770-885 ft) of ledge- to slope-forming light gray to light tan, fine-grained, well sorted, well rounded and cross-bedded sandstone; the sandstone is thick bedded and is somewhat friable. The Nugget Sandstone is eolian and is part of a large erg system. The Carmel Formation (Middle Jurassic) is 87 to 126 m (290-410 ft) of ledge- to slope-forming red and yellow mudstone, light brown to gray limestone, brown to yellow sandstone, and thinly-bedded sandy limestone; the upper part is mostly slope-forming red and yellow mudstone, and siltstone, lower part is brownish-gray, light gray and reddish brown limestone, tan siltstone and thinly bedded brownish orange medium to coarse sandstone. The limestone is oolitic and fossiliferous in places. The Camel Formation evidently represents a period of marine deposition. The Entrada Sandstone (Middle Jurassic) is almost always covered across the quadrangle. It is about 50 m (160 ft) thick and is slope-forming. The upper section is reddish-orange fine-grained sandstone and reddish-brown mudstone and siltstone, lower part is light gray, pink, and light brown sandstone; the lower sandstone is more resistant but still slope-forming. The Entrada Sandstone records a period of eolian deposition. The Stump Formation (Upper Jurassic) was deposited in a shallow marine setting. It is 63 to 91 m (210-300 ft) of light brownish-gray limestone (oolitic in places), greenish-gray thinly bedded limestone, light brown and yellowish medium-grained ripple-laminated sandstone and light gray to greenish-gray shale. The sandstone pinches and swells in places. The shale is found near the top of the formation, and a bivalve packstone and wavy algal laminations are found near the base. The limestone is muddy and laminated in places. The Morrison Formation (Upper Jurassic) is nearly always covered in the quadrangle. Sprinkel, (2006) describes it as “soft, light gray, olive-gray, red, and light purple shale, claystone, siltstone, and minor cross-bedded sandstone, conglomerate, and bentonite; 90 to 287 m (300-940 ft) thick”. The exposed Morrison Formation in the quadrangle was deposited in a fluvial channel and is 15 m (50 ft) of tan, poorly-sorted, pebble conglomerate and very coarse- to medium-grained sandstone.

Eocene Strata

The exposed Eocene strata in the quadrangle consist of the early Eocene Wasatch Formation and the middle to late Eocene Bridger Formation. A conglomeratic facies of the Bridger Formation has also been mapped. The early to middle Green River and Paleocene Fort Union Formations are covered in the quadrangle, but evidence of these formations is found in the Carson Peak Unit 1 well. These formations were deposited in the basin north of the Uinta Mountains (Figure 6) as a result of the uplift and erosion of the Uinta Mountain range.

The Paleocene Fort Union Formation is found in the section of the Carson Peak Unit 1 well from 2438-3322 m (7990 to 10900 ft). Overall, this section, mostly composed of sandstone and shale, is much finer-grained than the overlying Wasatch Formation. This is because the Fort Union Formation is composed of the erosional clastic material from the relatively soft Mesozoic strata. An analysis of the cuttings and lithology log of the well has shown that the Fort Union Formation is composed of the erosional remains of the Cretaceous Baxter Shale, Cretaceous Frontier Sandstone, Cretaceous Dakota Sandstone, Cretaceous Mowry Shale, Cedar Mountain Formation and the Jurassic Morrison Formation.

The Wasatch Formation (Early Eocene and Paleocene [?]) is yellow, orange, and gray conglomerate, sandstone, siltstone, and mudstone (Figure 5). The sandstone is friable to well-cemented and fine- to very coarse-grained. The conglomerate clasts are pebble- to boulder-sized and principally consist of gray limestone (Paleozoic), yellow well-cemented sandstone, and chert. Phil Pico Mountain is principally composed of a conglomeratic facies about 400 m (1300 ft) thick, consisting of cobble to boulder petromict conglomerate and some interbeds of very coarse-grained yellowish sandstone. The thickness of the Wasatch Formation from the Carson Peak Unit 1 well is 1530 m (5010 ft).

The Green River Formation is 390 m (1280 ft) of light to medium gray, light to medium brown, limestone, dolomite, and sandy limestone, and white, orange, gray and greenish moderately to poorly sorted, calcite- to pyrite-cemented sandstone, occasional thin pebble conglomerate layers; the upper part interfingers with the overlying Bridger Formation, and the lower part interfingers with underlying Wasatch Formation.

The Bridger Formation (middle and late Eocene) is variegated red, gray, light green, and yellow siltstone, red, green, grayish, and light brown mudstone, occasional light-gray limestone, light tan, medium- to coarse-grained sandstone and light gray to tan conglomerate; generally coarsens upward; 0-500 m (0-1640) thick. The Bridger Formation conglomeratic facies (middle and late Eocene) is light gray to tan, thick bedded, pebble to boulder conglomerate. Conglomerate clasts are subangular to subrounded, poorly sorted, clasts are dominated by gray Paleozoic Limestones (~60%), well-cemented yellow sandstone (~15%), and red and purple sandstone and quartzite (5-30%); 0 to 470 m (1540 ft) thick.

The Gilbert Peak Erosion Surface

The Gilbert Peak erosion surface formed in Oligocene time and was later tilted during Miocene extension of the Uinta Mountains (Sprinkel, 2000). There is no apparent evidence of this surface in the quadrangle due to the extensive erosion that has occurred since its formation. However, this surface, now capped by the Oligocene Bishop Conglomerate, can be found north of the quadrangle at Cedar Mountain and Black Mountain (Figure 6).

Glacial Deposits

Pleistocene glacial deposits cover the southern section of the Phil Pico Mountain quadrangle. Until recently, the glacial history of the Uinta Mountains has received little attention. However, recent work by Munroe (2005) and Laabs & Carson (2005) has helped to unravel more of the glacial history of the Uinta Mountains.

Glacial deposits from at least three glacial episodes were discovered and mapped in the Phil Pico Mountain quadrangle. These were mapped as Smiths Fork, Blacks Fork, and pre-Blacks Fork deposits. The Smiths Fork deposits represent the most recent glacial period and generally show little weathering. The moraines mapped as Smiths Fork are rugged, have little or no soil, and typically have steep narrow crests. The Blacks Fork moraines are more subdued, commonly have several centimeters of soil, and have less continuous moraine crests. The moraines mapped as pre-Blacks Fork have thick soil, no recognizable moraine crest, and a much more subdued topography than either the Blacks Fork or Smiths Fork aged moraines.

The Smiths Fork and Blacks Fork glacial episodes were named by Bradley (1936). Richmond (1965) and Laabs & Carson (2005) correlate these episodes to the Pinedale Glaciation (24 to 12 ka BP) and the Bull Lake Glaciation (186 to 128 ka BP) in the Wind River Mountains. Laabs & Carson (2005) also suggest that the pre-Blacks Fork glacial episode may correlate to the Sacagawea Ridge Glaciation (659 to 620 ka BP).

PALEOGENE DEPOSITIONAL HISTORY

The Eocene sedimentary deposits on Phil Pico Mountain contain key information regarding the tectonic and erosional history of the north flank of the Uinta Mountains. However, previous published reports on the age and identity of the sedimentary rocks on Phil Pico Mountain do not agree on which units are present. The conglomeratic mass that makes up most of Phil Pico Mountain has been assigned to various formations. Powell (1876, p. 170) first assigned these strata to the ‘Bishop Mountain conglomerate’ and Emmons (1877, p. 247) assigned them to the ‘Wyoming conglomerate’, a synonymous term no longer in use. Schultz (1918, plate V) showed Bishop Conglomerate capping Phil Pico Mountain. However, Bradley (1936, p. 172) concluded that Phil Pico Mountain was made up of a conglomeratic facies of the Bridger Formation and was not capped by Bishop Conglomerate. Forrester (1937, p. 641) found it to be “chiefly made up of the conglomeratic facies of the Green River and the Bridger formations.’ Anderman (1955a) “assigned all of the conglomeratic mass at Phil Pico Mountain to the Green River Formation on the basis of similar conglomerates in the Green River Formation at other places in the area that can be traced into Phil Pico Mountain,” but noted that the deposition of the upper conglomerates on Phil Pico may be time-correlative with the Bridger Formation to the north. More recently, the conglomeratic strata at Phil Pico Mountain have been mapped as undifferentiated Eocene (Bradley, 1964), stratigraphically equivalent to the Bridger Formation (Hansen, 1984), upper Bridger Formation (Rowley et al., 1985), and Wasatch and Bridger Formations (Sprinkel, 2006). Hansen (1986) concluded that the conglomerates at Phil Pico contain “rocks of Wasatch, Green River, and Bridger age.”

This study shows that the Eocene rocks

that make up Phil Pico Mountain are largely conglomeratic facies of the Wasatch and Bridger Formations in agreement with Sprinkel (2006). At Phil Pico these formations are separated by the Henrys Fork fault which cuts through the northern section of Phil Pico Mountain. The fault has thrust early Eocene Wasatch Formation northward over late Eocene Bridger Formation with a vertical offset of approximately 2100 m (6800 ft). The northern third of the mountain is Bridger Formation and the remainder is Wasatch Formation (Figure 4). Detailed field and laboratory observations supporting these and other related conclusions are discussed in the following sections.

The Bishop Conglomerate is not present in the quadrangle. It has likely been removed by erosion. The nearest Bishop Conglomerate caps Cedar Mountain 14 km (9 mi) to the northwest (Figure 6) (Hansen, 1984). The Bishop Conglomerate there is 50 m (160 ft) thick and is dominated by gray limestone, although Uinta Mountain Group and chert clasts also are also present. The Bishop Conglomerate also caps Black Mountain 24 km (15 mi) to the northeast (Figure 6). The Bishop Conglomerate at these locations likely contains some recycled clasts from the Phil Pico Mountain area.

Wasatch Formation

The Wasatch Formation (Paleocene [?] to Early Eocene) is a thick body of fluviatile deposits shed from the Uinta Mountains (Figure 6). It was named by Hayden (1869) for exposures in Echo and Weber Canyons, Utah. The upper Wasatch Formation interfingers with the lower lacustrine Green River Formation (Bradley, 1964 A1). The Wasatch Formation is 600 to 1500 m (2000-5000 ft) thick in the Flaming Gorge area approximately 20 km (12 mi) east (Lehi Hintze, Brigham Young University, personal communication).

Description

The Wasatch Formation (Early Eocene) exposed at the Phil Pico Mountain quadrangle was deposited at the northern margin of the Uinta Mountains and is largely conglomeratic. The Wasatch Formation in the quadrangle is composed of yellow, orange, and gray conglomerate, light yellow to gray very coarse- to fine-grained sandstone, light gray and brown to orange siltstone and mudstone. The sandstone beds are friable to well-cemented and fine- to very coarse-grained. The conglomerate beds are generally petromict sedimentary clast conglomerates. The clasts are pebble to boulder sized and mainly consist of gray limestone, yellow well-cemented sandstone, and chert. The southern section of Phil Pico Mountain (Figure 4) is principally composed of a conglomeratic facies of the Wasatch Formation about 400 m thick, consisting of cobble to boulder petromict conglomerate and some interbeds of very coarse-grained yellowish sandstone. The clast size is quite variable (pebble to boulder size) but generally decreases up section. The clasts are generally rounded to subangular. However some clasts in the basal conglomerate along the south flank are angular, such as the tabular dark limestone clast shown in Figure 7. Yellow sandstone clasts are generally the largest in the lower section of the mountain. One such clast, located near the mouth of Birch Spring Draw in the southeast section of Phil Pico Mountain, measures nearly 5 m in diameter (Figure 4, location 3). Gray limestone clasts are the largest in the upper section.

The conglomeratic strata on the southern flank of Phil Pico dip north. This dip gradually decreases from 25-30° at the base to 10° in the upper section (Appendix 1, Plate I), suggesting that the Wasatch Formation is an early Eocene synorogenic formation. The systematic change in dip indicates that there was ongoing uplift or folding during the deposition of these beds.

The exposures of the Wasatch Formation in the western section of the quadrangle are finer-grained and lower stratigraphically than the Wasatch Formation on Phil Pico Mountain. These strata mostly consist of light yellow to light gray sandstone. Light gray to light brown siltstone, shale, and a few thin light tan pebble to cobble conglomerate layers are also present

(Figure 5).

Outcrops of the Wasatch Formation in the southwest corner of Phil Pico Mountain (Figure 4, location 2) reveal an abrupt vertical change in lithology (Figure 5), from sandstone, siltstone, and mudstone in the lower section to almost exclusive conglomerate in the upper section. This basal conglomerate can be traced continuously to the well-exposed basal conglomerate along the south flank of Phil Pico Mountain. Above this basal conglomerate, there are about 400 m (1310 ft) of conglomeratic facies. This abrupt coarsening upward is apparently due to the uplift and erosion of the resistant Permian Park City Formation and Pennsylvanian Weber Sandstone. The finer-grained Wasatch Formation below the basal conglomerate apparently contains erosional clastic material from the Triassic Dinwoody Formation. The Wasatch at these locations contain a fairly high percentage of light gray to light brown siltstone, mudstone and sandstone (Figure 5) which is quite similar to the composition of the Dinwoody Formation. The Wasatch Formation at these locations is also composed of yellow sandstone with sand grains similar to those found in the Weber Sandstone.

Clast Composition

The clast composition of the Wasatch Formation on Phil Pico Mountain was studied along the south flank (locations 1, 11, 13, Figure 4), near the summit (location 12, Figure 4) and in the southwest (location 2, Figure 4), southeast (location 3, Figure 4), and western section (location 10, Figure 4) of the mountain. It was found that the clast composition varies from location to location. Overall the clast composition is gray limestone (25 to 70%), yellow sandstone (15 to 20%), chert (5 to 10%), red sandstone (<1% to 15%), white dolomite (<1% to 25%), white sandstone (<1% to 15%), and light gray sandy limestone (<1% to 10%). The overall clast composition of the Wasatch Formation on Phil Pico Mountain changes significantly from the base to the top of the mountain.

The approximate clast composition of the basal conglomerate on the south flank of Phil Pico at location 1 (Figure 4) is 65% gray limestone, 20% yellow sandstone, 10% chert, and 5% other; at location 2 (Figure 4) it is approximately 40% gray limestone, 25% white dolomite, 20% yellow sandstone, 7% chert, and 5% red sandstone (Figure 5). However at location 13 (100 to 150 m above the basal conglomerate), the percentage of yellow sandstone clasts decreases from 20% to less than 10%, and the percentage of red sandstone clasts increases from almost zero to about15%. At location 12 (near the summit of Phil Pico Mountain) the clasts are almost exclusively gray limestone (~85%). There are also clasts of yellowish, gray, and red chert (~10%) and a few clasts of red and purple sandstone (~2%). However, there were no observed yellow sandstone clasts. These changes in clast composition provide evidence of the erosional unroofing of the Uinta Mountains and will be discussed in the following section.

Carter Oil Company Carson Peak Unit 1 well

The Carter Oil Company Carson Peak Unit 1 well just off the northeast flank of Phil Pico Mountain (Figure 4) provides additional evidence of Wasatch Formation within the quadrangle. During the drilling of the Carson Peak Unit 1 well a detailed lithology log with descriptions of the cuttings from each 10 foot interval was created. Well cuttings and the lithology log show that in the well (on the footwall of the Henrys Fork Fault); the Wasatch Formation is buried beneath the fluviatile deposits of the Bridger Formation and the lacustrine limestones of the Green River Formation (Figure 8, Figure 9). Furthermore, the Wasatch Formation in the well is much thicker (1530 m or 5010 ft) than the Wasatch Formation exposed on Phil Pico Mountain (400 m or 1300 ft). The section of the well from 908 to 2435 m (2980 to 7990 ft) has been picked as Wasatch Formation (Figure 9). The upper Wasatch Formation in the well interfingers with the lacustrine deposits of the Green River Formation from of 823 to 908 m (2700 to 2980 ft). The upper contact was placed just below the first thick (10 m) section of Green River Formation limestone. The lower contact with the Fort Union Formation was placed just above the first coal and just below the first limestone conglomerate clast. There is also a color change in the shales across the contact from gray-green on the Fort Union side to orange and red on the Wasatch side.

Using the lithology log, I analyzed and summed the dominant lithology for each 10 foot interval and found that that approximately 25% of the total Wasatch Formation interval is conglomeratic, 30% is sandstone, and 45% is mudstone and siltstone. Based on these same 10 foot interval descriptions, I also estimated and graphed the total percentage of conglomerate for each 100 ft interval in the well (Figure 8, Figure 9). The proportion of conglomerate from interval to interval was quite variable and ranged from 0 to 75%. The sandstones of the Wasatch Formation interval were described in the lithology log as orange, red, gray, white, and green, fine- to coarse-grained, calcareous, and well to poorly sorted. The siltstones were most commonly noted in the lower Wasatch and were described as orange and red in color. White, gray and light green siltstones were also noted, but much less commonly. Shale and mudstone were described as dominantly orange and red and were less commonly described as maroon, gray, green and white.

Analysis of the well cuttings (see Methods) revealed that the overall conglomerate clasts composition in the Wasatch Formation clearly and systematically varies with depth (Figure 9). These variations show an inverted cobble stratigraphy and unroofing succession of the Uinta Mountains, which is described in more detail in the following section. The sandstone clasts and quartz grains are more dominant in the lower Wasatch interval from 1920 to 2408 m (6300 to 7900 ft). Intervals of mixed clasts (sandstone, limestone, chert, and loose quartz grains) occur throughout the Wasatch at the following depths: 1494 to 1890 m (4900 to 6200 ft), 1097 to 1219 m (3600 to 4000 ft), 2042-2073 m (6700 to 6800 ft), and 2408 m (7900 ft). Clasts of limestone, dolomite and chert are more dominant in the upper Wasatch from 914 to 1067 m (3000 to 3500 ft) and from 1250 to 1463 m (4100 to 4800 ft) (Figure 9).

Sandstone clasts are of at least four different types. The first is a light-colored, fine-grained, well-rounded and well-sorted sandstone. This type is abundant and is found most commonly in the lower portion of the Wasatch interval, 2134 to 2408 m (7000 to 7900 ft). Loose sand grains similar to the sand in these clasts also commonly occur in this interval. The second sandstone clast type is yellow to light gray, fine to medium grained, subrounded to subangular, and well cemented. This type is also abundant and is most commonly found from 1676 to 1981 m (5500 to 6500 ft). Loose sand grains similar to the sand in these clasts also commonly occur in this interval. The third type is a gray well cemented sandstone or quartzite. This type is less abundant and is found in the interval from 1554 to 1890 m (5100 to 6200 ft). The fourth clast type is red fine-grained sandstone. This type is not abundant but is most often found in the interval from 1585 to 2042 m (5200 to 6700 ft). However, these red sandstone clasts are similar to and difficult to distinguish from the native Wasatch Formation sandstone. The limestone and dolomite clasts in the Wasatch Formation are usually light to dark gray. There are also occasional white or black limestone/dolomite clasts. Single oolitic limestone clasts were found at 1951 m (6400 ft) and 2073 m (6800 ft). Gray sandy limestone clasts were found at 884 m (2900 ft), 1158 m (3800 ft), 1250 m (4100 ft), and 2225 m (7300 ft). Light gray, dark gray, and white chert clasts are the most common varieties. Red chert was found at 1524 m (5000 ft) and 1585 m (5200 ft).

Unroofing and Inverted Cobble Stratigraphy

The clasts in the Wasatch Formation conglomerates show a vertical compositional change indicative of the uplift and progressive erosion of the Uinta Mountains. This has produced an inverted cobble stratigraphy called a “normal unroofing sequence” as described in Colombo (1994). Evidence of this normal unroofing sequence or succession is found both on Phil Pico Mountain and in the Carson Peak Unit 1 well.

Evidence of this unroofing sequence in the Carson Peak Unit 1 well (Figure 4) was found through study of the cuttings at the Utah Geological Survey's (UGS) Utah Core Research Center (see Methods). The cuttings from several dozen 10 ft (3 m) intervals were examined and classified under a binocular microscope and the composition and proportion of the conglomeratic material was determined. These cutting show that the Wasatch interval (908-2435 m or 2980-7990 ft) contains clasts eroded from the Uinta Mountains. Clasts were identified from most of the strata between and including the Mississippian Madison Limestone and the Jurassic Stump Formation. These clasts were generally found in reverse order from their stratigraphic position (i.e. the younger the clast, the lower its position in the well). Clasts from Jurassic Stump Formation were found at a depth of 2420 m (7940 ft), clasts from the Nugget Sandstone at 2286 m (7500 ft), clasts from the Park City Formation and the Weber Sandstone at 1981 m (6500 ft) and so on until clasts of the Madison Limestone were found from 914 to 1219 m (3000 to 4000 ft) (Figure 8, Figure 9).

Gray limestone clasts found at 2408 m (7900 ft) are the first non-Tertiary limestone clasts to appear in the Wasatch Formation (moving up from the bottom) and are interpreted as being derived from the Jurassic Stump Formation. Above this interval, from 2134 to 2408 m (7000 to 7900 ft), there is an abundant sandstone clast type which closely matches the properties of the Jurassic Nugget Sandstone. These sandstone clasts are light-colored and have fine-grained, well-rounded and well-sorted sand grains. Loose sand grains similar to the sand in these clasts also commonly occur in this interval. These clasts and sand grains are therefore interpreted as being derived from the Nugget Sandstone. The abundance of these clasts can also be explained by the thickness of the Nugget Sandstone (234 to 270 m). A gray oolitic limestone clast was found at 1951 m and 2073 m (6400 and 6800 ft). These clasts are evidently from the oolitic limestone in the Jurassic Carmel Formation. Clasts of micaceous sandstone at 1951 m, 2012 m, and 2042 m (6400, 6600 and 6700 ft) are similar to the micaceous sandstone of the Triassic Dinwoody Formation and are interpreted as such. Above this interval from 1676 to 2042 m (5500 to 6700 ft), abundant clasts of yellow to light gray, fine- to medium-grained, subrounded to subangular, moderately to well-sorted sandstone were found. Loose sand grains similar to the sand in these clasts also commonly occur in this interval. These clasts are very similar to and were likely derived from the Permian/Pennsylvanian Weber Sandstone. Less abundant clasts of red fine-grained sandstone were found from 1585 to 2042 m (5200 to 6700 ft). These clasts are similar to the fine-grained red sandstone of the Pennsylvanian Morgan Formation. Light and dark gray limestone clasts are abundant in the upper part of the Wasatch Formation from 914 to 1554 m (3000 to 5100 ft). These clasts are similar to and were likely derived from the Pennsylvanian Round Valley Limestone and the Mississippian Madison Limestone. While these limestone clasts were not distinguished the clasts in lower interval from 1494 to 1554 m (4900 to 5100 ft) are interpreted as Round Valley clasts based on the red chert clasts found at 1524 m (5000 ft) and 1585 m (5200 ft).

The Wasatch Formation on the south flank of Phil Pico Mountain shows a similar pattern (Figure 10). The youngest clasts appear in the lower section of the mountain and the older clasts are found in the upper section of the mountain. In the lower section the beds have clasts of gray limestone, light gray sandy limestone, white dolomite, and chert similar to rocks found in the Permian Park City Formation. Abundant clasts of yellowish to light tan, fine- to medium-grained, quartz-rich, and well-calcite-cemented sandstone similar to the Pennsylvanian/Permian Weber Sandstone are also found in the lower section. Both these clast types decrease in abundance up-section while clasts of red sandstone become more abundant moving up-section. These red sandstone clasts are similar to and were likely derived from the Pennsylvanian Morgan Formation. The section of Phil Pico that evidently contains erosional debris from the Morgan Formation forms a largely covered east-west strike valley along the mountain (Figure 10). The cover along the strike valley has a reddish color as would be expected if this section of the Wasatch contains debris from the erosion of the Morgan Formation. The Morgan Formation contains red shale, siltstone and sandstone and is less resistant than the surrounding formations. The upper 100 m of conglomerate on Phil Pico Mountain has a clast composition that closely resembles the Pennsylvanian Round Valley Limestone (mostly gray limestone with some red and yellow chert). Clasts from the Mississippian Madison Limestone are also likely present.

The overall clast compositional pattern on Phil Pico Mountain evidently matches the section of well from 1520 to 1980 m (5000 to 6500 feet) (Figure 8). In both locations clasts from the Park City Formation and Weber Sandstone are found at the base, with clasts from the from the Morgan Formation found higher up-section, and clasts from the Round Valley and Madison Limestone in the upper section (Figure 8, Figure 10).

Clasts from the Proterozoic Uinta Mountain Group are rare or absent in the Wasatch Formation. While, none were found in the well or in the field that could definitely be assigned to the Uinta Mountain Group, a few clasts of purple and red sandstone were found near the top of Phil Pico Mountain that may have been derived from the Uinta Mountain Group. Anderman (1955) observed “a few cobbles of dull brown to reddish brown, coarse grained to granule-size, arkosic sandstone” at the top of Phil Pico near the bench mark which he believed “were certainly derived from the Uinta Mountain Group.”

Bridger Formation

The Bridger Formation is middle to upper Eocene age (Roehler 1992) and was named by Hayden (1873) for badland exposures in the central part of the Green River Basin of Wyoming. It is largely composed of fluviatile sediments syndepositional with the uplift of the Uinta Mountains. The Bridger Formation overlies the lacustrine deposits of the Green River Formation. However, the lower Bridger commonly interfingers with these lacustrine deposits (Bradley 1964). Bradley (1964) noted 427 m (1400 ft) of Bridger Formation exposed at Twin Buttes (22 km northeast of Phil Pico Mountain) (Figure 6). The Bridger Formation fills the basin north of Phil Pico Mountain (Love and Christiansen, 1985) (Figure 6).

In the Phil Pico Mountain quadrangle, the Bridger Formation is exposed across the northern section of the quadrangle. Just north and west of Phil Pico Mountain the Bridger Formation is variegated red, gray, light green and yellow siltstone, red, green, grayish, and light brown mudstone, and light tan, medium- to coarse-grained sandstone and light gray to tan conglomerate with occasional thin bed of light gray limestone (Figure 11). The Bridger generally coarsens upward and becomes conglomeratic moving toward Phil Pico Mountain (Figure 12, Appendix 1, Plate I). The estimated maximum thickness of the Bridger Formation in the quadrangle is 970 m (3200 ft).

On Phil Pico Mountain, we have subdivided and mapped a conglomeratic facies of the Bridger Formation. This facies, found just north of the Henrys Fork fault on Phil Pico Mountain, grades into and interfingers with a finer-grained facies lower in section. This is evident from field data and data from the Carson Peak Unit 1 well. The conglomeratic facies consists mostly of light gray to tan, thick-bedded, pebble to boulder conglomerate. The conglomerate clasts are subangular to subrounded, poorly sorted, with a coarse-grained calcite-cemented sand and pebble matrix. The clast composition is laterally and vertically variable, but in most cases the clasts are gray Paleozoic limestones (60%), well-cemented yellow sandstone (15-25%), red and purple sandstone and quartzite (5-30%), and chert (5%). However, at one outcrop in the northwest section of Phil Pico Mountain, the clasts are dominantly well-cemented yellow sandstone (60%), and gray Paleozoic limestones (30%) (Figure 4, location 4). On the northeast section of Phil Pico Mountain (Figure 4, location 5) there is a progressive increase in Uinta Mountain Group clasts (dark reddish sandstone and red purple and quartzite) from about 7% in the lower outcrop (Figure 13) to 30% in an outcrop 90 m (295 ft) up section.

The Bridger Formation is 521 m (1710 ft) thick at the location of the Carter Oil Company Carter Oil Company Carson Peak Unit 1 well. Another 450 m (1476 ft) of mostly conglomeratic Bridger Formation occurs above the well on Phil Pico Mountain. Therefore, its total thickness is about 970 m (3200 ft). The lithology log of the well suggests that the Bridger Formation interfingers with the light gray and light brown limestones of the Eocene Green River Formation in the interval from 521 to 640 m (1710 to 2100 ft). The lower contact with the Green River Formation was drawn just above the highest Green River Formation limestone at a depth of 521 m (1710 ft). The Green River Formation is 387 m (1270 ft) thick in the well and separates the Bridger and Wasatch Formations (Figure 9).

Two samples of organic-rich shale within the Bridger Formation, collected at an outcrop 0.4 km north of the quadrangle boundary (UTM 4539664 N, 586930 E), were analyzed by Gerald Waanders, a consulting palynologist, for pores and pollen. Estimates of the age, paleoenvironment, HCL reaction, total organic recovery, kerogen content, and thermal alteration index are summarized in Table 1. The age estimate was determined as Late Eocene. According to the report, “the occurrences of Carya *veripites*, Momipites *coryloides* and M. *tenuipolus* indicate an age no younger than Late Eocene. The stratigraphic position of the samples is approximately equal to the outcrops of Bridger Formation along the northern edge of the quadrangle (~80 m beneath the base of Phil Pico Mountain). There are approximately 530 m (1740 ft) of additional Bridger Formation stratigraphically above these beds at Phil Pico Mountain.

Well Data

From the lithology log of the Carter Oil Company Carson Peak Unit 1 well, approximately 45% of the Bridger interval is conglomeratic, 37% is sandstone, and 18% mudstone and shale. Figure 8 shows the total conglomerate percentage for each 100 ft (30 m) interval. This shows that the conglomerate percentage is quite variable and ranges from 5% to 90%. The sandstones of the Bridger are described in the lithology log as generally poorly sorted and calcareous, and as orange, red, light gray, dark gray, or white. They are also described as friable in places and pyrite-cemented in places. Siltstones were not described in the Bridger interval. The mudstones were generally calcareous and varied in color from orange to red to maroon to light brown. A light gray ashy micaceous mudstone was noted at 137 m (450 ft) and black coaly shale at 183 m (600 ft).

Carson Peak Unit 1 well cuttings show that the conglomerate clast composition in the lower Bridger is variable, but generally dominated by light and dark gray carbonates. Well-cemented yellow sandstone, chert (light, gray, dark, yellow, red, orange), and loose quartz grains are also common. Light-colored and red sandstone and red and purple quartzite are sometimes present but are not abundant. At 155 to 158 m (510 to 520 ft) and 223 to 226 m (730 to 740 ft) there are a few clasts of Tertiary limestone similar to the limestones found in the Eocene Green River Formation.

In the Carson Peak Unit 1 well the first clear Precambrian Uinta Mountain Group-like clasts (dark red sandstone and purple and red quartzite) appear in the middle Bridger Formation. Dark red sandstone clasts are found at a depth of 549 m (1800 ft), and reddish purple quartzite are found at depths of 457 m (1500 ft), 214 m (700 ft), 152 m (500 ft), 122 m (400 ft), and 15 m (50 ft). However, even in the intervals where they are found, these clasts only make up a small percentage of the total cuttings and clastic material from the interval.

Rational for mapping Bridger Formation in quadrangle

Field and well data support our conclusions that the conglomerates in the northern section of Phil Pico Mountain are Bridger Formation. Stratigraphic, age, and structural data are all consistent with the known Bridger Formation. At Phil Pico, conglomeratic facies interfinger with a finer-grained fluviatile lithology that closely resembles known Bridger Formation (Anderman, 1955). Data from the Carson Peak Unit 1 well also demonstrate that the strata on the north flank of Phil Pico lie in a stratigraphic position consistent with known Bridger. The well shows 518 m (1700 ft) of fluviatile Bridger-like strata overlying and interfingering with the lacustrine deposits of the Green River Formation. The pollen described above (Table 1) also lies within the known age of the Bridger Formation (middle to late Eocene). The rocks mapped as Bridger Formation also have a slight northern dip which places their deposition in the latter stages of uplift. The clast composition of the Bridger Formation conglomerates on the northern flank of Phil Pico is also consistent with strata deposited in the latter stages of uplift. Uinta Mountain Group clasts are relatively abundant in these conglomerates (10-30%) and are rare or absent in the conglomerates mapped as Wasatch Formation. The Uinta Mountain Group was the last formation breached during the erosion of the range.

CENOZOIC STRUCTURE

The Uinta Mountains form a large compound anticline bounded on the north and the south by thrust faults along which the mountains have been uplifted (Hansen, 1986; Bradley, 1995). Along the north flank, from west to east, these faults are the North Flank thrust, the Henrys Fork fault, the Uinta thrust, and the Sparks fault (Bradley 1988) (Figure 2). The Henrys Fork fault cuts through the northern section of the Phil Pico Mountain quadrangle. East of the quadrangle, the Henrys Fork fault overlaps with the Uinta thrust fault and eventually dies out 24 km (15 mi) east near the Flaming Gorge Reservoir (Figure 2). The western trace of the Uinta thrust fault evidently terminates in the Jessen Butte quadrangle to the east of the Phil Pico Mountain quadrangle (Figure 3). Bradley (1988) noted that as displacement on the Uinta Thrust decreases, displacement along the Henrys Fork fault increases.

According to Bradley (1995), there were two periods of uplift along the north flank of the Uintas. The first period of uplift in the latest Cretaceous to early Paleocene (approximately 65 Ma), caused displacement on the North Flank and Uinta thrusts. During the second, in the late early to early middle Eocene (approximately 48 Ma), there was growth of the Henrys Fork Fault and Sparks Fault and reactivation of the North Flank and Uinta thrusts. Bradley's conclusions were largely based on the age of the formations truncated by these faults.

Eocene Structural History

This study has produced new evidence of the timing and magnitude of uplift in the area. Dip data along the south flank of Phil Pico Mountain suggest that there was active uplift during deposition of the Wasatch Formation (early Eocene). The lower Wasatch beds on the south flank dip steeply (20 to 36°) to the north. This dip gradually decreases up section; the dip of the middle beds range from 17 to 22° and the upper beds from 7 to 15° (Appendix 1, Plate I).

Within the Phil Pico Mountain quadrangle there is also evidence of early to middle Eocene folding. Whereas the Early Eocene Wasatch Formation in the quadrangle is folded, the late Eocene Bridger Formation north of the Henrys Fork fault shows no evidence of folding. The exact age of this folding is unknown but must have occurred after the deposition of the Wasatch Formation on Phil Pico Mountain and before the deposition of the exposed Bridger Formation in the quadrangle. The fold axis is nearly north-south, suggesting that there was component of east-west compressional stress during the time of folding.

This folding is apparent throughout most of the quadrangle. The strata south of the Henrys

Fork fault in the eastern section of the quadrangle are folded into a broad syncline (Figure 3). A related anticlinal fold occurs in the eastern adjacent quadrangle and a related but more subdued anticlinal fold occurs in the northwestern section of the quadrangle (Figure 3). The folding of Mesozoic and early Eocene strata on the eastern edge of the quadrangle is especially prominent. The strike abruptly changes from east-west along the south flank of Phil Pico Mountain to nearly north-south on the eastern flank of Phil Pico (Figure 3). Evidence of this folding is found throughout the Wasatch Formation on Phil Pico Mountain (Figure 3). The Wasatch beds on the northeastern flank of Phil Pico strike southwest, beds on south flank strike east-west and beds on the western flank strike northwest (Appendix 1, Plate I). This folding is also apparent in the Mesozoic, Paleozoic and Precambrian strata south of Phil Pico Mountain (Appendix 1, Plate I). However, the folding in the Precambrian Uinta Mountain Group is more subdued. This is evidently due to movement along a right lateral strike-slip fault which appears to have accommodated much of the strain of folding (Figure 15).

The Wasatch Formation is thick and coarse-grained over the synclinal part of the fold. It is thin and fine-grained over the anticlinal fold in the western part of the quadrangle and absent over the anticlinal fold just east of the Phil Pico Mountain quadrangle (Sprinkel, 2006). The Wasatch Formation at Phil Pico Mountain is apparently the thickest accumulation of Wasatch Formation south of the bounding faults on the north flank. This suggests that either the erosional clastic material was funneled through and accumulated within the syncline or that the subsequent folding somehow led to the preservation of these deposits.

Data from the Carson Peak Unit 1 well, located in the northeast corner of Phil Pico Mountain, provide constraints on the erosional history of the Uinta Mountains in this area. The well penetrates nearly 3350 m (11,000 ft) of Paleocene and Eocene synorogenic and lacustrine deposits (the Paleocene Fort Union Formation and the Eocene Wasatch, Green River, and Bridger Formations). As described earlier, the conglomerate percentage for each 30 m (100 ft) interval was estimated and graphed versus depth (Figure 8) based on descriptions from the lithology log. The cuttings from the well were used to determine the composition of the conglomerate clasts (see Methods). The clast composition and conglomerate percentage were then compared at depth (Figure 8, Figure 9).

The proportion of conglomerate in the well is influenced by several variables. Three of the most important are 1) the erosional resistance of the parent rock, 2) the proximity of the parent rock, and 3) the gradient of the slope which is influenced by rate of uplift. Other factors such as climate and stream drainage location likely play a lesser role and were not included in this interpretation. It was assumed that the stream location changed sufficiently through time to cancel out its influence.

It was found that intervals with high conglomerate percentage generally correlate with the erosion of resistant formations such as the Pennsylvanian Round Valley Limestone. These intervals, such as the interval from 1490 to 2010 m (4900-6600 ft), are interpreted as periods of uplift, while intervals with low conglomerate percentage are interpreted as periods of slowed or stopped uplift or as periods dominated by the erosion of a soft formation (Figure 8, Figure 9). It was found that some sections of the well with little or no conglomerate correlate to the erosion of soft slope-forming units. For example, the interval from 2440 to 2620 m (8000-8600 ft) has a low conglomerate percentage, but only clasts from the soft Jurassic Morrison and Cretaceous Cedar Mountain Formations were found in this interval. Therefore, because only soft formations were exposed during the deposition of this interval, the low conglomerate percentage does not necessarily translate to slowed uplift. Thus, the variations in uplift rate are unclear and could have been constant. However, the interval from 610 to 880 m (2000-2900 ft) can be confidently interpreted as a period of slowed or stopped uplift because it has a low conglomerate percentage and clasts from the resistant Madison Limestone are found above, below, and occasionally within the interval.

Field relationships of the Eocene deposits at Phil Pico Mountain provide constraints on the timing of uplift along the Henrys Fork fault. Within the current study area there was uplift along the Henrys Fork fault until at least the late Eocene. The Henrys Fork fault cuts through the northern section of Phil Pico Mountain placing early Eocene Wasatch Formation next to late Eocene Bridger Formation. This offset of the late Eocene Bridger Formation requires late Eocene uplift along the Henrys Fork Fault. The beds in the late Eocene Bridger Formation, well-exposed in the northeast section of Phil Pico Mountain, dip about 5° to the north.

The Carson Peak Unit 1 well also provides constraints on the timing of uplift along the Henrys Fork Fault. This well is located on the footwall less than a kilometer north of the Henrys Fork fault (Figure 4). Therefore, uplift along the fault would generally be expected to cause a significant increase in the amount of conglomeratic material arriving at the well. General uplift of the range would likely produce a more gradual increase in conglomerate, a pattern seen in the lower section of the well. On the other hand, the pattern in the upper portion of the well where the Henrys Fork fault is thought to have been active is quite different. The conglomerate percentage spikes from 20% to 60% at 1190 m (3900 ft), from 20% to 75% at 460 m (1500 ft), from 20% to 85% at 305 m (1000 ft), and from 10% to 90% at 60 m (200 ft) (Figure 8). The conglomerate clasts in the Bridger Formation at these depths generally have high percentages of chert and quartz and a mixed composition that resembles recycled Wasatch Formation (Figure 9).

The large spike in the percentage of conglomerate at 1190 m (3900 ft) seems to suggest that the initial activation of Henrys Fork fault occurred in the late early Eocene, prior to the deposition of the 390 m (1270 ft) of Green River Formation in the well. However, this spike could also be explained by localized folding and uplift. There is a large anticlinal fold just southeast of the well, where the Wasatch and Mesozoic Formations dip steeply to the north. The age of this folding is unknown but must have occurred after the deposition of the Wasatch Formation exposed on Phil Pico Mountain and before the deposition of Bridger Formation exposed in the quadrangle. During deposition of the Green River Formation, little or no uplift occurred along the Henrys Fork Fault. However, the spike in conglomerate percentage at 460 m (1500 ft) indicates that uplift occurred along the Henrys Fork fault just after the last deposition of Green River Formation limestones in the well (early middle Eocene) (Smith et al., 2008). There is also evidence for Henrys Fork fault uplift at 305 m (1000 ft) (middle Eocene) and 60 m (200 ft) (late Eocene [?]) (Figure 8, Figure 9). The conglomerates at 60 m (200 ft) are approximately depth-equivalent with late Eocene organic-rich shale (Figure 2) 7.5 km west. Above the well an additional 460 m (1500 ft) of conglomeratic Bridger Formation preserved on Phil Pico Mountain suggest that the Henrys Fork fault remained active for some time into the late Eocene.

Henrys Fork Fault

The Henrys Fork thrust fault is part of a system of south-dipping thrust faults along the north flank of the Uinta Mountains (Bradley 1988). The Henrys Fork fault extends from Flaming Gorge Reservoir to at least the Middle Fork of Beaver Creek (Bradley, 1988) (Figure 2). Anderman (1955a, 1955b) connected the Henrys Fork fault and the North Flank thrust because he believed that they were the same fault. The North Flank thrust-Henrys Fork fault extends from Rockport to Flaming Gorge, a linear distance of about 145 km (Bradley, 1988).

As stated earlier, the Henrys Fork fault zone cuts through the northern section of Phil Pico Mountain quadrangle, thrusting early Eocene Wasatch Formation next to middle to late Eocene Bridger Formation. The Wasatch Formation is south of the fault on the hanging wall and the

Bridger Formation is on the footwall to the north (Appendix 1, Plate I, Figure 4). Because the Henrys Fork fault is nearly always covered by quaternary colluvium across the quadrangle, its location has been approximated based on changes in clast composition, dip domain, and topographic relief.

Age of Henrys Fork fault uplift

Bradley (1995) concluded that there was active uplift along the Henrys Fork fault in the late early to early middle Eocene, with possible minor displacement occurring through late Eocene. Bradley’s conclusions were mainly based on his observations east of Phil Pico Mountain where he states that “the Henrys Fork fault cuts the Paleocene and Eocene age main body of the Wasatch Formation and the lower member of the Eocene Bridger Formation”. Bradley also believed that the Henrys Fork fault was buried across Phil Pico Mountain by what he called the late Eocene lower member of the Bridger Formation and that the slight northern dip (<10°) of these beds “perhaps” supports “minor displacement occurring through the late Eocene” (Bradley 1995). However, this study concludes, as discussed above, that the Henrys Fork fault was most active from the middle to late Eocene and that the lower Bridger Formation is actually Wasatch Formation. Anderman (1955) cited “a 60° angular unconformity within Eocene sediments on Phil Pico Mountain” as evidence that “the Henrys Fork fault was active in [the] middle Eocene.” Bradley (1995) cited evidence from east of Phil Pico for “active uplift along the Henrys Fork fault in the late early to early middle Eocene with perhaps minor displacement occurring through the late Eocene.”

Offset and sense of motion

Anderman (1955a) estimated the throw of the Henrys Fork fault at Phil Pico Mountain as 3660 m (12,000 ft) and Bradley (1964) estimated it as 610 m (2,000 ft). From data collected during the mapping of the Phil Pico Mountain quadrangle and from observations of the Carson Peak Unit 1 well, we estimate the post-Paleocene throw of the Henrys Fork fault to be 2070 m (6800 ft), with a minimum offset of 1430 m (4700 ft) and a maximum offset of 2260 m (7400 ft). This estimate is principally based on the amount of offset between the Wasatch Formation on Phil Pico Mountain and the corresponding section of Wasatch in the Carson Peak Unit 1 well (Figure 7, Figure 4). The Wasatch Formation on Phil Pico Mountain described for this comparison is about 6 km (3.8 mi) south of the well site (Figure 4, location 11). The estimated offset described above is the post-Paleocene offset and represents a minimum total offset, as there was surely subsurface faulting prior to the deposition of the Wasatch Formation. Sprinkel (2006) shows a throw of about 6000 m (19,700 ft) on the Henrys Fork fault at a location 6.5 km (4 mi) east of Phil Pico Mountain. At that location, and based on data from the Noble Energy Company Antelope Hollow State 32-20 well, Sprinkel (2006) places the top Baxter Shale at 4125 m (13,500 ft) depth in the footwall and maps a thin section of Baxter just south of the Henrys Fork fault on the headwall.

The clast composition and unroofing pattern seen in both the Wasatch on Phil Pico Mountain (Figure 10) and the section of the well from 1430 to 1950 m (4700 to 6400 ft) are quite similar (Figure 8, Figure 9). The conglomerate percentage is also high in both sections. In the well, the conglomeratic clasts from 1490 to 1620 m (4900 to 5300 ft) are light and dark gray limestone, gray chert, and gray quartzite, interspersed with quartz grains and red chert. This matches the clast composition of conglomerates described near the top Phil Pico Mountain (Figure 4, location 12). In the well from 1620 to 1830 m (5300 to 6000 ft) the conglomerate clasts are mostly fine-grained red, yellow, and gray sandstone, with some dark and light gray limestone. This composition is quite similar to the conglomerate clasts composition halfway up Phil Pico Mountain (Figure 4, location 13) where the clasts are mostly gray limestone, fine-grained red sandstone, and less yellow sandstone. In the well from 1830 to 1950 m (6000 to 6400 ft) the clasts are mostly yellow sandstone and quartz grains with some light and dark gray limestone. The conglomerates exposed along the lower south flank (Figure 4, location 6) also have a clast composition dominated by yellow sandstone and gray limestone. The one difference is that the well has less limestone and more yellow sandstone. The higher percentage of limestone on the south flank of Phil Pico Mountain is likely due to its proximity to the source of the limestone, the Park City Formation (0.1-0.5 km south). The higher sandstone percentage in the well is likely due to the fact that the Weber Sandstone is more than three times thicker than the Park City Formation.

Mapping the Henrys Fork fault

In the quadrangle, we have identified three splays within the Henrys Fork fault system (Appendix 1, Plate I). Two of the splays were previously unmapped. The southernmost splay and only bedrock exposure of the fault system cuts through the Jurassic Nugget Sandstone on the western side of Phil Pico Mountain (Figure 4, location 18) (Appendix 1, Plate I). It cuts out approximately 35 m (115 ft) of section within the Nugget (based on the estimated thickness of the Nugget Sandstone across the fault). Measurements along the fault plane reveal a steep southern dip (Figure 14) striking 124° and dipping 59°. Riedell shear indicators along the fault show a reverse sense of motion and rake measurements indicate a near dip-slip sense of motion with little or no strike-slip component (Table 2). The eastern trace of this splay is covered and it is less defined on the eastern side of Phil Pico Mountain. Its location is queried and is based mainly on a change in strike and dip of beds in the Wasatch Formation across an east-west trending canyon.

The northern splay is covered by quaternary deposits across the quadrangle, and its location has been approximated. Because the Eocene conglomerates in the central part of Phil Pico Mountain are poorly exposed, the trace of the Henrys Fork fault also had to be approximated in that section of the mountain.

On the western side of Phil Pico Mountain, the trace of the northern splay is north of a steeply-dipping outcrop of sandstone and pebble conglomerate. This outcrop is exposed at location 19 (Figure 4) and dips 64° to the north. It is composed of buff to gray pebble conglomerate and light orange to gray, fine- to very coarse-grained, poorly- to moderately-sorted sandstone. Gray, light gray and black chert are the dominate clast types, although a few yellowish quartzite clasts are also present. We have mapped this ridge as Jurassic Morrison Formation because of the high percentage of dark chert and the absence of gray limestone and other clasts indicative of the Eocene conglomerates in the area. Most of the offset along the Henrys Fork fault must have occurred along the covered northern splay north of this outcrop; the exposures of Mesozoic strata to the south show no evidence of major offset. Quaternary units blanket the area north of this outcrop. However, Bradley mapped the ridge as a lower member of the Eocene Bridger Formation and, using this as evidence, concluded that "the western most exposure of the Henrys Fork fault is Sec. 23, T.3N., R.17E [location 19] where Jurassic Morrison Formation is thrust over the lower member of the Eocene Bridger Formation" (Bradley, 1995).

On the eastern side of Phil Pico Mountain the northern splay is placed on the basis of abrupt changes in composition, texture, dip and topography between the Bridger and Wasatch Formation conglomerates. The splay is drawn at the base of a large east-west trending canyon in the northeast section of Phil Pico Mountain (location 20, Figure 4). The strike and dip direction change abruptly across the canyon. The beds in the canyon change from striking 232° and dipping 21° northwest on the south side (Wasatch Formation) to striking 270° and dipping 5° north on the north side (Bridger Formation). The clast composition and clast size also change across the canyon. The conglomerate clasts change from 65% gray limestone, 15% fine grained white sandstone, 10% white limestone, 5% gray sandy limestone, 3% chert, and 2% yellow sandstone at a Wasatch Formation outcrop on the south side of the canyon (Figure 4, location 10), to 55% gray limestone, 20% yellow sandstone, 15% purple and red quartzite, 5% light sandstone, and 5% chert on the north side of the canyon at an outcrop of Bridger Formation near the same elevation (Figure 4, location 5). The average clast size also changes across the canyon from 3 cm (1.2 in) on the south side (location 4) to almost 15 cm (6 in) on the north side (location 5).

I mapped a central splay of the Henrys Fork fault on the eastern side of Phil Pico Mountain based principally on an abrupt angular unconformity found just east of location 10 and change in dip domain across an east-west trending canyon at location 10. On the western side of Phil Pico the trace of this central splay is queried just south of Morrison Formation ridge (Figure 4, location 19).

Uinta Mountain Group and Madison Limestone strike-slip fault

In the southeastern section of the quadrangle there is evidence of three approximately parallel, right lateral strike-slip or dip-slip faults (Figure 15). Because these faults are located along the transition from syncline on the east to anticline on the west they are likely related to the Eocene folding of the area. These folds are large and are clearly evident in the early Eocene Wasatch Formation and the older strata of the quadrangle. However, the folds are much more subdued in the Uinta Mountain Group. It appears that much of the strain of folding was accommodated through movement along these faults.

Within the Uinta Mountain Group there are at least two fault segments. They are both generally covered; however, the faults are exposed along an excavated canal. Abrupt changes in strike and dip and areas of intensive folding were observed along the canal. At two locations along the well the sandstone beds were offset and truncated (Figure 16). Air photos and field mapping show that the resistant Uinta Mountain Group sandstone ridges along this fault zone are offset approximately 1 km (0.6 mi) (Figure 15). The longest mapped fault in this zone strikes 334°. However, due to poor exposure, the dip of the fault is unknown. A segment of this fault also occurs in the Madison Limestone (Figure 15). At the location of the fault (Sec. 9&16, T.2N., R.18E) (Figure 4, location 14), the Madison Limestone strikes 320° and dips steeply (65°) northwest. Within the limestone at this locality there is a grayish-tan silicified zone approximately 20 m (66 ft) thick with slicken-lines near the base (Figure 17). Below the slicken lines is a zone of brecciated gray limestone about 25 m (80 ft) thick. Within this brecciated zone is an intensely brecciated layer 5 m (16 ft) thick with angular gray limestone clasts and a white sandy/cherty matrix. This fault segment strikes 320° and dips 85° north (Table 3). The rake on the fault plane ranges from 15E to 72E with an average rake of 39E. These data indicate that the fault is an oblique slip fault with a significant component of both dip slip and strike slip. The throw on this segment is unknown but places Madison on Madison. Possible thinning within the Madison exists at the location of the fault. Across the fault the Madison Limestone is about 260 m (853 ft) thick, while in the quadrangle the Madison averages 309 m (1014 ft) thick.

Minor thrust faults at Long Park Dam

According to an unpublished geologic report (Rasely et al., 1998), drilling and other site investigations at the Long Park Reservoir discovered two minor faults about 25 m below the contact of the Madison Limestone. These faults may be segments related to Uinta thrust fault, but because of their minor offset (<10 m) and lack of surface exposure they were not included on the map. The Long Park Reservoir lies along the east-central boundary of the quadrangle (Figure 4, location 8).

PROTEROZOIC RED PINE SHALE

The Red Pine Shale is the uppermost unit in the Uinta Mountain Group (Dehler et al., 2005). In the Phil Pico Mountain quadrangle it is overlain unconformably by the Mississippian Madison Limestone while its basal contact is gradational into the more sand-rich Uinta Mountain Group below. According to Dehler et al. (2005), the Red Pine Shale was deposited at the distal end of a westward prograding fluvial deltaic system and "comprises organic-rich gray shale, siltstone, and subordinate sandstone (quartz arenite to arkosic arenite)." Its thickness ranges from 300 to >1200 m (984 to 3937 ft) on the south flank and 500 to 1825 m (1640 to 5988 ft) on the north flank (Williams, 1953; Wallace, 1972; Bryant, 1992; Dehler et al., 2006). Ten kilometers (6 mi) west of the Phil Pico Mountain quadrangle near Hoop Lake there are "thick exposures (>500 m or 1640 ft) of Red Pine Shale comprising interbedded arkosic sandstone, siltstone, and organic-rich shale" (Dehler et al., 2005). However, the Red Pine Shale is apparently absent at the Sheep Creek Geological area 6 km (3.7 mi) east of the Phil Pico Mountain quadrangle. The strata just beneath the Madison Limestone at that location are dominantly sandstone beds, apparently of the Proterozoic Uinta Mountain Group (Figure 18). On the south flank, the Red Pine Shale also thins or undergoes a facies change toward the east. Most of this apparent thinning occurs in an area due south of the Phil Pico Mountain quadrangle (Sprinkel, 2006).

Observations

The Red Pine Shale is poorly exposed and nearly always covered across the quadrangle. Yet from stratigraphic data collected at three locations across the quadrangle it appears that the Red Pine Shale either thins or undergoes a facies change toward the east across the Phil Pico Mountain quadrangle.

Exposures of Red Pine Shale along USFS 221 near the western quadrangle boundary (Figure 4, location 6) show that the Red Pine at is 533 m (1749 ft) of maroon, green, and green-gray shale interbedded with fine grained light-green sandstone and siltstone and fine- to very coarse-grained light purple and buff to orange feldspar-rich sandstone. The shale intervals are commonly 20 to 30 m (66 to 98 ft) thick. The sandstone is thick- to thin-bedded, cross-bedded in places and siliceous. Sandstone beds increase toward the base of the Red Pine and are up to 20 m (66 ft) thick (Figure 19).

A measured section along a canal in the southeastern section of the quadrangle (Figure 4, location 7) reveals that the interval from 190 to 300 m (623 to 984 ft) below the Red Pine Shale/Madison Limestone contact is largely coarse-grained orange and purple sandstone with interbeds of greenish gray shale (Figure 20). This section was measured along an excavated canal in the southeast section of the quadrangle. (The measured section begins at N 4528839, E 592082 and ends near UTM N 4529004, E 591789). In this section there are approximately 65 m (213 ft) of sandstone and 45 m (148 ft) of shale. The depth-correlative section along USFS 221 is much more shale-rich, with about 20 m (66 ft) of sandstone and 90 m (295 ft) of shale (Figure 20).

Data from a well at the Long Park Reservoir dam, just outside the eastern-central edge of the quadrangle boundary (Figure 4, location 8), provide useful information about the stratigraphy just below the Madison Limestone. A well was drilled to a depth of 50 m (164 ft) during the repair of the Long Park Reservoir dam. A detailed description of the cuttings from this well was included in an unpublished geologic report (Rasely et al., 1998) and was used to construct a partial stratigraphic column from 15 to 60 m (49 to 197 ft) below the Madison contact. In addition, the part of this stratigraphic column from the Madison contact to 15 m below the contact was constructed by observations and measurements of the outcrop just west of the dam. The resulting stratigraphic section shows thick sandstone intervals with relatively thin interbeds of shale (Figure 21). The sandstone is generally maroon, medium- to coarse-grained, and feldspar-rich. The shale is maroon and green-gray. The sandstone intervals are much thicker and the shale intervals much thinner than the depth equivalent section measured just outside the western quadrangle boundary (Figure 22). Exposures just below the Madison Limestone at the Sheep Creek geological area 6 km east of the Long Park Reservoir are also dominated by purplish-red sandstone layers and have thin interbeds of maroon and green shale layers (Figure 18).

It is evident that the Red Pine Shale changes toward the east across the Phil Pico Mountain quadrangle. Possible causes for this change in the Red Pine Shale include 1) it may have been faulted out, 2) pinched out along an angular unconformity with the Madison Limestone, or 3) it may have undergone a facies change, from thick shale with sandstone interbeds in the west to sandstone with thin shale interbeds toward the east.

The Red Pine Shale does not appear to have been removed through faulting. The only evidence of faulting within the Red Pine is a right lateral strike-slip fault in the southeast section of the quadrangle (Figure 4, location 9). While this fault has offset the Red Pine Shale equivalent beds, it does not appear to remove any section. Aerial photos and geologic mapping reveal that the pattern of resistant sandstone ridges in the “Unnamed Member” of the Uinta Mountain Group is nearly identical on either side of the fault (Figure 15). In other words, it appears possible to restore the strata without loss of any section. Some of these resistant sandstone bodies within the “Unnamed Unit” can be traced east and west of the fault some distance without significant disruption (Figure 15). No evidence was found to support the suggestion that perhaps the Uinta thrust fault “cut[s] down into the Uinta Mountain Group and place[s] the probable upper-middle part of the Uinta Mountain Group over the Red Pine Shale” (Dehler et al., 2005).

Although there is a possible angular unconformity between the Red Pine Shale and overlying Madison Limestone 40 km (25 mi) south of the Phil Pico Mountain quadrangle on the south flank of the range (Doug Sprinkel, Utah Geological Survey, personal communication), I could find no evidence for this discordance in the Phil Pico Mountain quadrangle. In the quadrangle, there is no noticeable difference between the general strike and dip of the resistant sandstone beds of the Uinta Mountain Group and the general strike and dip of the Madison Limestone. In addition, there is no apparent loss of section along the Madison contact. However, because of limited outcrop data the possibility that at least part of the Red Pine Shale is cut out along the unconformity cannot be ruled out.

Based on limited evidence outlined above, the most likely cause of the differences in the Red Pine Shale is a facies change from thick shale intervals with thin interbeds of sandstone in the west to thick beds of sandstone with thin interbeds of shale toward the east. The thick shale succession exposed along SR 221, near the western quadrangle boundary (location 6, Figure 4) is apparently correlative with the more sandstone-rich intervals to the east (Figure 23). This interpretation is consistent with most paleogeographic models which place the sea to the west and a braided fluvial plain to the east and tend to predict a general coarsening toward the east away from the sea (Dehler et al., 2005).

Palynology Analysis

Four samples of organic rich shale were collected (Figure 15) and submitted for palynology analysis in order to clarify the age and extent of the Red Pine Shale. However, the analysis did not distinguish the Red Pine Shale from the undivided Uinta Mountain Group. This is because *Leiosphaeridia* spp., algal filaments, and *Trachyspaeridium laminaritum* occur both in the Red Pine and in the undivided Uinta Mountain Group (Sprinkel, 2006, Plate 3). Sample 1 and Sample 2 have *Leiosphaeridia* spp. and algal filaments and “most closely resemble the samples from the [Early Neoproterozoic] Jesse Ewing Canyon Formation” 40 km (25 mi) west. These samples were given an age of Mesoproterozoic to Early Neoproterozoic, a depositional environment of nonmarine, shallow water or tidal flat, and a T.A.I of 0.8-1.0 equivalent R_0. It was also noted that Sample 3 and Sample 4 “are more similar to the ‘Unnamed Unit.’” The Unnamed Unit underlies the Red Pine Shale and in the Phil Pico Mountain quadrangle is mapped and undivided

Uinta Mountain Group. These samples also have *Leiosphaeridia* spp. and algal filaments, but with the addition of *Trachyspaeridium laminaritum* and granulate sphaeromorphs, and were given an age of Early Neoproterozoic, a depositional environment of nonmarine, shallow water or tidal flat and a T.A.I of 0.8-1.0 equivalent R_0.

CONCLUSION

The most important results from recent mapping of this quadrangle include 1) the description and differentiation of the Eocene conglomeratic units within the quadrangle, 2) the determination of the erosional and uplift history of the area (Appendix 1) (Figure 24) the placement of the Henrys Fork thrust fault and, 4) the documentation of the lithologic changes occurring across the quadrangle in the Neoproterozoic Uinta Mountain Group.

Geologic mapping in the Phil Pico Mountain quadrangle has provided evidence that Phil Pico Mountain is largely composed of the conglomeratic facies of the Wasatch and Bridger Formations. These formations are separated by the Henrys Fork fault which has placed early Eocene Wasatch Formation on the south next to middle to late Eocene Bridger Formation on the north. The Wasatch Formation is clearly synorogenic and contains an unroofing succession of the Uinta Mountains. It was deposited in the early Eocene, subsequently folded, and then cut by the Henrys Fork fault in the late early or early middle Eocene. It has since been heavily eroded and recycled as Bridger Formation.

While the Henrys Fork fault is generally covered across the quadrangle, conglomerate clast composition, dip data, and topographic information have allowed for the identification of three splays within Henrys Fork fault system. The southernmost splay in the Nugget Sandstone on the western side of Phil Pico Mountain (Sec. 26, T.3N., R.17E) (Figure 4, location 18) is a high angle reverse fault at the surface (Figure 14). The northernmost fault splay has the greatest amount of offset. It is along this splay that the Wasatch Formation has been thrust over Bridger Formation across Phil Pico Mountain. West of Phil Pico Mountain this northern splay is covered by quaternary deposits but likely cuts through the Morrison Formation north of the outcropping Mesozoic strata.

The Carter Oil Company Carson Peak Unit 1 well provides evidence of uplift along the Henrys Fork thrust fault. Data from this well suggest that the Henrys Fork fault was most active in the middle and late Eocene and that initial uplift along the Henrys Fork Fault in this area may have occurred in the late early Eocene. The approximate post-Paleocene throw of the Henrys Fork fault at Phil Pico Mountain is 2073 m (6800 ft).

This mapping of the Neoproterozoic Uinta Mountain Group has shown that resistant sandstone beds can be traced across the quadrangle. The youngest formation of the group, the Red Pine Shale, appears to thin to the east across the quadrangle due to a change to a more sand-rich facies to the east.

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FIGURES

TABLES

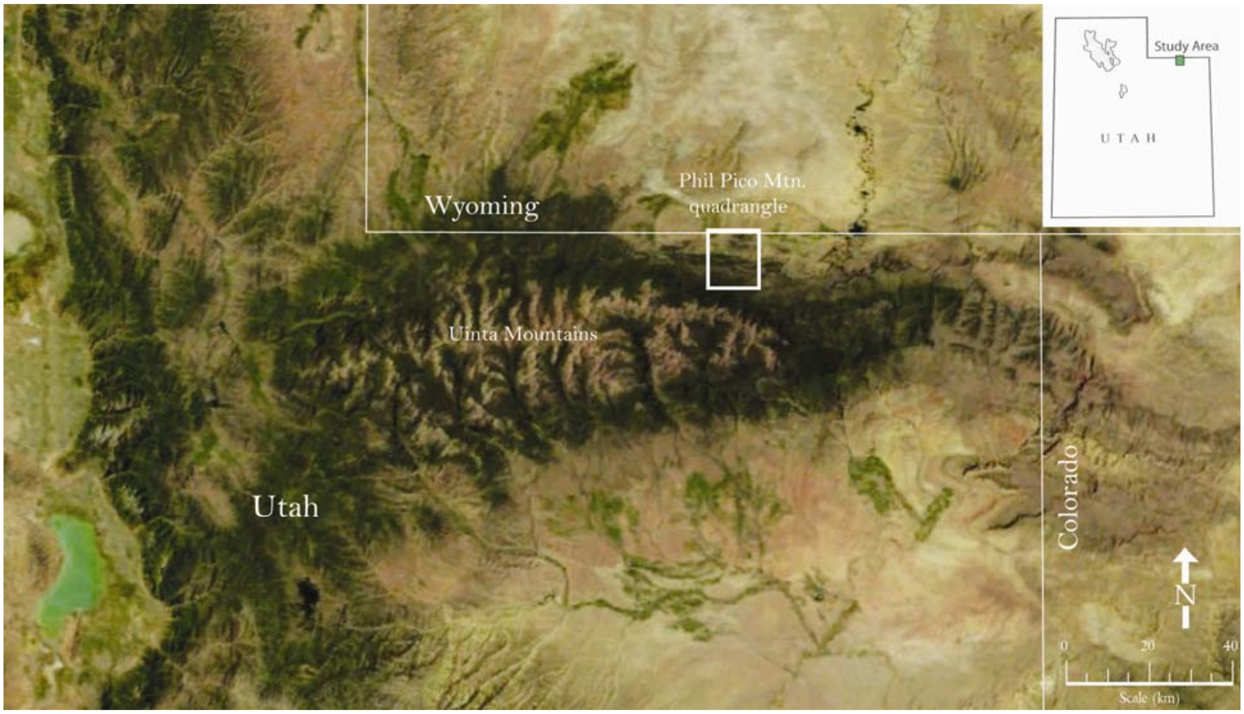


Figure 1: Index map showing the location of the Phil Pico Mountain quadrangle in northern Utah and southern Wyoming (NASA World Wind 1.4).

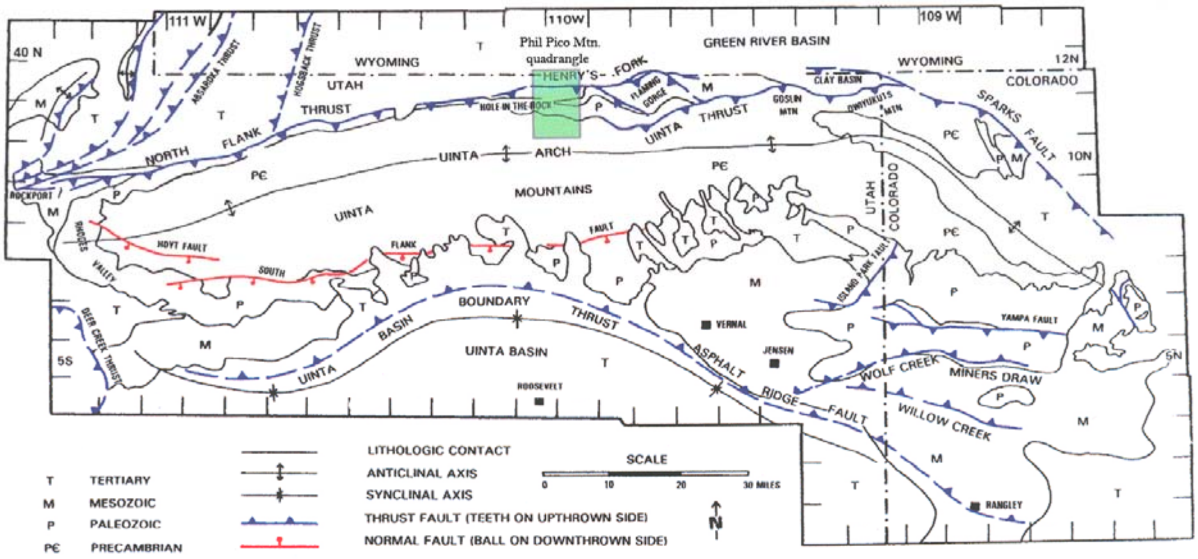


Figure 2: Generalized tectonic map of the Uinta Mountains highlighting the location of the Phil Pico Mountain quadrangle and showing the major bounding faults and lithology of the range (modified after Bradley, 1995).

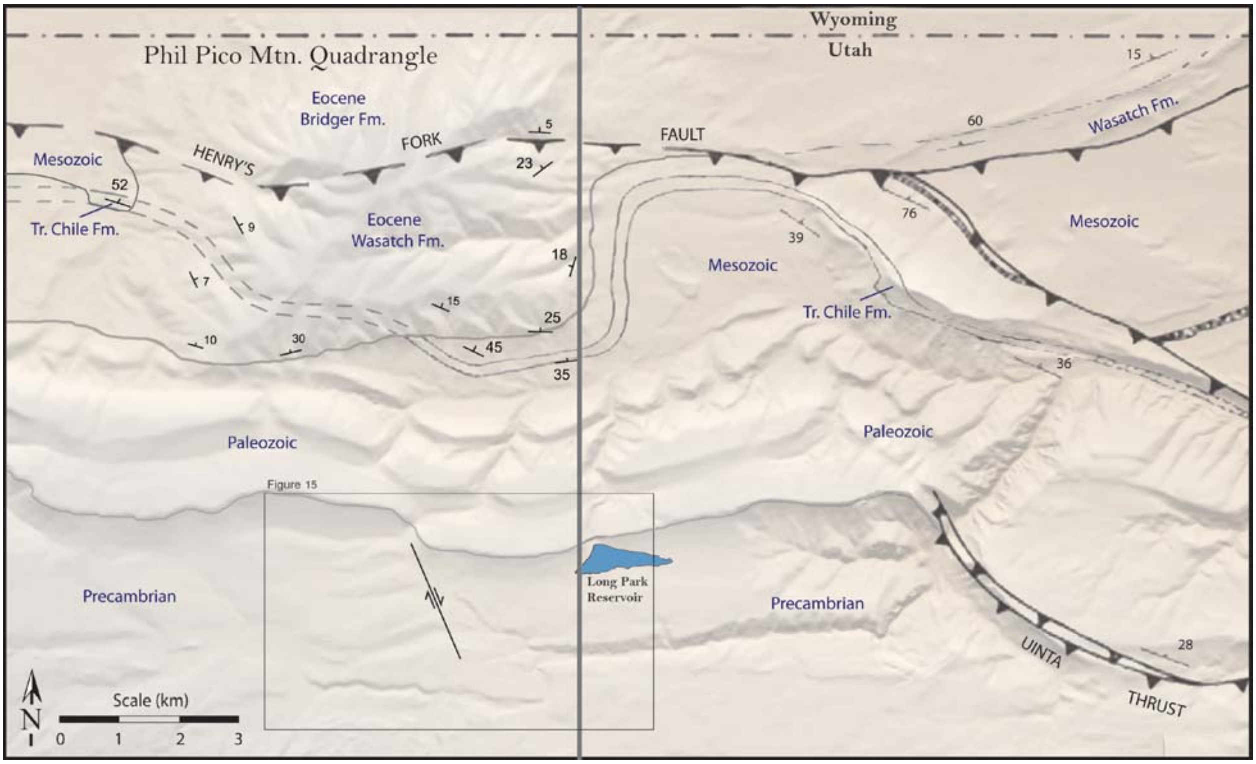


Figure 3: Generalized structural map of the Henry's Fork fault area on a shaded relief map. The Triassic Chinle Formation is shown to delineate structural trends and relationships (modified after Bradley, 1995).

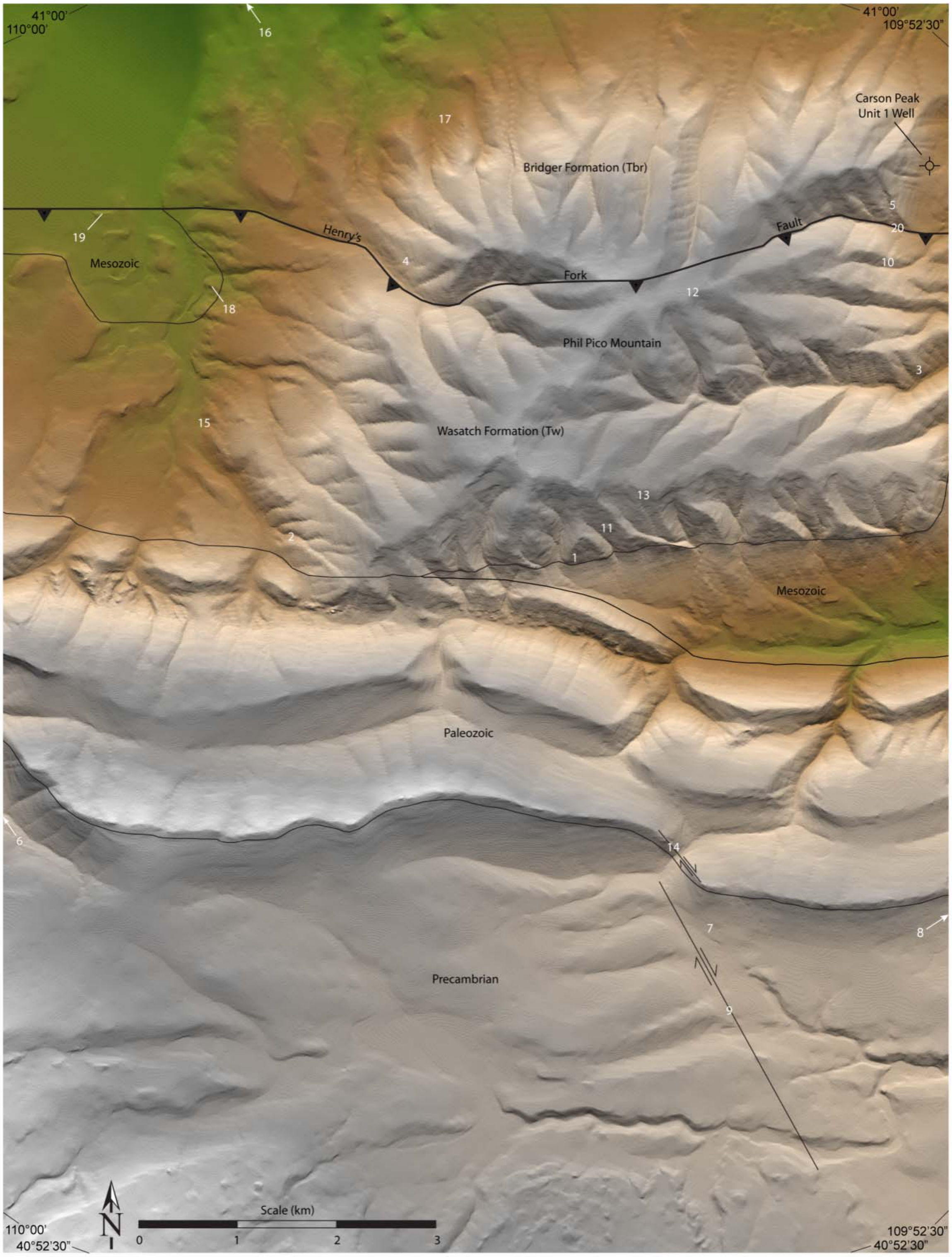
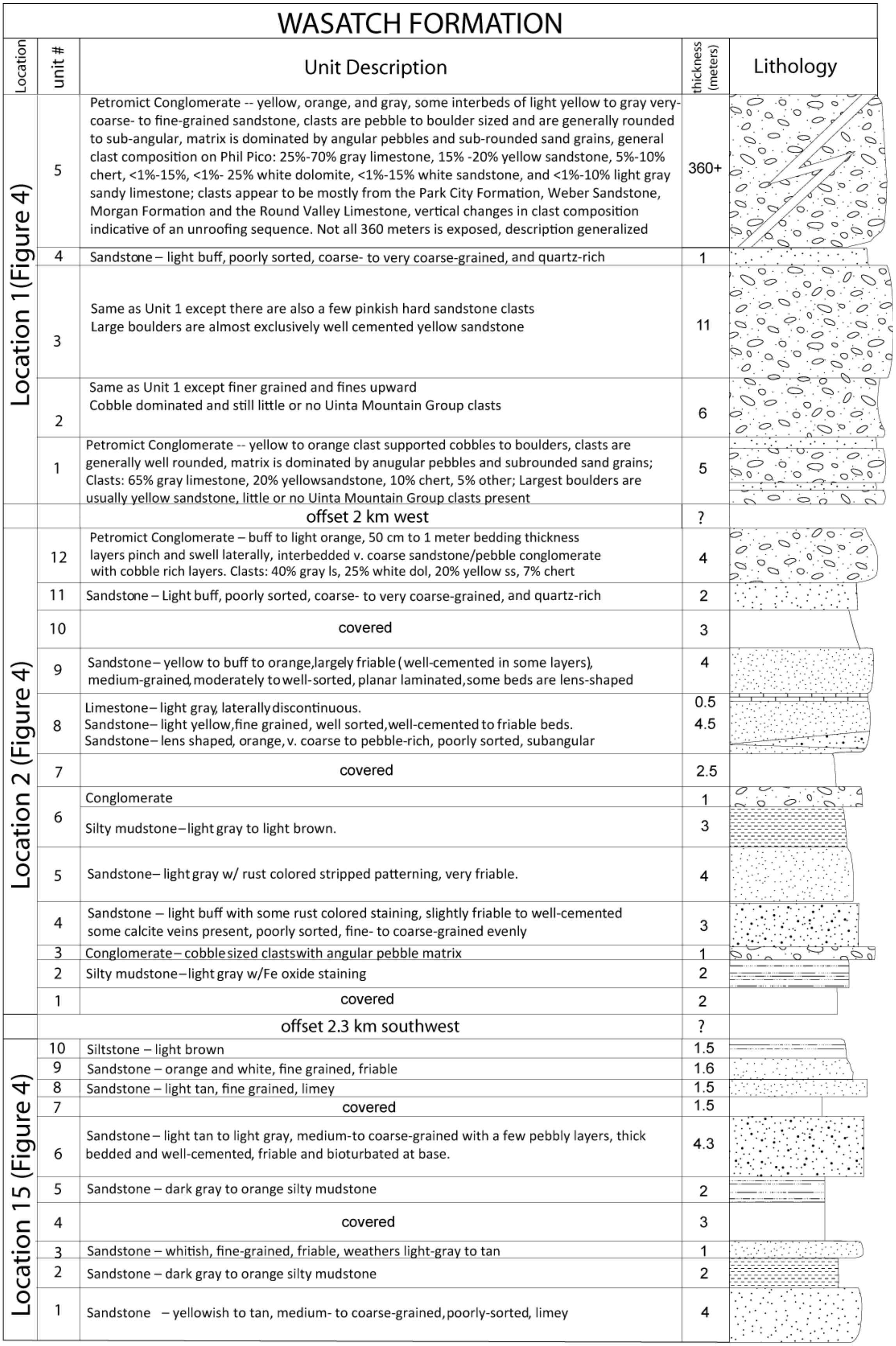


Figure 4: Phil Pico Mountain quadrangle with the generalized geology and topographic features of the quadrangle. The numbers reference locations discussed in the text.



WASATCH FORMATION

Location	unit #	Unit Description	thickness (meters)	Lithology
Location 1 (Figure 4)	5	Petromict Conglomerate -- yellow, orange, and gray, some interbeds of light yellow to gray very-coarse- to fine-grained sandstone, clasts are pebble to boulder sized and are generally rounded to sub-angular, matrix is dominated by angular pebbles and sub-rounded sand grains, general clast composition on Phil Pico: 25%-70% gray limestone, 15% -20% yellow sandstone, 5%-10% chert, <1%-15%, <1%- 25% white dolomite, <1%-15% white sandstone, and <1%-10% light gray sandy limestone; clasts appear to be mostly from the Park City Formation, Weber Sandstone, Morgan Formation and the Round Valley Limestone, vertical changes in clast composition indicative of an unroofing sequence. Not all 360 meters is exposed, description generalized	360+	
	4	Sandstone – light buff, poorly sorted, coarse- to very coarse-grained, and quartz-rich	1	
	3	Same as Unit 1 except there are also a few pinkish hard sandstone clasts Large boulders are almost exclusively well cemented yellow sandstone	11	
	2	Same as Unit 1 except finer grained and fines upward Cobble dominated and still little or no Uinta Mountain Group clasts	6	
	1	Petromict Conglomerate -- yellow to orange clast supported cobbles to boulders, clasts are generally well rounded, matrix is dominated by anugular pebbles and subrounded sand grains; Clasts: 65% gray limestone, 20% yellowsandstone, 10% chert, 5% other; Largest boulders are usually yellow sandstone, little or no Uinta Mountain Group clasts present	5	
		offset 2 km west	?	
Location 2 (Figure 4)	12	Petromict Conglomerate – buff to light orange, 50 cm to 1 meter bedding thickness layers pinch and swell laterally, interbedded v. coarse sandstone/pebble conglomerate with cobble rich layers. Clasts: 40% gray ls, 25% white dol, 20% yellow ss, 7% chert	4	
	11	Sandstone – Light buff, poorly sorted, coarse- to very coarse-grained, and quartz-rich	2	
	10	covered	3	
	9	Sandstone – yellow to buff to orange,largely friable (well-cemented in some layers), medium-grained, moderately to well-sorted, planar laminated, some beds are lens-shaped	4	
	8	Limestone – light gray, laterally discontinuous. Sandstone – light yellow,fine grained, well sorted,well-cemented to friable beds. Sandstone – lens shaped, orange, v. coarse to pebble-rich, poorly sorted, subangular	0.5 4.5	
	7	covered	2.5	
	6	Conglomerate Silty mudstone – light gray to light brown.	1 3	
	5	Sandstone – light gray w/ rust colored stripped patterning, very friable.	4	
	4	Sandstone – light buff with some rust colored staining, slightly friable to well-cemented some calcite veins present, poorly sorted, fine- to coarse-grained evenly	3	
	3	Conglomerate – cobble sized clasts with angular pebble matrix	1	
	2	Silty mudstone – light gray w/Fe oxide staining	2	
	1	covered	2	
		offset 2.3 km southwest	?	
Location 15 (Figure 4)	10	Siltstone – light brown	1.5	
	9	Sandstone – orange and white, fine grained, friable	1.6	
	8	Sandstone – light tan, fine grained, limey	1.5	
	7	covered	1.5	
	6	Sandstone – light tan to light gray, medium-to coarse-grained with a few pebbly layers, thick bedded and well-cemented, friable and bioturbated at base.	4.3	
	5	Sandstone – dark gray to orange silty mudstone	2	
	4	covered	3	
	3	Sandstone – whitish, fine-grained, friable, weathers light-gray to tan	1	
	2	Sandstone – dark gray to orange silty mudstone	2	
	1	Sandstone – yellowish to tan, medium- to coarse-grained, poorly-sorted, limey	4	

Figure 5: Wasatch Formation from measured sections at three locations.

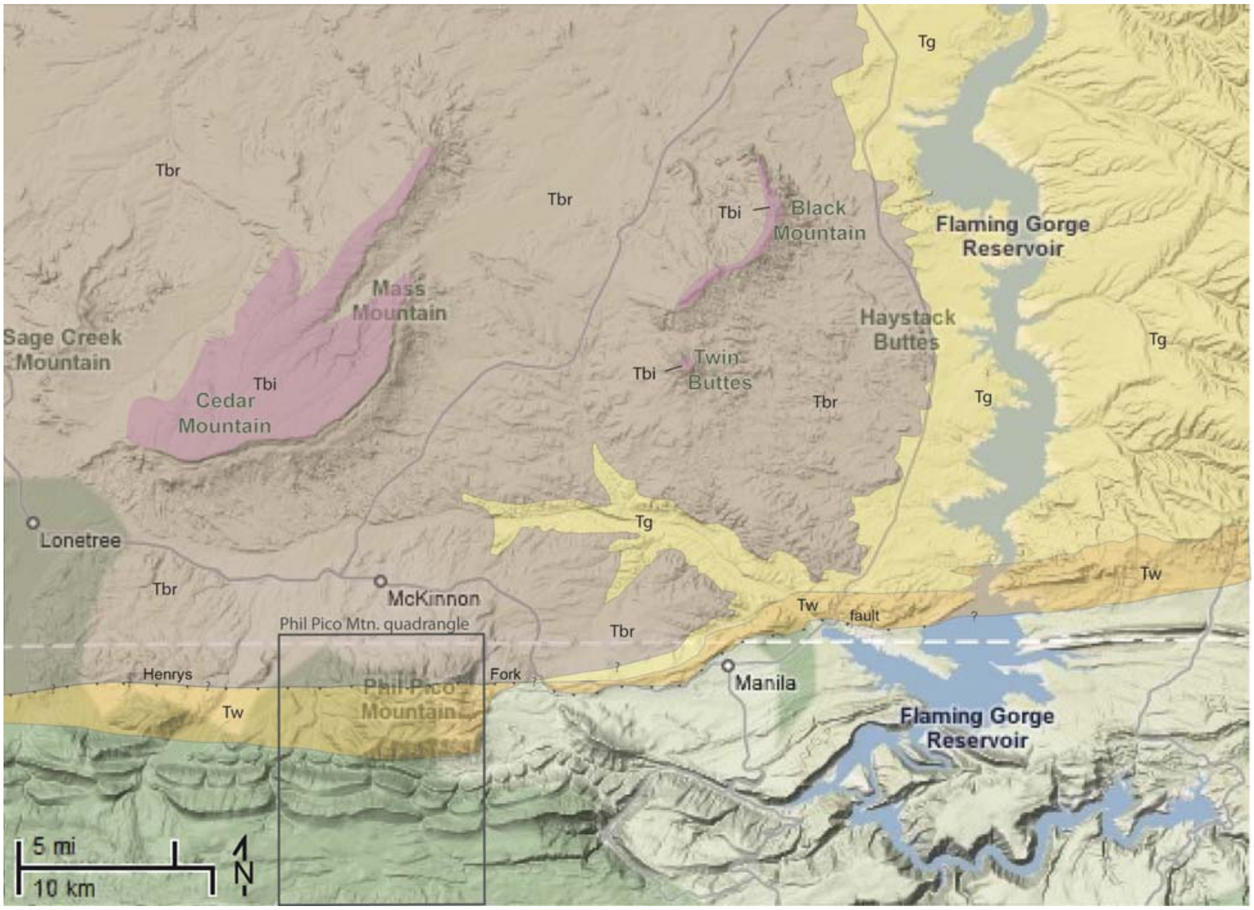


Figure 6 – Map of the approximate distribution of the Tertiary rocks in the Phil Pico Mountain area. Green base signifies areas of vegetation. Tw – early Eocene Wasatch Formation, Tg – early to middle Eocene Green River Formation, Tbr – middle to late Eocene Bridger Formation, Tbi – Oligocene Bishop Conglomerate. Geologic contacts are from Love and Christiansen, 1985 & Sprinkel, 2006.

Figure 7: Basal conglomerate of the Wasatch Formation on the south flank of Phil Pico Mountain (Figure 4, location 1). The large dark gray tabular clast is limestone and was likely derived from the Park City Formation. The Park City Formation outcrops 200 meters south of this location. The other large more rounded clast is sandstone and was likely derived from the Weber Sandstone.

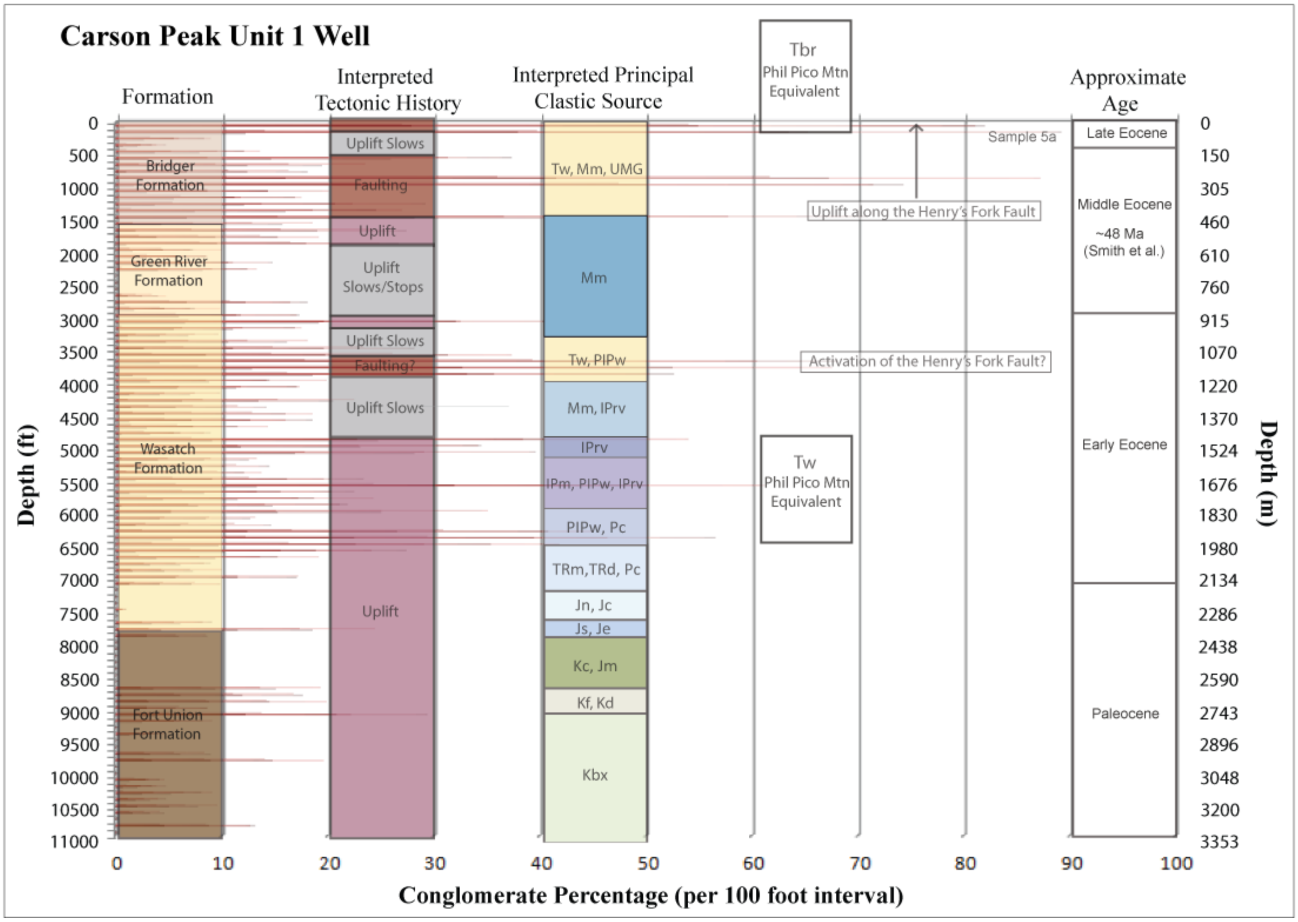


Figure 8: Stratigraphy and conglomerate percentage per 100 foot interval in the Carson Peak Unit 1 well. Conglomerate percentage was estimated from the lithology log of the well. The interpreted formation boundaries, tectonic history, and clast provenance, and approximate age of the deposits are also included. The Tw Phil Pico equivalent is based on the similar clast compositional patterns found on Phil Pico Mountain. The Tbr Phil Pico equivalent shows the approximate thickness of Bridger Fm. above the well. The cause of the conglomerate spike from 3600 to 4000 feet could also be interpreted as localized folding and uplift. Age estimate (48 Ma) based approximate Green River age deposits from Smith et al. (2008).

Depth(ft)	Formation	Cgl (%)	Interpreted Uplift History	Origin of Cgl Clasts	Cgl Clast Comp (cuttings)	Non-Cgl lithology
0		95		Uinta Mountain Group	gray ls, chert, red, purple ss	
100		85			light gray ls and light ss	
200		90	Henry's Fork fault uplift		light ss, yellow ss, chert	ls
300		10			dark ls, chert, qtz grains	ss, ash
400	~37 Ma	5		Mm and recycled IPrv	dark & gray ls, chert, d red ss	ss
500		15	Uplift slows/stops?	recycled Wasatch	pink peach ss, purple qtzite	ss
600		40	^	recycled Pm, PIPW	qtz grains, few ls	
700		25	|	recycled IPrv and UMG	gray ls, chert, pink qtzite	
800	Bridger	20	|			
900	Formation (Tbr)	90		Mm, recycled IPrv	dark gray ls, chert	
1000		85	Henry's Fork fault uplift		v. abd dark and gray ls	
1100		20	^	Mm		
1200		20	|		dark, gray, light ls & chert	
1300		30	|	native Bridger		cly or rd, ss or
1400		30	|		gray ls, chert, few qtz	
1500		75	Henry's Fork fault uplift	IPrv, PIPw, UMG	gray & dark ls, chert, qtz	
1600		20	|			
1700		30	possible folding?	Je-Jn, Jm?, PIPw,	yellow ss, chert, qtz grains	
1800		20	|	IPrv, Mm, first UMG?	dark ls/dol, chert, light ss	
1900	~48 Ma	30	Renewed Uplift	Mm?	chert	
2000		10	^			
2100		10	|			
2200	Green River	15	|			ss
2300	Formation (Tg)	15	|			
2400		0	|			
2500		0	|		dark gray ls, chert	
2600		0	|			
2700		5	|			
2800		20	|			
2900	~49.5 Ma	10	|		dark gray ls, gray ss, chert	
3000	Wasatch	20	Uplift slows/stops?		gray ss, gray ls	
3100	Formation	45	Renewed Uplift?	Mm	gray chert and ls, fine l. ss	
3200	Green River Fm.	20	|		gray chert and ls, fine l. ss	
3300		10	|			
3400		20	|		d ls, l ls, l cht, l ss	
3500		30	Uplift slows/stops?		d ls, l cht, gr cht, l ss	
3600		40	|	Recycled Wasatch	mixed clasts (l cht, drk ls, l ss)	
3700		75	|	PPw and Recycled	abd qtz grains, yw ss, l ss	
3800		70	|	Prv, Mm (Recycled)	chert, d ls, drk s. ls	
3900		60	Henry's Fork fault uplift?	Mm(recycled)		
4000		20	Renewed Uplift	PPw, Mm	qtz grains, d&l ls & chert	
4100	Wasatch	20	|		dark ls/dol ,chert, gray s. ls	
4200	Formation (Tw)	10	|		dark gr ls and d. sdy ls	sh rd or grn
4300		25	|		l&d gray ls/dol & chert	
4400		15	|		l&d gray ls/dol & chert	sh or rd mar, ss
4500		10	|			
4600		20	|			sh mar, ss or
4700		15	|			sh or rd mar
4800		10	Uplift slows/stops?			CORE (ss)
4900		55	^	Prv, Mm?	qtz grains, cht & l&d ls/dol	
5000		40	|	Prv, Mm?	qtz, cht, ls/dol	
5100		40	|	Prv, Mm?	chert, ls/dol, gr qtzite	
5200		15	|	Prv, Mm?	gr limey ss, chert	sh mar or grn
5300		15	|	Pm, Prv, PPw	f red ss, qtz grains, f grn ss	

Depth(ft)	Formation	Cgl (%)	Interpreted Uplift History	Origin of Cgl Clasts	Cgl Clast Comp (cuttings)	Non-Cgl lithology
5400		15	I		ss, tr cht	
5500		25	I	Pm, PPw, Prv	qtz grains, yw & gr ss	
5600		65	Uplift	Pm, Prv, PPw	f red ss, qtz grains, d&l ss	
5700		25	I		ss, tr cht	
5800		25	I	Pm, PPw, first Prv	ang qtz grains, d ls, f gr ss	ss gr wh
5900		25	I	Pm, PPw	f gray ss, ang qtz grains	ss or rd gr
6000		35	I	PPw, Pm	ang qtz grains, l gr ss, l gr ls	cly or rd, sl
6100		15	I	PPw, Pm	ang qtz grains, l ss, d gr ls	ss or, sl or rd
6200		15	I	PPw, Pm, Jn?, Pc	qtz grains, red f ss, d&l ls	ss l gr, sl or rd
6300		50	I		ss, ll cht, tr arkosic	sh mar or rd
6400	Wasatch Formation (Tw)	60	Uplift	PPw, Pc	abd qtz, ylw ss, oolitic ls	cly wh, sl or mar
6500		45	I	PPw, Pc	yw ss, red f ss, few dark ls	ss or
6600		30	I	Trd, TRm, Pc	lrg qtz grains, mica ss, pyr ss	sh, or rd, sl rd
6700		20	I	Pc, TRd, TRm, PPw	red f ss, d ls, yw ss, mica ss	sh or mar, ss
6800		10	I	TRm, Jn, Jc, Pc, TRd	red mud, oolitic ls, mica f ss	sh, ss, sl or rd
6900		10	I			ss or, silst or rd
7000		20	I	Jn, TRm, Pc	light fine rounded ss	sh or rd, ss or
7100		10	I		ss, tr ls, tr cht	sl or rd, ss gr, sh
7200		0	I			cly rd brn wh
7300		0	I	TRm, Pc, Jn	red f ss, gray ls, dark sndy ls	sl or rd grn, ss
7400		0	I		light fine rounded ss	ss, sl, cly or grn
7500		1	I	Jn	light fine rounded ss	ss or, sl or rd
7600		0	I			ss p-sort, sh or
7700			I	Jn/Jc		ss or rd yl lav
7800		10	I	Je/Jc	light fine rounded ss	cly gr grn or rd
7900		10	I	Js/Je	gray ls, eolian sand grains	sh rd or
8000	56 Ma?	0	I			ss, sh gr grn, coal
8100		0	I			ss gr, sh grn
8200		0	I			sh gr grn, ss
8300		0	I	KJcm		lse ss, ss
8400		0	I			ss, tr shy coal
8500		0	I			shale gray, coal
8600		0	I			coal, sh gr grn
8700		20	I		gray ss, native coal	sh gr grn, coal
8800		20	I	Kd	qtz, cht	cly l gr
8900		20	I	Kd	qtz, cht	sh or rd
9000		10	I	Kmr	qtz, cht	sh or rd, coal
9100		30	Uplift?	Kf	dark cht	sh l gr grn
9200		10	I	Kf		ss arg
9300		0	I			cly l gr
9400	Fort Union Formation (Tfu)	5	I			sh l gr, ss grn tan
9500		0	I	Kbx		ss
9600		0	I			ss, cly
9700		10	I			sh gr grn
9800		20	I	Kd?	black sh clasts, light ss	ss, sh gr grn
9900		0	I			sh gr grn
10000		0	I			cly l gr, ss
10100		5	I	Kbx		cly l gr, ss
10200		5	I			cly l gr, ss arg
10300		10	I			cly l gr
10400		5	I			cly l gr, ss
10500		10	I			ss brn
10600		5	I			cl gr, ss, bone
10700		0	I	Kmv		sh d gr, ss br
10800	66 Ma?	15	I		brn ss	
10900	Lance Fm?	0	Uplift?			

Figure 9: Carter Oil Company Carson Peak Unit 1 well data. The depth, lithology and conglomerate percentage were determined from the lithology log, and the conglomerate clast composition was determined from the well cuttings. The formation picks, the interpreted uplift history, and interpreted origin of clasts are also included.

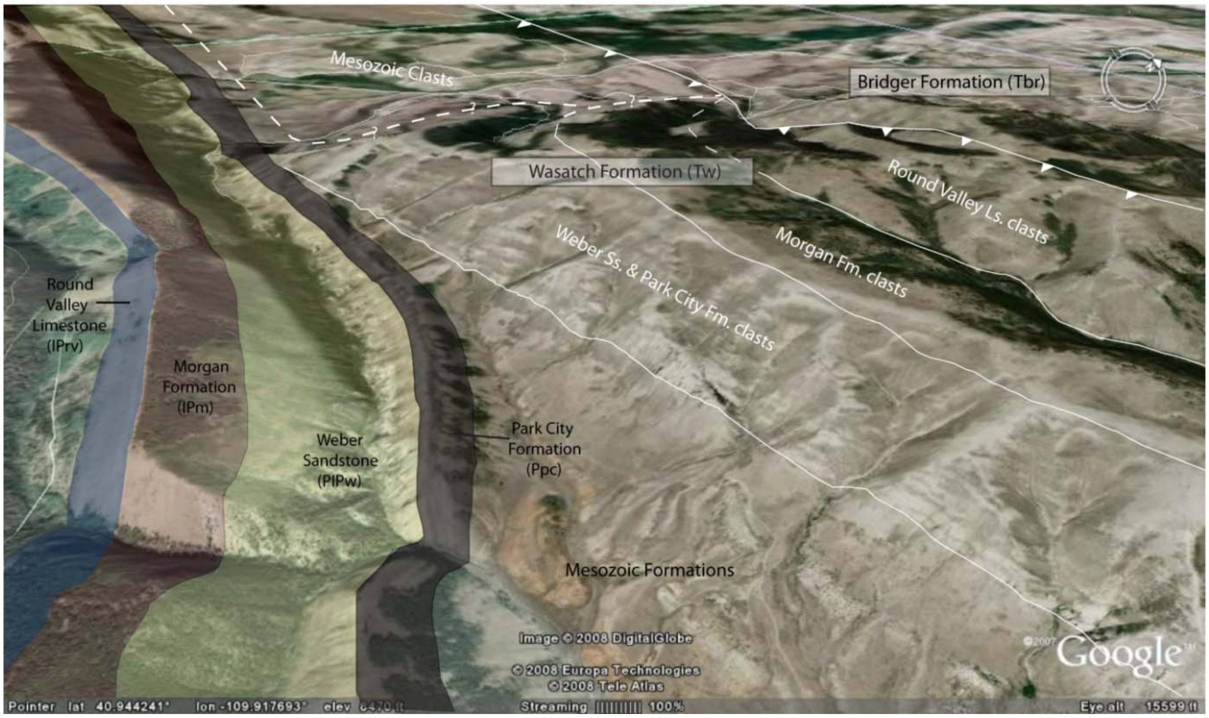
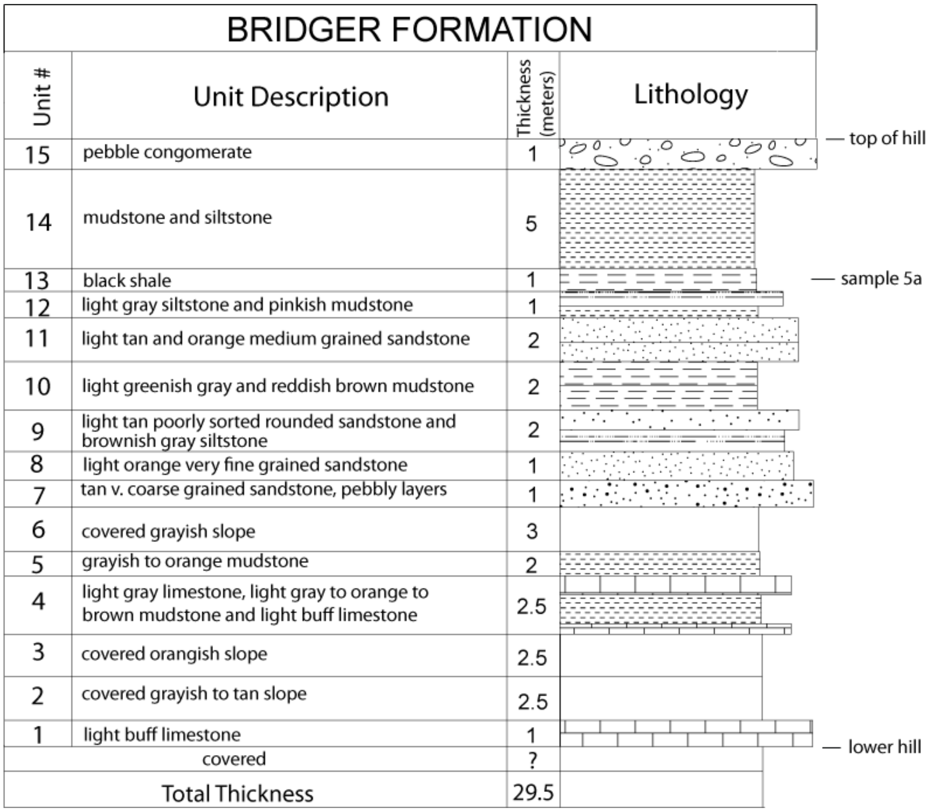


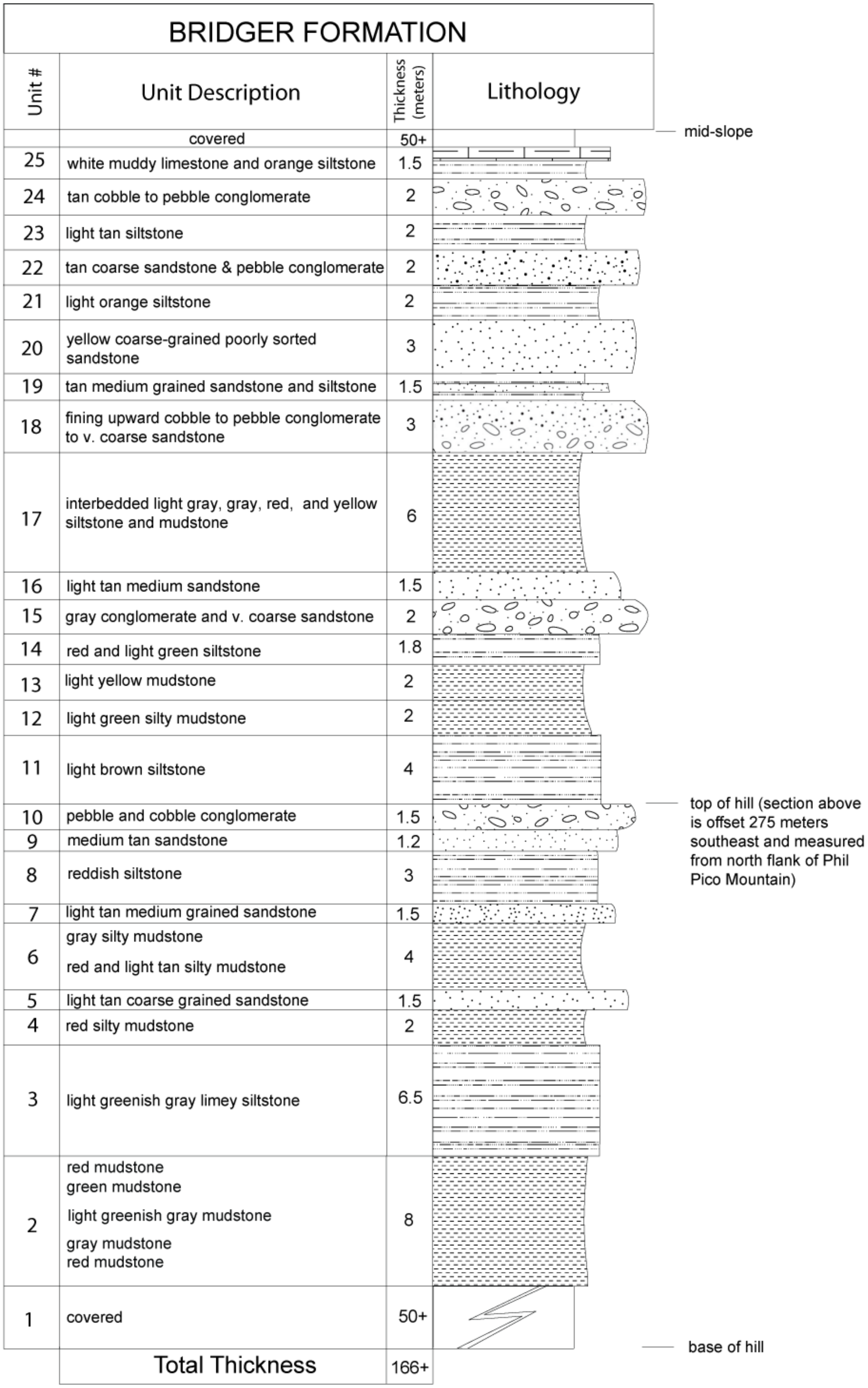
Figure 10: Shaded relief map of a section of the Phil Pico Mountain quadrangle showing the dominant clast types within the Wasatch Formation. The Paleozoic bedrock units are also highlighted.



BRIDGER FORMATION

Unit #	Unit Description	Thickness (meters)
15	pebble congomerate	1
14	mudstone and siltstone	5
13	black shale	1
12	light gray siltstone and pinkish mudstone	1
11	light tan and orange medium grained sandstone	2
10	light greenish gray and reddish brown mudstone	2
9	light tan poorly sorted rounded sandstone and brownish gray siltstone	2
8	light orange very fine grained sandstone	1
7	tan v. coarse grained sandstone, pebbly layers	1
6	covered grayish slope	3
5	grayish to orange mudstone	2
4	light gray limestone, light gray to orange to brown mudstone and light buff limestone	2.5
3	covered orangish slope	2.5
2	covered grayish to tan slope	2.5
1	light buff limestone	1
	covered	?
	Total Thickness	29.5

Figure 11: Bridger Formation stratigraphic column from a measured section 0.4 km north of the quadrangle boundary (Figure 4, location 16).



BRIDGER FORMATION		
Unit #	Unit Description	Thickness (meters)
	covered	50+
25	white muddy limestone and orange siltstone	1.5
24	tan cobble to pebble conglomerate	2
23	light tan siltstone	2
22	tan coarse sandstone & pebble conglomerate	2
21	light orange siltstone	2
20	yellow coarse-grained poorly sorted sandstone	3
19	tan medium grained sandstone and siltstone	1.5
18	fining upward cobble to pebble conglomerate to v. coarse sandstone	3
17	interbedded light gray, gray, red, and yellow siltstone and mudstone	6
16	light tan medium sandstone	1.5
15	gray conglomerate and v. coarse sandstone	2
14	red and light green siltstone	1.8
13	light yellow mudstone	2
12	light green silty mudstone	2
11	light brown siltstone	4
10	pebble and cobble conglomerate	1.5
9	medium tan sandstone	1.2
8	reddish siltstone	3
7	light tan medium grained sandstone	1.5
6	gray silty mudstone red and light tan silty mudstone	4
5	light tan coarse grained sandstone	1.5
4	red silty mudstone	2
3	light greenish gray limey siltstone	6.5
2	red mudstone green mudstone light greenish gray mudstone gray mudstone red mudstone	8
1	covered	50+
	Total Thickness	166+

Figure 12: Bridger Formation stratigraphic column from the western section of the north flank of Phil Pico Mountain(location 17). Units 1-10 are from a hill 275 m NW of Phil Pico Mountain.

Figure 13: Late Eocene Bridger Formation conglomerate. The large dark red clast is sandstone and is likely from the Uinta Mountain Group. Taken looking north in the northeast section of Phil Pico Mountain on the footwall of the Henry's Fork fault.

Figure 14: A segment of the Henry's Fork fault in the Jurassic Nugget Sandstone, looking north. Fault dips steeply south and has reverse sense of motion indicators, (see Table 2 for fault measurements), Photo taken at location 18 (see Figure 4) (UTM: N 456143, E 586353).

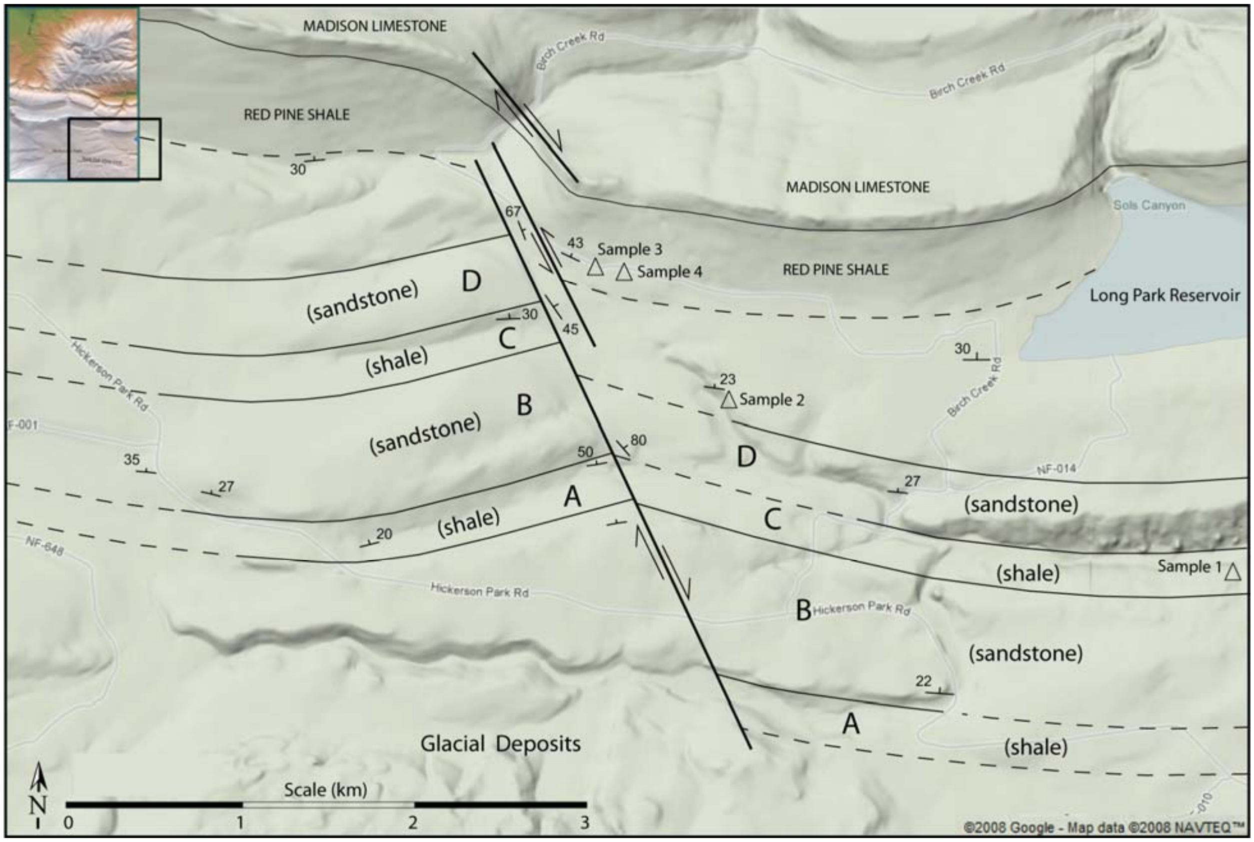
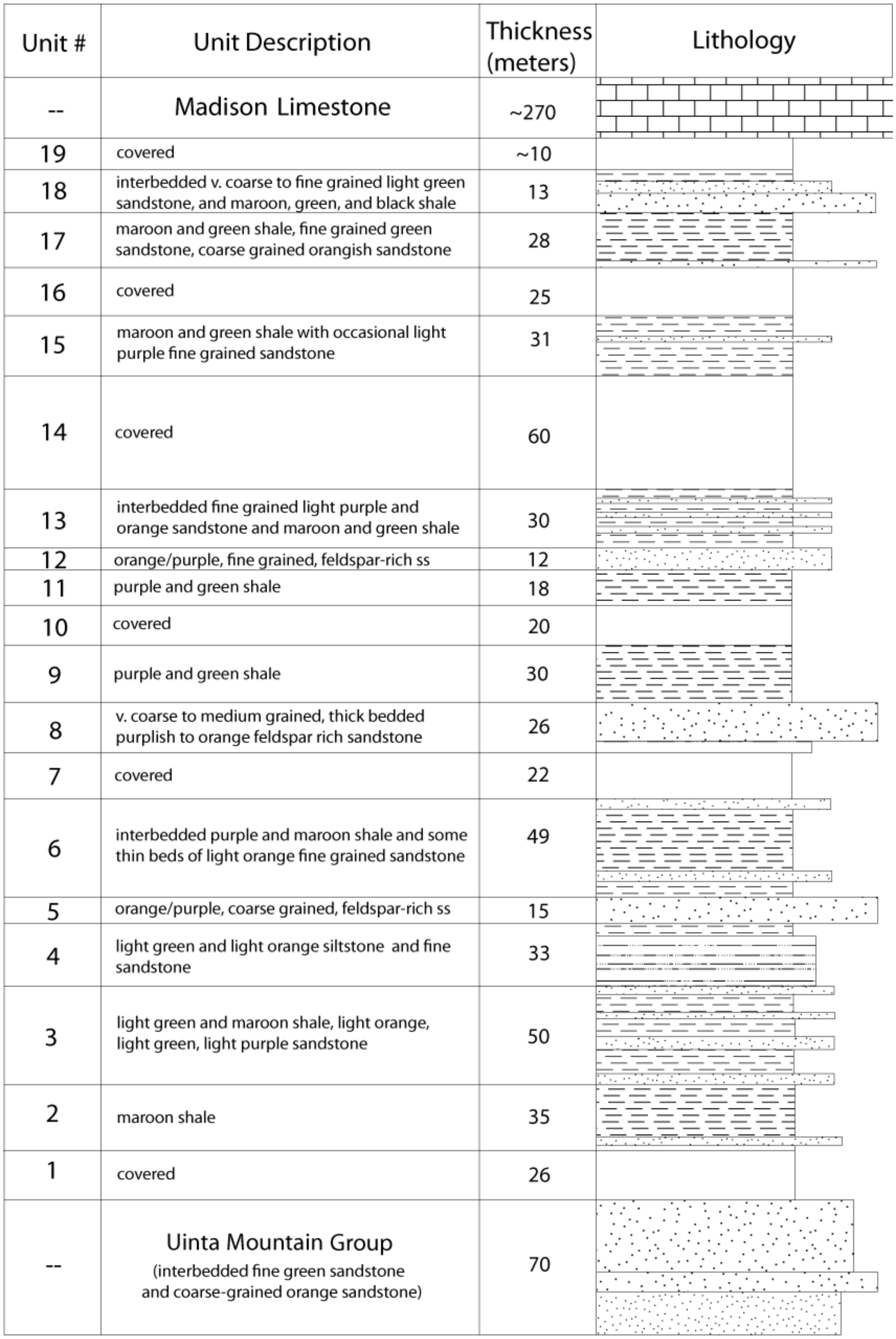


Figure 15: Generalized geologic map showing the palynology sample locations, delineating the structural trends of the area, highlighting the offset along Uinta Mountain Group strike-slip fault, and showing the approximate Red Pine Shale/Uinta Mountain Group contact.

Figure 16: Looking north at offset beds within the Red Pine Shale or Uinta Mountain Group (along an excavated canal) (likely a segment of a strike-slip fault). Photo taken near location 7, (Figure 4) (UTM: N 4529004, 591789).

Figure 17: A silicified and brecciated zone within the Madison Limestone related to an oblique slip fault (looking northwest). Slicken lines are found along left side of the near vertical ridge, (see Table 3 for fault data), (location 14, Figure 4).

Figure 18: Looking north at the Middle Upper Proterozoic Uinta Mountain Group just below the unconformable contact with the Madison Limestone at Sheep Creek Canyon (6 km or 3.7 mi) east of the eastern edge of the Phil Pico Mountain quadrangle. The Uinta Mountain Group at this location is dominated by sandstone and the Red Pine Shale is apparently absent. The Mississippian Madison Limestone is the light colored ridge along the top and the right side of the photo.



Unit #	Unit Description	Thickness (meters)	Lithology
--	Madison Limestone	~270	
19	covered	~10	
18	interbedded v. coarse to fine grained light green sandstone, and maroon, green, and black shale	13	
17	maroon and green shale, fine grained green sandstone, coarse grained orangish sandstone	28	
16	covered	25	
15	maroon and green shale with occasional light purple fine grained sandstone	31	
14	covered	60	
13	interbedded fine grained light purple and orange sandstone and maroon and green shale	30	
12	orange/purple, fine grained, feldspar-rich ss	12	
11	purple and green shale	18	
10	covered	20	
9	purple and green shale	30	
8	v. coarse to medium grained, thick bedded purplish to orange feldspar rich sandstone	26	
7	covered	22	
6	interbedded purple and maroon shale and some thin beds of light orange fine grained sandstone	49	
5	orange/purple, coarse grained, feldspar-rich ss	15	
4	light green and light orange siltstone and fine sandstone	33	
3	light green and maroon shale, light orange, light green, light purple sandstone	50	
2	maroon shale	35	
1	covered	26	
--	Uinta Mountain Group (interbedded fine green sandstone and coarse-grained orange sandstone)	70	

Figure 19: Stratigraphic column of the Red Pine Shale from a measured section near the western edge of the quadrangle along Birch Creek Canyon road (USFS 221) (Figure 4, location 6), lower contact drawn above the thick sandstone of the Uinta Mountain Group. Total measured thickness of the Red Pine Shale at this location is 533 meters (1750 ft).

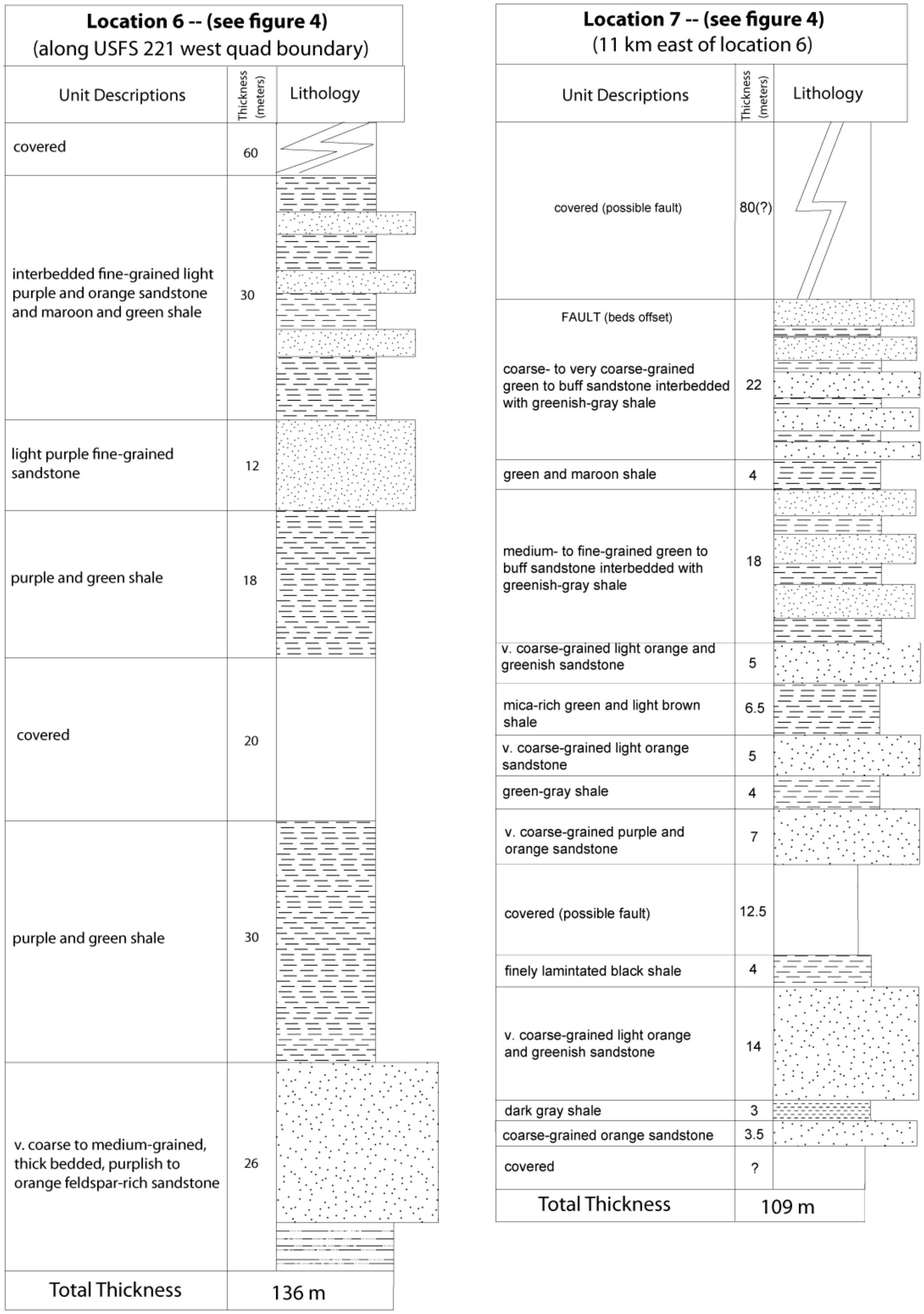


Figure 20: Comparison of Red Pine Shale stratigraphic columns (locations 6 and 7). These columns are approximately depth equivalent as determined by their distance below the contact with the Madison Limestone. However, the Red Pine Shale is largely covered between these two sections and therefore the loss of some section can't be ruled out. Total thickness does not include the upper covered sections.

Figure 21: Looking west from the Long Park Reservoir dam (location 8, Figure 4). The Mississippian Madison Limestone is to the right of the drawn contact. The outcrop below the Madison Limestone is described in the Figure 22 stratigraphic column (the 15 meters of section just below the Madison Limestone).

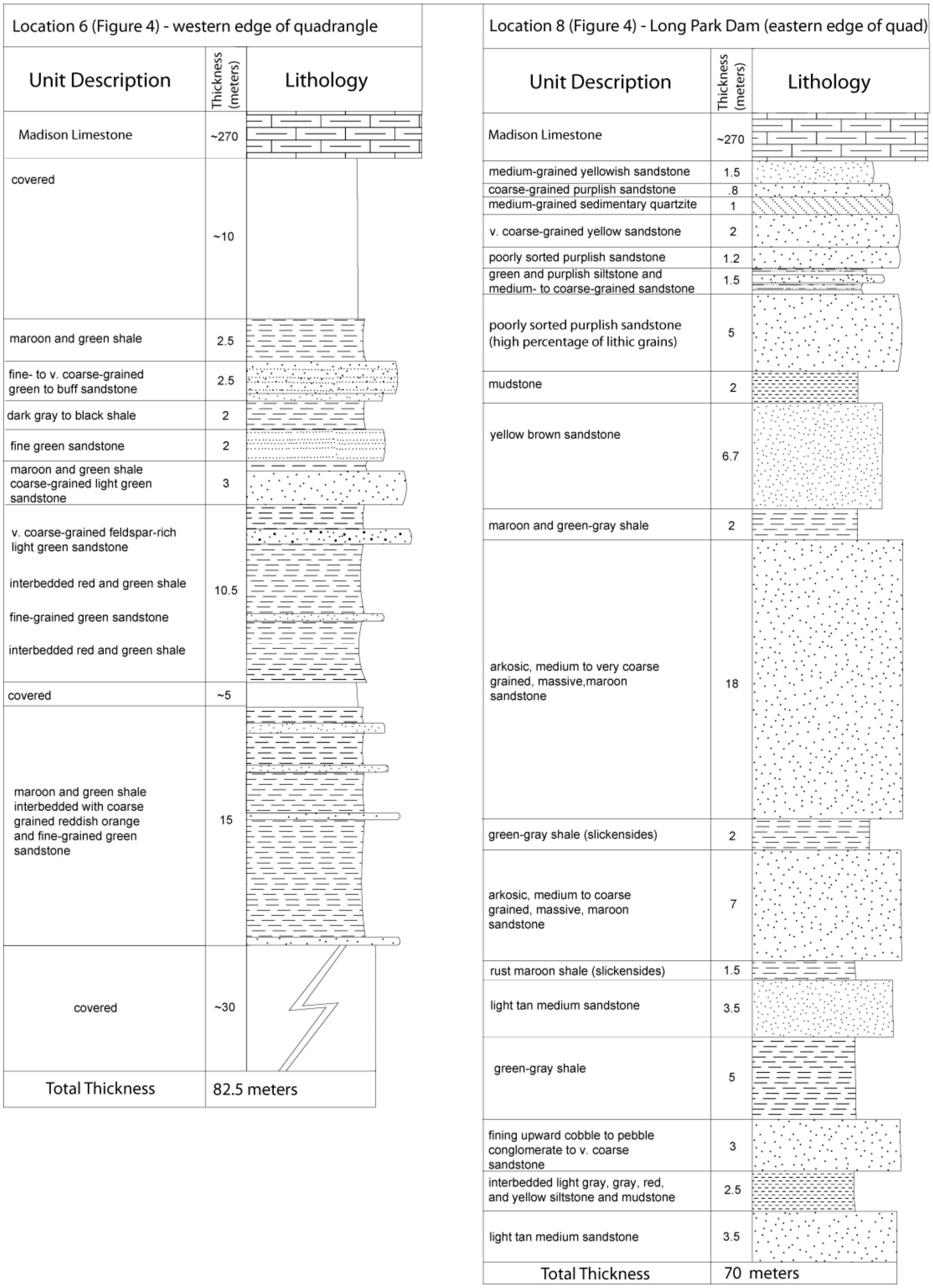
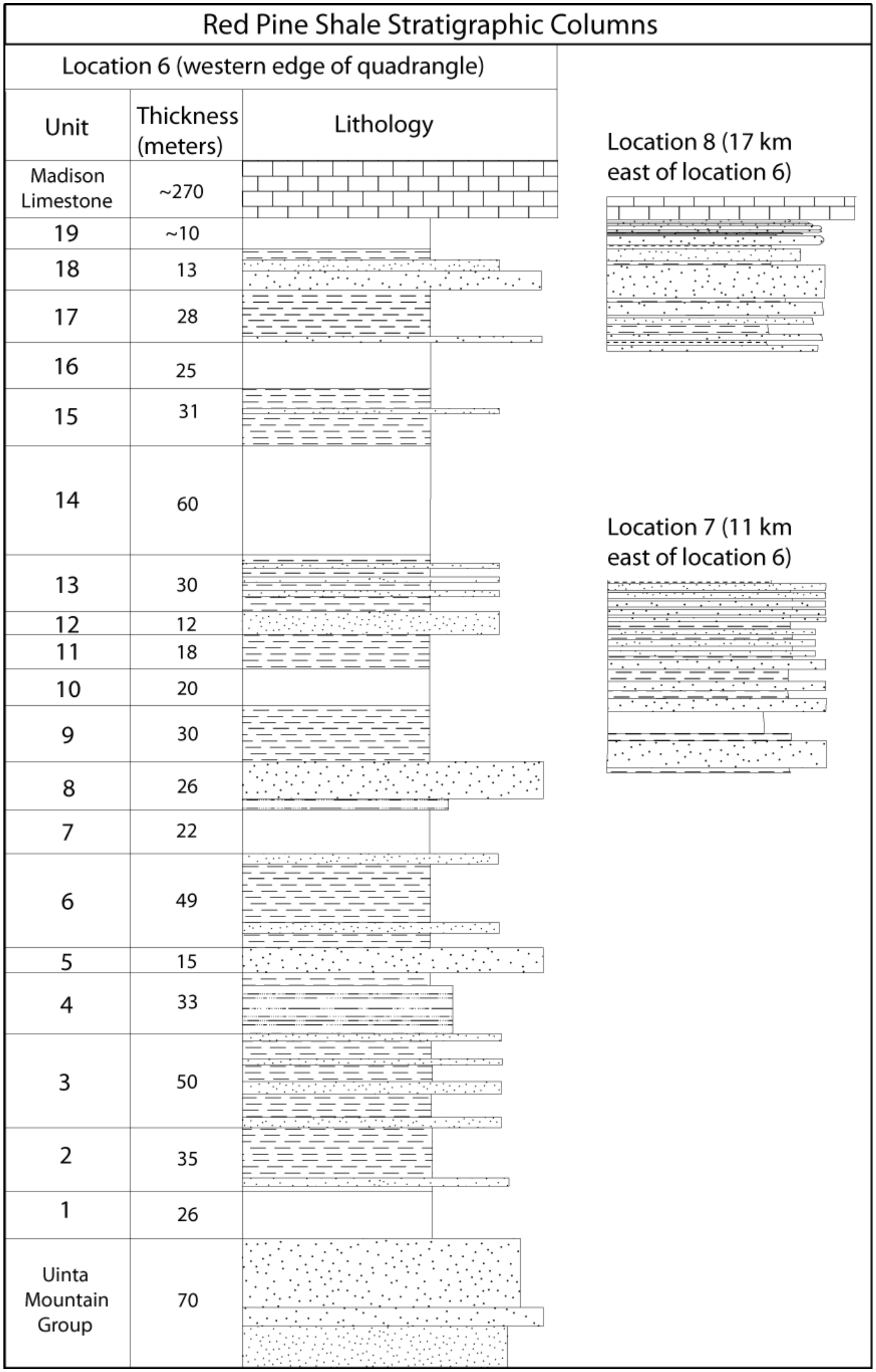


Figure 22: Comparison of Red Pine Shale stratigraphic columns (locations 6 and 8). The location 6 column is from a measured section. The location 8 column is from measured section and well data. The Madison Limestone contact and the 15 meters below are from a measured section at Long Park Reservoir (Figure 21), the remainder of the column was constructed from well data and other cite observation made by geologists during construction and repair of the dam (Rasely et al., 1998).

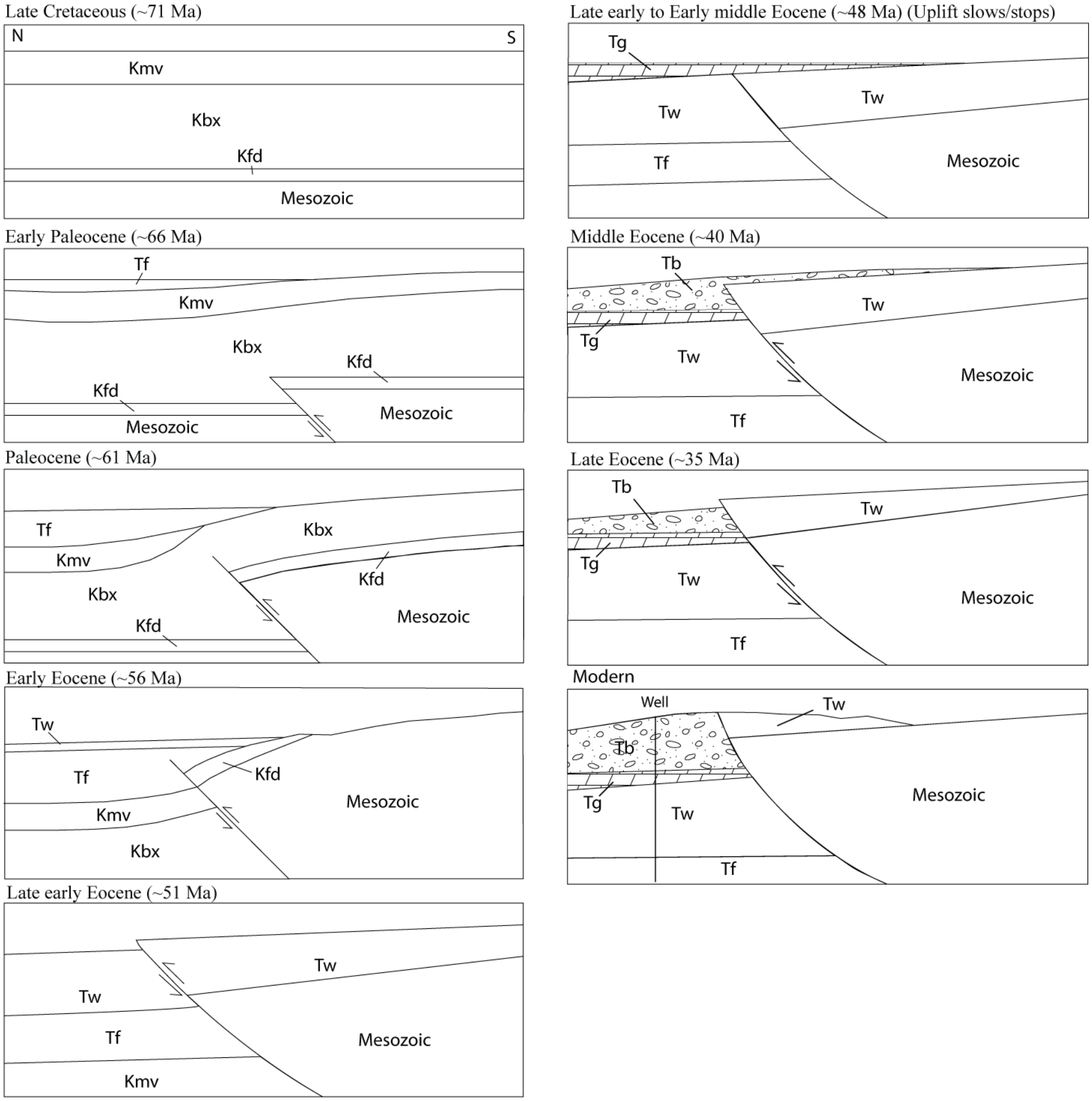


Red Pine Shale Stratigraphic Columns

Location 6 (western edge of quadrangle)

Unit	Thickness (meters)
Madison Limestone	~270
19	~10
18	13
17	28
16	25
15	31
14	60
13	30
12	12
11	18
10	20
9	30
8	26
7	22
6	49
5	15
4	33
3	50
2	35
1	26
Uinta Mountain Group	70

Figure 23: Comparison of Red Pine Shale stratigraphic columns (locations 6, 7, and 8).



Late Cretaceous (~71 Ma)

Early Paleocene (~66 Ma)

Paleocene (~61 Ma)

Early Eocene (~56 Ma)

Late early Eocene (~51 Ma)

Late early to Early middle Eocene (~48 Ma) (Uplift slows/stops)

Middle Eocene (~40 Ma)

Late Eocene (~35 Ma)

Modern

Figure 24. Cross-sections from north to south across Phil Pico Mountain through time, showing the approximate erosional and uplift history at Phil Pico Mountain (Appendix 1). These interpretations are based on field data in the Phil Pico Mountain quadrangle and on an analysis of the cuttings and lithology log of the Carson Peak Unit 1 well (Figure 8, Figure 9), and on well data from Noble Energy Company Antelope Hollow State 32-20 well 6.5 km east (Sprinkel, 2006) which places the top Baxter Shale at 4125 m (13,500 ft). The Carson Peak well (Figure 4) is shown in the modern cross-section as a reference point. Kfd – Cretaceous Dakota Sandstone, Mowry Shale and Frontier Sandstone, Kmv – Cretaceous Mesaverde Formation, Kbx – Cretaceous Baxter Shale, Tf – Paleocene Fort Union Formation, Tw – Early Eocene Wasatch Formation, Tg – Eocene Green River Formation, Tb –Middle to Late Eocene Bridger Formation.

TABLE 1. POLLEN AND SPORE ANALYSIS OF SAMPLE 5A, SAMPLE FROM THE BLACK SHALE SHOWN IN FIGURE 8, ANALYSIS BY GERALD WANDERS

Age:	Late Eocene
Environment:	Lacustrine
Spores and Pollen:	*Abies* spp., *Betula* sp., *Carya veripites, Deltoidospora* spp., *Gleicheniidites* sp., *Juglans spp., Kurzipites sp., Laevigatosporites* sp., *Momipites coryloides, Momipites tenuipolus, Picea* spp., *Pinus* spp., *Psilatricolpites* sp., *Taxodiaceae, Tsuga* spp.
HCl Reaction:	Very Strong (no HF needed for maceration)
Total Organic Recovery:	Very Good
Kerogen Content:	98% Amorphous, 51% Cuticular and 1% Woody
T.A.I:	0.3-0.4 Equivalent R_0

TABLE 2. HENRY'S FORK FAULT DATA

Strike	Dip	Rake	Riedell Sheer
125	55	83w	
146	64	85e	
125	67	90	
136	61	87e	possible reverse
136	45	78w	
85	46	86e	
98	44	80w	
124	58	82e	definite reverse
142	66	81e	definite reverse
163	70	62e	reverse
108	60	85w	
120	62	90	
102	70	90	
118	66	82e	
114	58	68e	reverse
148	55	75e	

TABLE 3. MADISON LIMESTONE FAULT DATA

Strike	Dip	Rake(e)
313	85n	35
300	83n	38
295	90n	50
322	88n	72
128	58s	15
340	80n	23

APPENDIX

1. Interpretation of the Erosional and Uplift History from the Carson Peak Unit 1 Well
2. Plate I
3. Plate II

Interpretation of the Erosional and Uplift History from the Carson Peak Unit 1 well

I. Paleocene Uplift
    a. Deposition of the Fort Union Formation
    b. Erosion of the Mesaverde Formation through the Morrison Formation (~2900 m or 9500 ft of strata)
    c. No evidence of surface faulting
II. Latest Paleocene-Early Eocene uplift (continued uplift and folding without surface faulting)
    a. Deposition of Wasatch Formation begins (clasts show unroofing succession)
    b. Folding within the Wasatch
    c. Erosion of the Jurassic Stump Formation through part of the Mississippian Madison Limestone (~2150 m or 7050 ft of strata)
III. Uplift slows/stops (early Eocene)
    a. Deposition of 244 m (800 ft) of Wasatch Formation mostly sandstone and shale
    b. Conglomerate percentage drops to about 15%
IV. First surface faulting of the Henrys Fork fault at Phil Pico Mountain (late early Eocene)
    a. Deposition of 210 m (700 ft) of upper Wasatch Formation
    b. Erosion of middle Wasatch Formation, Madison Limestone, and other bedrock units
    c. Spike in conglomerate percentage in well then gradual decrease in conglomerate
V. Uplift slows/stops (late early to early middle Eocene)
    a. Deposition of 305 m (1000 ft) of Green River Formation (lacustrine deposits)
    b. Fluviatile erosion slows
    c. Conglomerate percentage decreases dramatically
VI. Renewed uplift (early middle Eocene)
    a. Deposition of Bridger Formation begins
    b. 90 m (300 ft) of interfingering lacustrine Green River Formation deposits and fluviatile Bridger Formation deposits
    c. Fluviatile sandstone and conglomerate percentage gradually increases
    d. Erosion of Paleozoic limestones then Mesozoic sandstones
VII. Renewed uplift and surface faulting along Henrys Fork fault (middle Eocene)
    a. Deposition of 305 m (1000 ft) of Bridger Formation
    b. Erosion of Wasatch Formation, other bedrock units, and evidently Green River Formation (two clasts of Tertiary limestone found in the Bridger Formation conglomerate in the well)
    c. Spike in conglomerate percentage
VIII. Uplift slows/stops (late middle or late Eocene)
    a. Deposition of 90 m (300 ft) of Bridger Formation
IX. Renewed uplift along Henrys Fork fault (late middle and late Eocene)
    a. Deposition of 90 m (300 ft) of Bridger Formation
    b. Deposition of additional 460 m (1500 ft) of Bridger Formation above the well
    c. Erosion of Uinta Mountain Group increases

Utah Geological Survey
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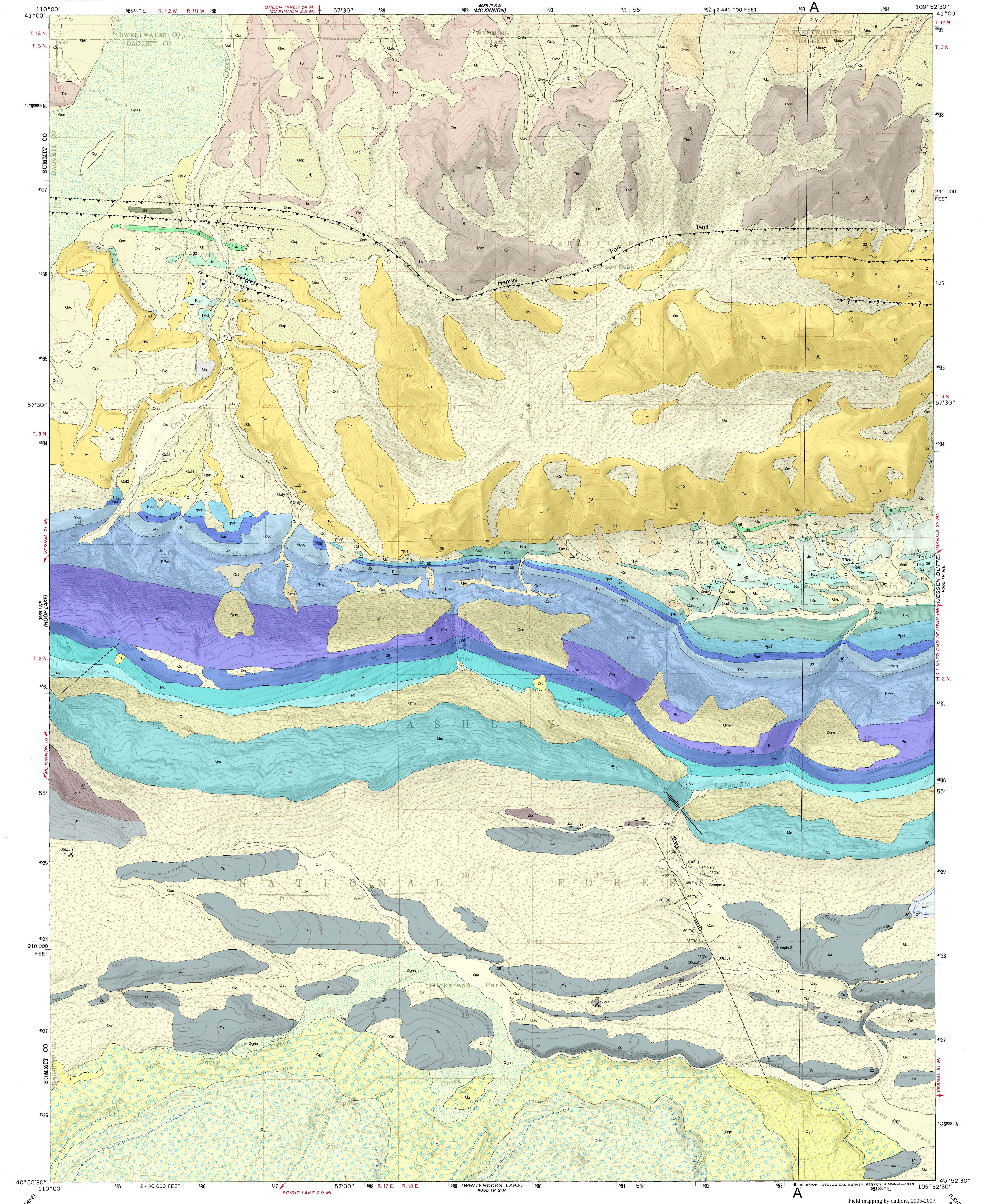
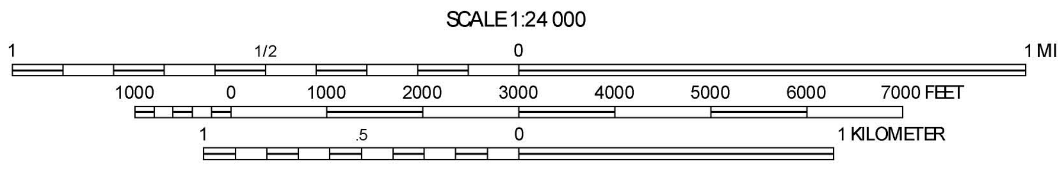
Plate 1
Utah Geological Survey Miscellaneous Publication 07-?
Geologic Map of the Phil Pico Mtn. Quadrangle



Field mapping by authors, 2005-2007.
GIS Analyst, Kent D. Brown, Utah Geological Survey, 2007.

Basemap from U.S. Geological Survey
Phil Pico Mountain 7.5' Quadrangle, 2001
Base map datum is NAD 1927.



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GEOLOGIC MAP OF THE PHIL PICO MTN. QUADRANGLE
DAGGETT COUNTY, UTAH AND SWEETWATER COUNTY, WYOMING

by
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2008

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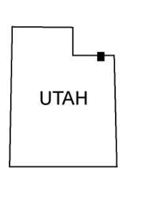
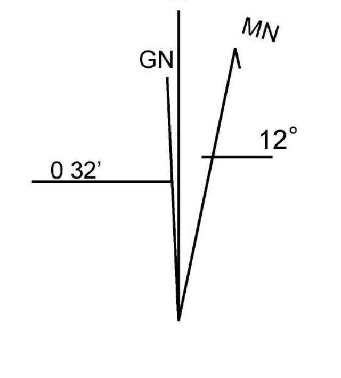




Utah Geological Survey
a division of
Utah Department of Natural Resources
in cooperation with
Brigham Young University Department of Geological Sciences

Plate II
Utah Geological Survey Miscellaneous Publication 07-?
Geologic Map of the Phil Pico Mtn. Quadrangle

DESCRIPTION OF MAP UNITS

QUATERNARY DEPOSITS

Qh	**Disturbed Ground (Historical) –** Abandoned quarry near Birch Creek that is currently used as a landfill.
Qal	**Alluvial stream deposits (Holocene) –** Unconsolidated clay, silt, and sand, gravel, and cobbles in modern streams and rivers; sediment size and composition are largely controlled by drainage area lithology ; less than 15 meters thick.
Qal_2	**Older alluvial stream deposits (Holocene) –** Unconsolidated clay, silt, sand, gravel, and cobbles deposited 2-3 meters above modern stream level; sediment is from within the drainage area of the stream; less than 10 meters thick.
Qac	**Mixed alluvium and colluvium (Holocene and Pleistocene) –** Unconsolidated clay, silt, sand, gravel, cobbles, and boulders within or along intermittent and small stream channels; includes gravity slope deposits, residual deposits and regolith, generally poorly to moderately sorted; less than 10 m thick.
Qat_2 Qat_3 Qat_4 Qat_5	**Alluvial terrace deposits (Quaternary) –** Unconsolidated, moderately to poorly sorted, silt, sand, and cobbles overlying river-cut terraces at the mouth of Birch Creek Canyon; composed of sediment derived from Birch Creek Canyon; Qat2 terrace is 7 meters above current stream channel; Qat3 is 14 meters above current stream channel; Qat4 terrace is 21 meters above current stream channel; Qat5 terrace is 28 meters above current stream channel; deposits generally less than 2 meters thick.
Qap	**Piedmont alluvium (Holocene and Pleistocene) –** Unconsolidated, poorly to moderately sorted boulders, cobbles, sand, silt and clay; form a thin layer on pediment and terrace surfaces; less than 4 meters thick
Qaf	**Alluvial-fan deposits (Holocene) –** Poorly sorted, unconsolidated, boulder, gravel, sand, and silt; less than 30 m thick.
Qafy	**Young alluvial-fan deposits (Holocene) –** Poorly sorted, unconsolidated, boulder, gravel, sand, and silt; less than 30 m thick.
Qafo	**Older alluvial-fan deposits (Holocene and Pleistocene) –** Poorly sorted, unconsolidated, boulder, gravel, sand, silt, and clay; less than 30 m thick.
Qc	**Colluvium –** Gravity slope deposits including residual deposits and regolith, poorly sorted, unconsolidated, boulders, cobbles, gravel, silt, and clay; grain size and composition are largely controlled by source area lithology, boulders, cobbles, and gravel are dominant where derived from resistant local sources; sand, silt, and clay sized particles are dominant where derived from less resistant fine-grained local sources; 0.5-7 meters thick.
Qcm	**Mixed mass movement and colluvial deposits –** Gravity slope deposits, including mass movement, residual deposits and regolith, poorly sorted, unconsolidated, boulders, cobbles, gravel, silt, and clay; grain size and composition largely controlled by source area lithology, boulders, cobbles, and gravel are dominant where derived from resistant local sources; sand, silt, and clay sized particles are dominant where derived from less resistant fine-grained local sources; 0.5-40 meters thick.
Qms Qmsy	**Mass movement deposits (Holocene and Pleistocene) –** Poorly sorted, unconsolidated slump and landslide deposits, generally boulder, gravel, sand, silt, and clay; grain size and composition largely controlled by source area lithology; Qmsy (Holocene) – Younger mass movement deposits.
Qs	**Spring deposits (Holocene) –** Unconsolidated, moderately well sorted, clay, silt, and sand, generally locally derived weather rock material.
Qsm	**Spring marsh deposits –** Unconsolidated, moderately well sorted, organic-rich, clay, silt, and sand; generally locally derived weather rock material.
Qn	**Nivation deposits (Pleistocene) –** Unconsolidated, locally derived, poorly sorted, angular to rounded boulders, cobbles, and pebbles within nivation hollows on top of Phil Pico Mountain.
Qg	**Glacial till, Undivided (Pleistocene) –** Unconsolidated, poorly sorted, angular to rounded boulders, cobbles, pebbles, and sand; clasts are dominantly dark red sandstone and red and purple quartzite; age of glaciation unknown; 1-50 m thick.
Qgs	**Smiths Fork Till (Upper Pleistocene) –** Unconsolidated, poorly sorted, angular to rounded boulders, cobbles, pebbles, and sand; clasts are dominantly dark red sandstone and red and purple quartzite; topography is rugged, moraine crests are generally narrow and steep, kettles are abundant, little or no soil formation; Smiths Fork Till correlated to the Pinedale Glaciation (24 to 12 ka BP) by Laabs & Carson (2005); less than 50 m thick.
Qgb	**Blacks Fork Till (Middle Pleistocene) –** Unconsolidated, poorly sorted, angular to rounded boulders, cobbles, pebbles, and sand; clasts are dominantly dark red sandstone and red and purple quartzite; topography is generally hummocky with low ridges, discontinuous moraine crests, and occasional kettles, well-developed soils; Blacks Fork Till correlated to Bull Lake Glaciation (186 to 128 ka BP) by Laabs & Carson (2005); less than 50 m thick.
Qgo	**Pre-Blacks Fork Till (Middle Pleistocene) –** Unconsolidated, poorly sorted, angular to rounded boulders, cobbles, pebbles, and sand; clasts are dominantly dark red sandstone and red and purple quartzite; topography is subdued but slightly hummocky with no recognizable moraine crests or kettles, thick soil formation; pre-Blacks Fork Till correlated to pre-Bull Lake Glaciation (659 to 620 ka BP?) by Munroe (2001); less than 50 m thick.
Qga	**Glacial Outwash, Undivided (Pleistocene) –** Unconsolidated, well-rounded, moderately sorted cobbles, pebbles, sand, silt, and clay; clasts are dominantly dark red sandstone and red and purple quartzite; deposited by the meltwater of glaciers of undetermined age; less than 20 m thick.
Qgas	**Smiths Fork Outwash (Upper Pleistocene) –** Unconsolidated, well-rounded, moderately sorted cobbles, pebbles, sand, silt, and clay; clasts are dominantly dark red sandstone and red and purple quartzite; deposited by the meltwater of Smiths Fork-age glaciers; less than 20 m thick.

EOCENE ROCKS

Tbr	**Bridger Formation (Middle to Late Eocene) –** Variegated red, gray, light green, and yellow siltstone, red, green, grayish, and light brown mudstone, occasional light-gray limestone, tan, medium- to coarse-grained sandstone and light gray to tan conglomerate; generally coarsens upward; 0-500 m thick.
Tbrc	**Bridger Formation conglomeratic facies (Middle to Late Eocene) –** Light gray to tan, thick bedded, pebble to boulder conglomerate, conglomerate clasts are subangular to subrounded, poorly sorted, clasts are dominated by gray Paleozoic limestones (~60%), well-cemented yellow sandstone (~15%), and dark red and purple sandstone and quartzite (5-30%); 0-470 m thick.
Tg	**Green River Formation (Early to Middle Eocene)** – (not exposed) – Light to medium gray, and light to medium brown, limestone, dolomite, and sandy limestone, and white, orange, gray and greenish, moderately to poorly sorted, calcite- to pyrite-cemented sandstone, occasional thin pebble conglomerate layers; upper part interfingers with the overlying Bridger Formation, and the lower part interfingers with underlying Wasatch Formation; thickness from well is 387 m, (description from well log of Carson Peak Unit 1 well).
Tw	**Wasatch Formation (Early Eocene and Paleocene [?]) –** Yellow, orange, and gray conglomerate, sandstone, siltstone, and mudstone; sandstone is friable to well-cemented and fine- to very coarse-grained, conglomerate clasts are pebble to boulder sized and principally consist of gray limestone (Paleozoic), yellow well-cemented sandstone, and chert. Phil Pico Mountain is principally composed of a conglomeratic facies about 400 m thick, consisting of cobble to boulder petromict conglomerate and some interbeds of very coarse-grained yellowish sandstone. General clast composition of the conglomeratic facies on of Phil Pico Mtn is ~ 65% gray limestone, 10% yellow sandstone, 7% red sandstone, 7% chert, and 5% white sandstone, inverted cobble stratigraphy on Phil Pico Mtn and Carson Peak well; thickness from well is 1527 meters.

CRETACEOUS ROCKS

Kbx	**Baxter Shale (Upper Cretaceous) –** (not exposed) – Gray, soft, slope-forming calcareous shale containing numerous beds of fine-grained, ripple-marked sandstone and minor limestone; equivalent to Mancos Shale; only mapped on north flank of Uinta Mountains; 1890-2100 m thick, (description from Sprinkel, 2006).
Kf	**Frontier Sandstone (Upper Cretaceous) – (**not exposed) – Upper part resistant, light-brown to light-gray and yellow, fine-grained and ripple-marked sandstone with local petrified wood and invertebrate fossils; lower part soft, light- to dark-gray calcareous shale; locally includes minor limestone (with bivalve coquina) and coal beds in the lower part; 36-85 m thick (description from Sprinkel, 2006).
Kmr	**Mowry Shale (Upper and Lower Cretaceous) –** (not exposed) – Dark-gray, siliceous shale that weathers silver gray; contains abundant fossil fish scales and [some] disarticulated fish bones (Anderson and Kowallis, 2005); 10-75 m thick, (description from Sprinkel, 2006).
Kd	**Dakota Sandstone (Lower Cretaceous) –** (not exposed) – Upper and lower resistant, yellow and light-gray, medium- to coarse-grained sandstone beds separated by a carbonaceous shale; contains coal beds in exposures along south flank of Uinta Mountains; 15-76 m thick, (description from Sprinkel, 2006).
Kcm	**Cedar Mountain Formation (Lower Cretaceous)** – (not exposed) – Purple, gray, and greenish-gray mudstone, siltstone, minor sandstone and limestone; contains calcrete beds that weather out as carbonate nodules; 0-60 m thick, (description from Sprinkel, 2006).

JURASSIC ROCKS

Jm	**Morrison Formation (Upper Jurassic) –** Tan, poorly-sorted, pebble conglomerate and very coarse- to medium-grained sandstone; thickness of exposed section is 15 meters. Sprinkel (2006) describes Morrison Formation as soft, light-gray, olive-gray, red, and light-purple shale, claystone, siltstone, and minor cross-bedded sandstone, conglomerate, and bentonite; 90-287 m thick.
Js	**Stump Formation (Upper Jurassic) –** Light brownish-gray limestone (oolitic in places), greenish-gray thinly bedded limestone, light brown and yellowish medium-grained ripple-laminated sandstone and light gray to greenish-gray shale; sandstone pinches and swells in places, shale is found near the top of the formation, bivalve packstone and wavy algal laminations are found near the base, limestone is muddy and laminated in places; 63-91 m thick.
Je	**Entrada Sandstone (Middle Jurassic) –** Upper section is reddish-orange fine-grained sandstone and reddish-brown mudstone and siltstone, lower part is light-gray, pink, and light-brown sandstone; lower sandstone is more resistant but still a slope former, the Entrada Sandstone is almost always covered within the quadrangle; thickness at exposed location is 50 m .
Jc	**Carmel Formation (Middle Jurassic) –** Red and yellow mudstone, light brown to gray limestone, brown to yellow sandstone, and finely bedded sandy limestone; upper part is slope-forming red and yellow mudstone and siltstone, lower part is brownish-gray, light gray and reddish-brown limestone, tan siltstone and thinly bedded brownish-orange medium- to coarse-grained sandstone, limestone is oolitic and fossiliferous in places; 87-126 m thick.
Jn	**Nugget Sandstone (Lower Jurassic) –** Light gray to light tan, fine-grained, well rounded, well sorted, and cross-bedded sandstone; sandstone is thick bedded and somewhat friable; generally forms ledges; 234-270 m thick.

TRIASSIC ROCKS

TRcu	**Upper Chinle Formation (Upper Triassic) –** Light tan and green, fine-grained sandstone interbedded with red, light green, pink, and purple siltstone and greenish-brown limey siltstone, blocky reddish-orange silty mudstone, and purple and green mudstone, sandstone is ripple laminated in places; 51-60 m thick.
TRcl	**Chinle Formation (Upper Triassic) –** Red, purple, yellow, and orange mudstone and silty mudstone, base is resistant 0.5 to 3 meter medium- to very coarse-grained poorly sorted purplish channelized sandstone possibly correlative with the Gartra Member; 71-75 m thick.
TRm	**Moenkopi Formation (Lower Triassic) –** Medium to dark red, and dark reddish-orange interbedded siltstone, mudstone, and thinly bedded fine-grained sandstone, some ripple laminations and rip up clasts; mostly slope-forming; 230-254 m thick.
TRd	**Dinwoody Formation (Lower Triassic) –** Light gray to light brown and greenish-gray, shale, siltstone, and fine-grained thinly bedded micaceous sandstone with minor amounts of limestone; mostly slope-forming; 90-182 m thick.

PERMIAN ROCKS

Ppcf	**Franson Member of Park City Formation (Lower Permian) –** Resistant gray cherty limestone and gray dolomite interbedded with fine-grained light tan to gray sandstone and minor amounts of gray, green, and red shale; silica-rich fossil hash interbedded with sandy dolomitic layers occur near the top of this member; 52-64 m thick.
Ppm	**Meade Peak Phosphatic Shale Member of the Phosphoria Formation (Lower Permian) –** Slope-forming, dark gray phosphatic and red to ochre shale with interbeds of sandstone and limestone; 34-42 m thick.
Ppcg	**Grandeur Member of Park City Formation (Lower Permian) –** Resistant light-gray, light tan and brownish-gray limestone, dolomite, and sandstone; undulatory contact with Weber Sandstone; 64-78 m thick.
PPw	**Weber Sandstone (Lower Permian to Middle Pennsylvanian) –** Yellowish-gray fine- to medium-grained sandstone, a few thin limestone and dolomite beds occur in the lower section, sandstone is thick bedded to massive and commonly cross-bedded, cliff forming in places; 309-365 m thick.

PENNSYLVANIAN ROCKS

Pm	**Morgan Formation (Middle Pennsylvanian) –** Red, light gray and purple fine-grained sandstone, red, gray, and light tan shale and siltstone, and gray to lavender limestone; limestone is fossiliferous and cherty in places; 152 -285 m thick.
Prv	**Round Valley Limestone (Lower Pennsylvanian) –** Light gray limestone with some interbeds of red shale; limestone is fossiliferous and cherty in places; chert is gray, yellowish, and red, forms ledges and cliffs; 85-136 m thick.
Md	**Doughnut Shale (Upper Mississippian) –** Dark gray shale, and a few thin beds of limestone and sandstone, red shale is found in the lower section; slope forming and generally poorly exposed; 52-106 m thick.

MISSISSIPPIAN ROCKS

Mh	**Humbug Formation (Upper Mississippian) –** Light gray to yellow to red fine-grained sandstone interbedded with purple, gray, and light tan muddy limestone, light gray micritic limestone and red to light gray mudstone and shale; sandstone is red near top of formation; slope former, poorly exposed; 90-116 m thick.
Mm	**Madison Limestone (Lower Mississippian) –** Gray limestone; chert abundant in some layers, chert is typically light gray, contains some small caves and alcoves; 282-335 m thick.

PROTEROZOIC ROCKS

Zur	**Red Pine Shale, Uinta Mountain Group (Middle Upper Proterozoic) –** Maroon, green and green-gray shale interbedded with fine-grained light green sandstone and siltstone and fine- to very coarse-grained light purple and buff to orange, feldspar-rich sandstone, sandstone is thick to thin bedded, cross-bedded, and siliceous. Sand interbeds increase toward the base and are up to 20 meters thick. Section measured near western quadrangle boundary, apparently becomes more sand-rich toward the east, generally slope forming and poorly exposed; 553 meters thick near western quadrangle boundary, thickness toward east is unknown.
Zu Zuf	**Uinta Mountain Group, Undivided (Middle Upper Proterozoic) –** Light orange and light purple medium- to very coarse-grained, feldspar-rich sandstone interbedded with light green, green-gray, maroon, and dark gray shale; sandstone is thick to medium bedded with cross-bedding in places; sandstone thickness increases and shale interbeds decrease toward base, shale interbeds are up to 60 meters thick, palynomorphs recovered from dark-gray shale at four locations; over 1400 m thick.
water	**Long Park Reservoir**

GEOLOGIC SYMBOLS

Contact -- dashed where approximated

Fault -- dashed where approximately located; dotted where concealed; high-angle reverse or thrust fault – teeth on upthrown side; strike-slip-- arrows show component of strike-slip movement

Glacial Moraine Crest

Water - Long Park Reservoir

A———A'
Cross-section line

25 Inclined, 65 Overturned, Vertical
Strike and Dip of Bedding

Well location - dry and abandoned

Sample location - for palynology

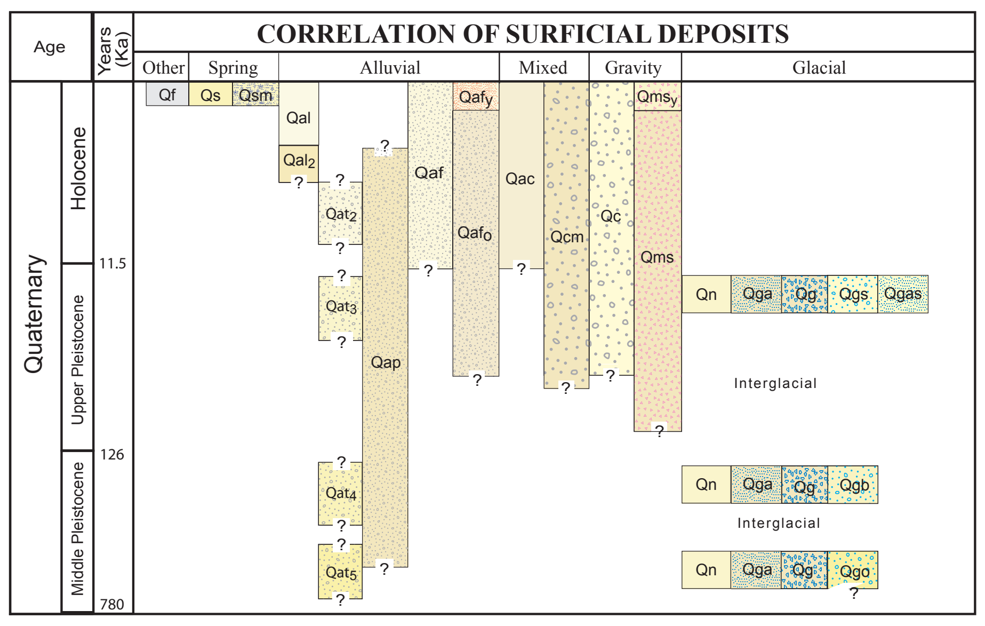
Shale quarry

ROADS AND TRAILS

Paved or improved dirt road

Unimproved dirt road;
4WD = four-wheel drive

CORRELATION OF SURFICIAL DEPOSITS



Well Used in Cross-Section

(tops picked by A.D. Anderson)

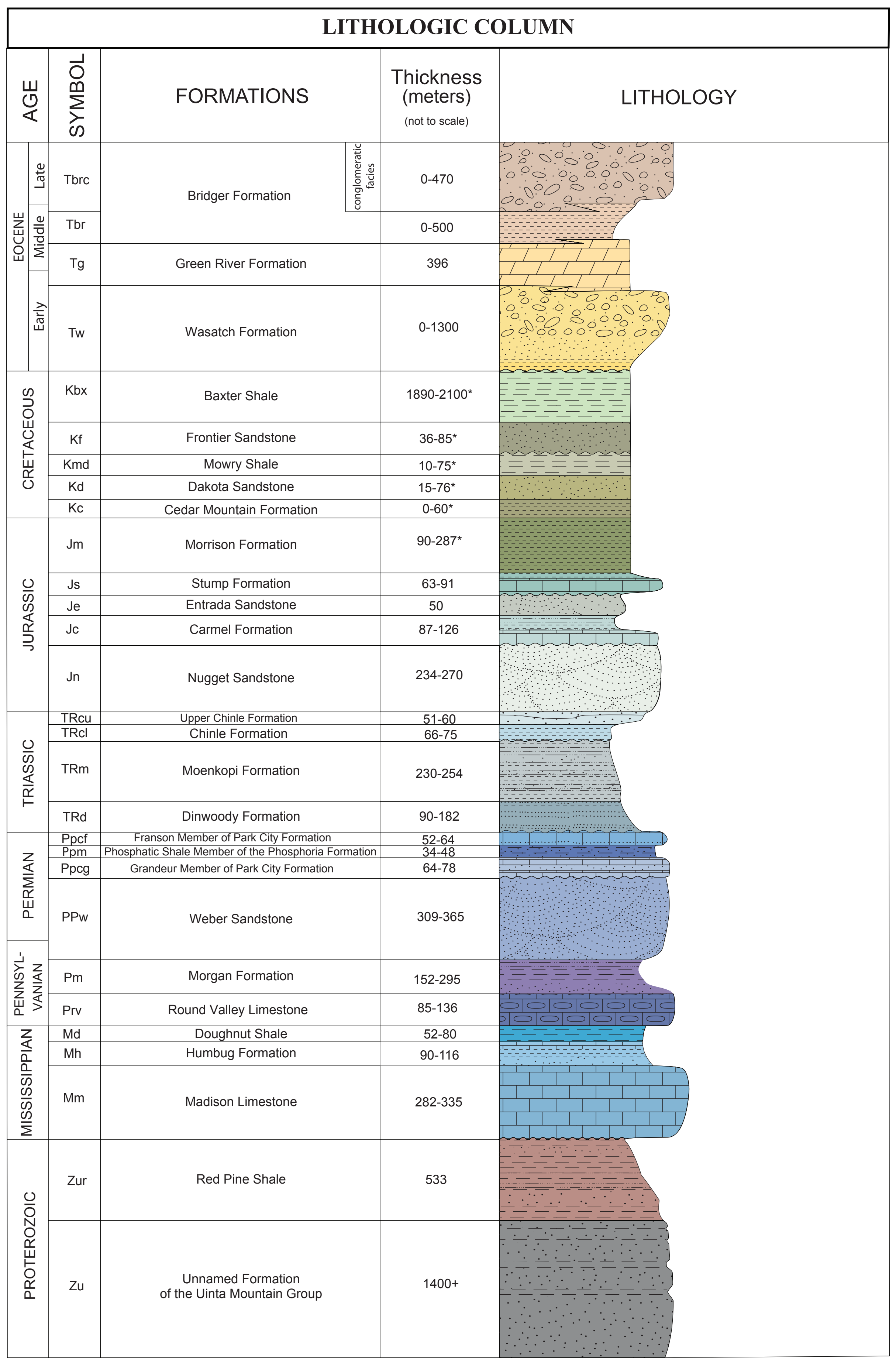
Cross Section	Well Information	Formation	Top (m)	Thick (m)	Top (ft)	Thick (ft)
A - A'	Carter Oil Company	Bridger Formation	0	521	0	1710
	Carson Peak Unit 1	Green River Formation	521	387	1710	1270
	NE1/4NE1/4 section	Wasatch Formation	908	1527	2980	5010
	22, T.3N., R.18E.	Fort Union Formation	2435	914	7990	3000
	Daggett County, Utah	Total Depth	3350		10990	

Palynology Analysis

(analysis by Gerald Waanders, Consulting Palynologist)

Sample number	Formation	Age	Microfossils	UTM
1	UMG	Mesoproterozoic to Early Neoproterozoic	Leiosphaeridia spp., Algal? filament fragments, Other assorted algal? cellular debris	4527313 N 595505 E
2	UMG	Mesoproterozoic to Early Neoproterozoic	Leiosphaeridia spp., Algal? filament fragments, Other assorted algal? cellular debris	4528074 N 592860 E
3	Red Pine Shale ?	Early Neoproterozoic	Granulate sphaeromorphs, Leiosphaeridia spp., Trachysphaeridium laminaritum, Algal? filament fragments, Other assorted algal? cellular debris	4528869 N 592042 E
4	Red Pine Shale ?	Early Neoproterozoic	Leiosphaeridia spp., Trachysphaeridium laminaritum, Algal? Filament fragments, Other assorted algal? cellular debris	4528839 N 592082 E
5a	Bridger Formation	Early Eocene	Abies spp., Betula sp., Carya veripites, Deltoidospora spp., Gleicheniidites sp., Juglans spp., Kurzipites sp., Laevigatosporites sp., Momipites coryloides, Momipites tenuipolus, Picea spp., Pinus spp., Psilatricolpites sp., Taxodiaceae, Tsuga spp.	4539664 N 586930 E
5b	Bridger Formation	Indeterminate	Araucariacites australis, Lycospora sp. (recycled Pz), Taxodiaceae	4539664 N 586930 E

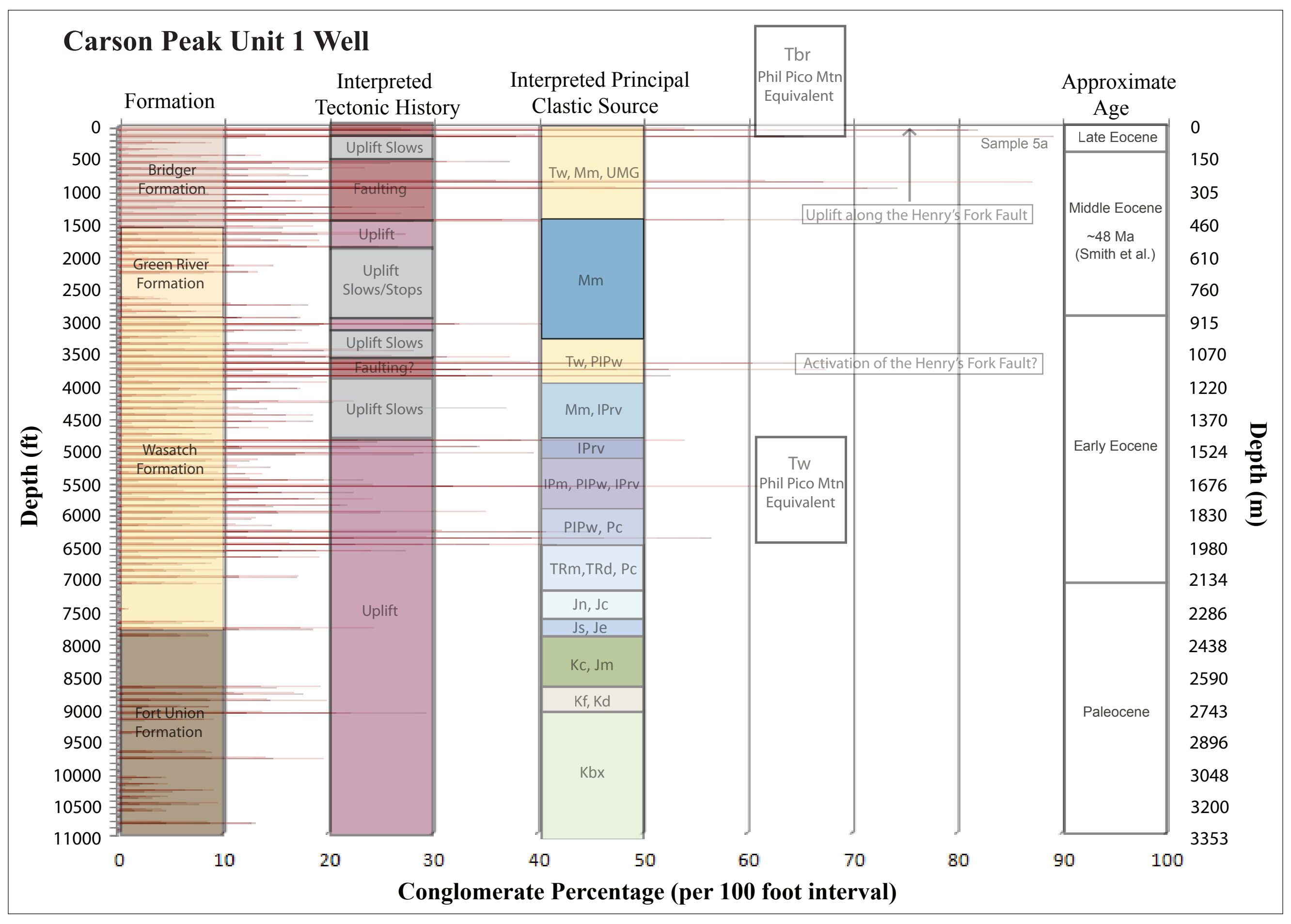
LITHOLOGIC COLUMN



AGE		SYMBOL	FORMATIONS	Thickness (meters) (not to scale)
EOCENE	Late	Tbrc	Bridger Formation (conglomeratic facies)	0-470
	Middle	Tbr		0-500
		Tg	Green River Formation	396
	Early	Tw	Wasatch Formation	0-1300
CRETACEOUS		Kbx	Baxter Shale	1890-2100*
		Kf	Frontier Sandstone	36-85*
		Kmd	Mowry Shale	10-75*
		Kd	Dakota Sandstone	15-76*
		Kc	Cedar Mountain Formation	0-60*
JURASSIC		Jm	Morrison Formation	90-287*
		Js	Stump Formation	63-91
		Je	Entrada Sandstone	50
		Jc	Carmel Formation	87-126
		Jn	Nugget Sandstone	234-270
TRIASSIC		TRcu	Upper Chinle Formation	51-60
		TRcl	Chinle Formation	66-75
		TRm	Moenkopi Formation	230-254
		TRd	Dinwoody Formation	90-182
PERMIAN		Ppcf	Franson Member of Park City Formation	52-64
		Ppm	Phosphatic Shale Member of the Phosphoria Formation	34-48
		Ppcg	Grandeur Member of Park City Formation	64-78
		PPw	Weber Sandstone	309-365
PENNSYLVANIAN		Pm	Morgan Formation	152-295
		Prv	Round Valley Limestone	85-136
MISSISSIPPIAN		Md	Doughnut Shale	52-80
		Mh	Humbug Formation	90-116
		Mm	Madison Limestone	282-335
PROTEROZOIC		Zur	Red Pine Shale	533
		Zu	Unnamed Formation of the Uinta Mountain Group	1400+

* Covered or mostly covered in quadrangle, thicknesses are from Sprinkel (2006).

Carson Peak Unit 1 Well



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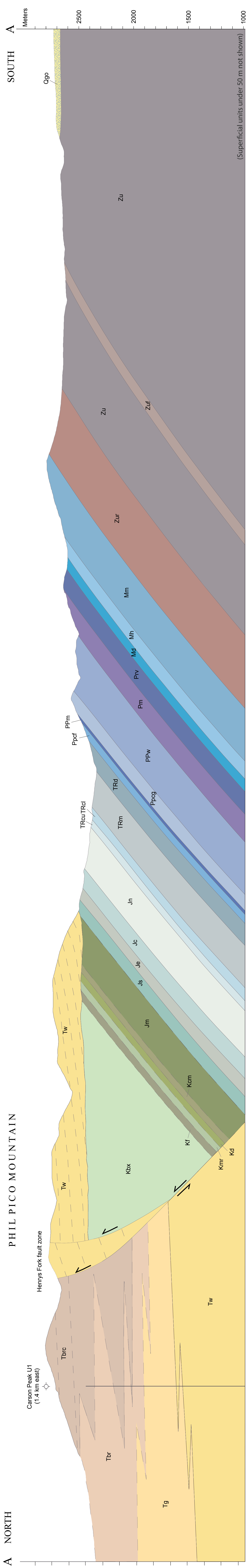

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