Text and references accompanying Nevada Bureau of Mines and Geology Map 177

Geology Map of the Ute Quadrangle, Clark County, Nevada

by

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INTRODUCTION

The Ute 7.5' quadrangle contains a sedimentary and tectonic history that spans from Paleozoic to latest Holocene. The oldest rocks are exposed in the southeastern part of the quadrangle, which includes a small portion of the North Muddy Mountains. There, Mississippian to Triassic marine carbonate and terrestrial rocks that were strongly deformed by thrusting related to the dominantly Cretaceous-age Sevier orogeny dip steeply and form hogbacks and intervening valleys. The rest of the quadrangle is a valley drained by the California Wash. Gravity and seismic reflection studies indicate that the valley has as much as 2 km of sedimentary basin fill within it, the deepest part being just south of the quadrangle (Langenheim et al., 2001). This basin, called the California Wash basin by Langenheim et al. (2001), was created in the early to middle Miocene and filled with Miocene to Pliocene sediments, including lacustrine deposits. Following the basin filling, the base level was lowered and gravel-rich alluvium prograded out into the basin, forming a pediment and armoring the softer Tertiary basin fill, especially where petrocalcic horizons were formed. The valley appears to have had very little base level change during and following deposition of these conglomerates until early to middle Pleistocene, when downcutting between alluvial surfaces increased.

A Miocene through latest Quaternary fault, called the California Wash fault, separates the older rocks and structures from the basin deposits, and was one of the main faults responsible for the development of the California Wash basin. The California Wash fault is a west-side down, normal dip-slip fault that bounds the western side of the North Muddy Mountains. This fault developed in the Miocene, was reactivated in the Pliocene and Quaternary and is one of the most important seismic hazards in southern Nevada.

The Ute quadrangle is made up mostly of piedmonts flanking the California Wash, small hills, and a small portion of the North Muddy Mountains in the southeast corner. Elevations range from 480 m (1574 ft), where the California Wash exits the quadrangle on its northern side, to 850 m (2788 ft) on some mountain tops in the North Muddy Mountains. A single drainage basin extends over the Ute quadrangle. Drainages are generally in a dendritic pattern in the piedmonts and are commonly structurally and lithologically controlled where bedrock is exposed.

The quadrangle is crossed diagonally by Interstate 15 and has an active railroad line running across it. About 80% of the quadrangle is part of the Moapa River Indian Reservation and the rest is managed by the U.S. Bureau of Land Management. The Ute quadrangle is a little south of the community of Moapa and is about 72.5 km (45 mi) northeast of Las Vegas.

This report describes the stratigraphic and structural framework of the geology of the Ute quadrangle. Mapping of the quadrangle occurred between 2008 and 2011 and was sponsored the Bureau of Land Management through the Southern Nevada Public Land Management Act. This project has been a collaborative effort by the Nevada Bureau of Mines and Geology at the University of Nevada, Reno and the Department of Geoscience at the University of Nevada, Las Vegas. Permission to map on reservation land was granted by the Moapa Band of Piutes.

GEOLOGIC SETTING

Previous Work

Pioneering work was done on the Ute quadrangle by Professor Chester Longwell from Stanford University. He helped to establish and name many of the units, determined their age by gathering and identifying fossils, and recognized important geologic structures in the North Muddy Mountains and elsewhere, including thrust faults and folds related to the ~140 to 50 Ma Sevier orogeny (e.g., Longwell, 1949; Longwell et al., 1965; DeCelles, 2004). The geology of the North Muddy Mountains was further studied in detail by Bohannon (1983, 1992), and our mapping largely follows and extends to the southwest the bedrock geology of the Weiser Ridge quadrangle (mapped by Bohannon, 1992). The geology of the Glendale basin, immediately to the north of the Ute quadrangle, was mapped by Gardner (1968) and Schmidt et al. (1996). Their mapping and unit descriptions served as an excellent foundation for mapping the basin sediments in the Ute quadrangle.

Stratigraphic Framework

The general stratigraphic setting is given here. Individual formations and map units are described in the "Description of Map Units" section.

Quaternary Deposits

About 80% of the Ute quadrangle covers the California Wash valley, and thus the map is dominated by a slightly smaller, but still high percentage, of Quaternary (2.6 Ma) deposits. The California Wash crosses diagonally through the quadrangle and divides a western piedmont from an eastern piedmont within the valley. The Quaternary alluvium in the piedmonts can be further divided into three general types: older alluvium that lacks surfaces and may be related to the earliest Quaternary sedimentation, pediment/petrocalcic deposits that are also likely middle to early Quaternary, and middle Quaternary and younger alluvial, alluvial fan, and eolian deposits.

Tertiary Sediments

Tertiary deposits are sedimentary rocks related to the formation and filling of the Miocene California Wash basin and are made up of terrestrial sandstones and siltstones, lacustrine siltstones, claystones, limestones, and fluvial sandstones. The oldest of these deposits are assigned to the Horse Spring Formation, which are thought to make up the lower half of the sediments in the basin (Langenheim et al., 2001).

Tertiary sedimentary rocks are also present as patches in the exposed footwall of the California Wash fault. These are sandstones, siltstones, claystones, limestones, minor matrix-supported gravels, and a few tuffaceous layers. The sediments indicate that this was a relatively low energy inundation of the footwall with only rare gravel lenses. In many cases these sediments are colored red and yellow. In a few locations the siltstones near the upper part of these appear more like the classic peach- or light-brown-colored siltstones of the Muddy Creek Formation. Thus, these younger Tertiary sedimentary rocks may be part of the Horse Spring Formation, part of the Muddy Creek Formation, or both.

In the western North Muddy Mountains, a large deposit of megabreccia and debris flows overlies Paleozoic and Tertiary sedimentary rocks. This deposit likely accumulated in a paleovalley and is now inverted due to being more resistant than surrounding units (Rowland et al., 1985). This offers insight into the Miocene paleogeography of the western North Muddy Mountains and partly constrains relative uplift and erosion since the Miocene.

Several freshwater limestone deposits are also exposed in the footwall of the California Wash fault. These limestones have many vugs, reed casts, and possible algal structures. They may correlate with the Bitter Ridge Limestone Member of the Horse Spring Formation. Bohannon (1984) noted that Bitter Ridge Limestone Member occurs in the western Muddy Mountains to the south. These limestones are probably lacustrine in origin and may also represent an episode of spring activity. To the northwest, along the Arrow Canyon Range, Schmidt et al. (1996) mapped a limestone member of the Horse Spring Formation that appears to be in a similar setting.

Younger Miocene and Pliocene sediments continued to fill the basin until the basin-forming tectonism waned. The basin filled to the point where sediments crossed over the California Wash fault and began to accumulate in the footwall. The oldest package of sediments in this sequence was the Muddy Creek Formation, which locally has widely varied types of deposits indicating a wide range in paleoenvironments. Subaerial environments are indicated by red-bed sandstones with cross-bedding formed in dunes. Playa and basin floor environments are indicated by light-brown siltstones, claystones, and sandstones in thin semi-continuous beds. Lacustrine environments are indicated by reduced-iron, green-colored siltstones and claystones with fine layers (varves?). In some areas these different deposits are within a vertical section, whereas in other areas there are lateral variations in facies indicating adjacent different environments (e.g., sand sheets and dunes surrounding a lake). The Muddy Creek Formation usually dips gently to near horizontal unless proximal to a fault, where moderate dips are common. Deposits of the Muddy Creek Formation are faulted in several locations, including along the California Wash fault and the Hogan Spring fault zone.

The youngest Tertiary deposits are the Pliocene White Narrows marl, which have a whitish color characteristic of carbonate-rich deposits. The deposits are white, whitish-gray, light-brown, or reduced-Fe green carbonate-rich sands, silts, muds, limestones, and carbonate- and gypsum-rich marls. These deposits are fault-bound in several locations on the Ute and Moapa West quadrangles and were thought by Schmidt et al. (1996) to have been partially deposited in grabens. After the youngest deposits of the White Narrows marl were laid down, a period of erosion ensued before these deposits were buried by Quaternary gravel-conglomerate pediments.

Early Mesozoic and Late Paleozoic Sediments

The late Paleozoic and early Mesozoic rocks exposed in the Ute quadrangle are a nearly complete southern Nevada Triassic to Mississippian section, but are greatly attenuated by faulting. A wide variety of sedimentary rocks are represented from marine limestone to terrestrial eolian sandstone. The formations are largely steeply to moderately dipping and are overturned, except in the southeasternmost corner of the map, where lower structural levels are exposed and units are upright.

Table 1. Mesozoic and Paleozoic formations in the Ute quadrangle

Period	Geologic Formation	Member
Jurassic	Aztec Sandstone	(cross section only)
Triassic	Chinle Formation	Petrified Forest Member
		Shinarump Conglomerate
Triassic	Moenkopi Formation	Upper red member
		Virgin Limestone Member
		Lower red member and Timpoweap Member
Permian	Kaibab Formation	Harrisburg Member
		Fossil Mountain Member
Permian	Toroweap Formation	Woods Ranch Member
		Brady Canyon Member
		Seligman Member
Permian	Esplanade Sandstone	
Perm.-Miss.	Bird Spring Formation	
Mississippian	Monte Cristo Group	
Devonian	Sultan Limestone	(cross section only)
Ordovician	Ely Springs Dolomite	(cross section only)
Cambrian	Bonanza King Formation	(cross section only)

TECTONIC FRAMEWORK AND STRUCTURES

The tectonic episodes and structures developed in the Ute quadrangle go hand-in-hand and are easiest discussed together. There are five possible tectonic episodes that can be recognized in the geology of the Ute quadrangle. The word possible is used because some deformation may be late stage activity of the previous episode of deformation. The five episodes are:

1. Jurassic to Cretaceous Sevier folding and thrusting,
2. Cretaceous to early Tertiary (?) activity along high-angle faults within the North Muddy Mountains,
3. early Miocene to Miocene extensional activity,
4. Pliocene extension within California Wash valley, and
5. Quaternary activity along the California Wash fault.

Jurassic to Cretaceous Sevier Folding and Thrusting

Two major thrust faults were active during the Sevier orogeny in the Ute quadrangle, the Muddy Mountain and the Summit–Willow Tank thrust faults (Bohannon, 1992). Within the quadrangle, this contractional episode occurred principally during the late Jurassic and Cretaceous (Taylor et al., 2000). Contraction along these faults created folds and related faults, several of which can be observed in the North Muddy Mountains, but neither of these major thrust faults are exposed in the quadrangle. The Muddy Mountain thrust fault is buried below basin sediments and presumably some allochthonous rocks and is projected into the air above the North Muddy Mountains to the east of the California Wash fault, where it has been eroded. The Summit–Willow Tank thrust fault is projected at depth from the east using mapping and geologic reasoning from Bohannon (1992). This fault was the basal and forward thrust in the Sevier deformational belt at this latitude and underlies Paleozoic and Triassic units mapped on this quadrangle. One minor thrust fault that places Mississippian rocks over Pennsylvanian to Permian rocks is shown along cross section A–A'. The rocks exposed in the North Muddy Mountains are the upper part of a large, lower plate fold, called the Weiser syncline, which is most likely related to movement along the Muddy Mountain thrust fault (Bohannon, 1992). Most of the formations within this fold accommodated slip along bedding planes and formation contacts. These slip surfaces were formed during the folding and attenuation of these units.

Cretaceous (?) to Early Tertiary (?) Activity along High-Angle Faults within the North Muddy Mountains

A high-angle, north-northeast-striking fault zone within the North Muddy Mountains on the Ute quadrangle is a southwestern extension of a fault mapped by Bohannon (1992). Some of the faults within the Weiser syncline may also be related to this faulting episode. The zone appears to be made up of normal faults, at least one with a left-lateral strike-slip component. We infer normal motion along these faults (see cross section B–B') to explain the mapped juxtapositions of upper Paleozoic and lower Mesozoic rocks across them, within the context of the local structure. A left-lateral component is inferred on at least one fault strand based on drag folding of the distinctive Shinarump Conglomerate into the fault. A left-lateral component is also suggested by Bohannon (1992), based on geologic mapping and structural reconstructions. Our cross section B–B' also requires strike slip along some of these faults in order to be restorable. Bohannon (1992) commented that these “north-northeast-trending faults may be as young as Tertiary, but they are overlapped by Muddy Creek Formation of late Miocene age.”

Early to Late Miocene Extensional Activity

In the early to middle Miocene, extension initiated throughout the region (e.g., Bohannon et al., 1993; Beard, 1996) and locally produced the California Wash basin. Geophysical data developed by Langenheim et al. (2001) indicate that the California Wash basin is ~25 km long, ~12 km wide, and is generally 1 to ~2.5 km deep, with a long axis that trends slightly east of north-south. The steepest side of the basin is the eastern side of the deepest part. This corresponds to the California Wash fault indicating that this fault had an important role in the development of the basin. The nature of the gravity gradient along the eastern side of the basin suggests a downward increase in dip of the California Wash fault or a second basin-forming fault to the west, buried within the basin (Langenheim et al., 2001).

Some faults within the western part of the North Muddy Mountains may have also accommodated normal displacement during the Miocene basin-forming episode (cross section B–B'). There are some small normal offsets of the base of the Tertiary debris flows and megabreccia (near the southeastern corner of the quadrangle) indicating that some Cenozoic activity occurred along some intraformational faults within the mountains.

A detailed study of the California Wash basin has not been fully developed and documented, but the development of the basin is likely similar to the general tectonic histories for basins in the region (e.g., Bohannon et al., 1993; Schmidt et al., 1996). The earliest extensional deformation that Bohannon et al. (1993) recognized in the Virgin River area was a slow subsidence between 24 and 13 Ma. This was followed by a period of more rapid extension, and two distinct basins were produced when extension was focused on a few faults. Schmidt et al. (1996) noted that the Horse Spring Formation was a "synextensional basin-fill deposit that formed during the opening and subsidence of the Glendale basin" and reported that at least 823 m of Horse Spring Formation sedimentary rocks (13–19 Ma; Beard, 1996; Castor et al., 2000) were encountered in the lower part of drill hole EH-2A within the Glendale basin. Within the California Wash basin, Langenheim et al. (2001) recognized two sedimentary packages using gravity and seismic reflection data and correlated the lower package with the sedimentary rocks from the Horse Spring Formation. Whether the California Wash basin shares the same history as the Virgin River depression or more resembles the history of the Glendale basin is not known, but the latter may be indicated by the large thickness of inferred Horse Spring Formation deposits by Langenheim et al. (2001).

Miocene extension seems to have waned or stopped in California Wash valley during the deposition of the Muddy Creek Formation (late Miocene), which allowed sediments to prograde eastward across the California Wash fault and accumulate on the western flank of the North Muddy Mountains.

Pliocene Extension within California Wash Valley

North of the Ute quadrangle, the White Narrows marl was largely deposited within grabens containing the Muddy Creek Formation along the Hogan Spring fault zone (Schmidt et al., 1996). One of these grabens continues south into the Ute quadrangle. Schmidt et al. (1996) noted that in places the White Narrows marl is made up of sediments eroded from the Muddy Creek Formation. These observations are consistent with some extension following the deposition of the Muddy Creek Formation and during the deposition of the White Narrows marl, ~4–5 Ma (Schmidt et al., 1996). The eastern side of the graben on the Ute quadrangle is the northern part of the California Wash fault, and White Narrows marl deposits are absent in the footwall of the California Wash fault. Although the White Narrows marl deposits have some gravel stringers close to the California Wash fault, they are dominated by sandstones and siltstones.

The grabens to the north approximately correspond to the deeper parts of the Glendale basin (Schmidt et al., 1996; Langenheim et al., 2001), but are a narrower zone of deformation than the initial basin-forming episode. It is unknown whether this same style of deformation might continue to the south and be related to the California Wash basin, but the upper parts of the White Narrows marl are more widely distributed in this area.

Quaternary Activity along the California Wash Fault

Reactivation of the California Wash fault in the Quaternary induced rejuvenation of the North Muddy Mountains western range front, disrupted a piedmont that had built across the fault, and focused late Quaternary alluvial fan deposition along its immediate hanging wall. The fault has accommodated surface-rupturing earthquake events, the most recent of which is late Holocene.

The California Wash fault was named by Bohannon (1983), who mapped the fault crossing a Quaternary piedmont. The fault was mapped in its entirety at a scale of 1:250,000 by Dohrenwend et al. (1991) and was studied as a potential seismic hazard by Anderson and O'Connell (1993), who suggested that the youngest event was Holocene based on scarp morphology and that the most recent event had 2.1 m of apparent displacement of young fan alluvium. Anderson and O'Connell (1993) also recognized higher older alluvial surfaces that were offset by the fault indicating recurrent late Quaternary movement.

The Quaternary California Wash fault is approximately 28–32 km long, strikes north to northeast, and has a major normal dip-slip component and locally a possible left-lateral component. Fault dips exposed in stream-channel walls range from 50° to 85°W. The California Wash fault and other associated secondary faults in the zone form the western side of the North Muddy Mountains and the Muddy Mountains to the south and form the eastern side of the California Wash valley. The fault appears to be distributed at both ends with parallel, overlapping fault strands and is a more singular structure along the central portion, essentially the part that is opposite the deeper California Wash basin. This central portion can be divided into two sections, where the fault has a slight change in strike and some small secondary faults are exposed. Zaragoza et al. (2005) identified this as a right step in the fault and suggest that this indicates a linkage between two fault segments. Reconnaissance field observations indicate that the most recent event ruptured the entire California Wash fault, with the largest offsets in the area of the deepest part of the basin. The fault has spectacular Quaternary fault geomorphology, including nearly continuous, single-event and compound, alluvial and bedrock fault scarps that are from 0.5 to approximately 10 m in height.

On the Ute quadrangle, the California Wash fault has three different sections, each with its own structural character. The southern part has a N18°E strike and is a relatively straight, single fault trace, with small right steps within it. This portion may have a left-lateral component as well as normal displacement. This section of the fault forms a remarkable boundary between the North Muddy Mountains and its western piedmont. The fault bifurcates near 36° 32.5' latitude, with the dominant Quaternary activity occurring along the northerly striking trace bounding the western side of a small set of hills with uplifted Qoa in them. This is a 5.5-km-long, north-striking section with a complex set of grabens that are as much as 1.8 km wide and extend a total of 8 km along the fault (they extend southward into the straight, northeast-striking section and a little to the north as well). A shallower dip along the California Wash fault over this section may be responsible for these grabens. In addition to the grabens are a set of closely spaced, subparallel, normal faults with small amounts of Quaternary offset along them in the uplifted hills of Qoa (in the footwall of the main Quaternary fault trace).

The northern part of the fault in the quadrangle becomes poorly defined and is less understood. This section of the fault begins near the Byron exit along Interstate 15 and includes two uplifted areas: in one case a horst on the east side of the fault and in the other a tilted block (?) on the west side of the fault. Although fault traces could be found in some of the gullies along this inferred section of the fault, the confidence that all the fault traces that exist have been discovered and that the main fault trace has been identified in this area are low. The northern part of the fault overlaps with the southernmost part of the Hogan Spring fault zone, which is exposed a little over 3 km to the west. There appears to be some late Quaternary activity along the southernmost part of the Hogan Spring fault zone based on scarp morphology, even though it is generally mapped in older deposits (e.g., Schmidt et al., 1996). Thus, it is likely that there is some interaction between the California Wash fault and the Hogan Spring fault zone and that this interaction is responsible for the different character of the California Wash fault where the two faults overlap. It is also possible that the Hogan Spring fault zone has some structural influence on the central section of the California Wash fault that has grabens parallel to the fault.

Early in the deposition of the Qoa unit, or perhaps even inducing the deposition of the gravelly mudstones and conglomerates of Qoa, the modern episode of activity along the California Wash fault began, or accelerated, along with the relative uplift of the North Muddy and Muddy Mountains. Extensional activity along the California Wash fault had apparently waned in the late Miocene, allowing the relatively fine-grained Muddy Creek Formation deposits to fill the basin and prograde eastward across the fault and onto the flank of the North Muddy Mountains. There was likely some Pliocene activity along the California Wash fault during deposition of the White Narrows marl as well, but the sedimentary signal for renewed uplift of the North Muddy Mountains comes at the base of the Qoa, where debris flows with a matrix made up of eroded Muddy Creek Formation sediments were shed westward, followed by gravelly conglomerate deposition into California Wash valley.

In the area at about 36° 32.5' latitude, reconnaissance measurements were made of vertical offsets of different surfaces across the California Wash fault. The oldest record from the modern episode of movement is an approximate 46 to 60 m of vertical offset of a Qk surface across the California Wash fault zone, north of the Weiser Mine road. South of the road, there is about 16 to 20 m of apparent vertical offset of a Qao surface across the fault, indicating that half to two-thirds of the total modern offset occurred between the formation of Qk and the Qao surface.

Well-formed tectonic terraces in the footwall of the California Wash fault indicate that the fault likely accommodates movement with groups of earthquakes clustered in time. There is minimal relief between units of different ages in the piedmont formed on the hanging wall of the California Wash fault, indicating that climatic terrace formation along this part of the California Wash fault was small. Thus, the relief between terraces in the footwall of the California Wash fault is mostly generated by fault movement. The most recent cluster of earthquakes began following the deposition of Qayo; three events were interpreted to have occurred since a calendar-corrected ~16 ka radiocarbon date (Zaragoza et al., 2005) of a footwall unit exposed below colluvial wedges related to recent earthquakes. These events resulted in a total vertical offset of about 3.4 m. The next highest terrace widespread in the footwall is the Qai surface with a vertical offset of about 7 m, which is about twice the offset of the Qayo. A similar group of earthquakes clustered in time likely isolated the Qai surface with approximately 3.5 m vertical offset, and this was subsequently offset to a total of 7 m with the displacement of the more recent events.

With a potential length of about 30 km and a single-event displacement of at least 2.1 m, a significant earthquake hazard is indicated for the California Wash fault. Using the Wells and Coppersmith (1994) magnitude-versus-length and magnitude-versus-displacement scaling relationships, these surface offset parameters correlate with earthquakes of moment magnitude 6.8 to 6.9. Although there are several ways to distribute the three paleoearthquakes over the last ~16 ky and come up with different interseismic intervals, they are all on the order of a few to several thousand years. Considering the potential ages of offset units, it is likely that the intra-cluster time intervals (10s to 100s of ky) are much longer than the episodes of clustered earthquakes (10s ky). Based on available data, it is not possible to determine whether the California Wash fault has completed its contemporary earthquake cluster cycle or whether events will continue as part of this cluster. Thus, the California Wash fault should be considered a significant potential earthquake hazard in southern Nevada.

There may be a left-lateral component along the southern portion of the fault on the Ute quadrangle, where it strikes north-northeast. This part of the fault is remarkably straight overall and appears to be steeply dipping. In detail, it is made up of several northerly striking, right-stepping fault scarps, and some micro-drainages have been noted to have possible small left lateral offsets. However, other left-lateral offsets of larger drainages and deposits crossing the fault have not been observed, so there is uncertainty in this component.

GEOLOGIC HISTORY

A brief geologic history and context is given in this section for the deposits and important events recorded in the Ute quadrangle. The oldest rocks in the quadrangle presumably are buried below the California Wash basin in the hanging wall of the Muddy Mountain thrust fault. These rocks have been eroded off the top of the North Muddy Mountains, and would have resided above the Muddy Mountains thrust fault (Bohannon, 1992). These older rocks are likely the Bonanza King Formation (Upper and Middle Cambrian), which is exposed in the Muddy Mountains and Arrow Canyon Range (which bounds the western side of California Wash valley), the Ely Springs Dolomite (Upper Ordovician), and the Sultan Limestone (Lower Mississippian to Middle Devonian); the latter two are exposed in mountains to the north and the south of the Ute quadrangle.

In middle and late Paleozoic a foreland basin formed in eastern Nevada related to the Antler orogeny (Stewart, 1980). A westward-prograding carbonate shelf built into this region from the east in Mississippian time, and the limestone from the Monte Cristo Group (?) was deposited in this environment. In the Ute quadrangle, there is only a relict of what is likely Monte Cristo Group limestone in a westernmost faulted sliver in the western North Muddy Mountains. These deposits are highly distorted with small faults and stylolites but still have identifiable bedding planes. The rocks are made up of small fragments of shell fossils, which is consistent with a shelf environment.

After the carbonate shelf was built, shallow-marine limestones and sandstones were deposited during the Pennsylvanian and early Permian (Longwell et al. 1965; Stewart, 1980). Locally, these deposits are the Bird Spring Formation, which is made up of thin to medium-thick limestone, sandy limestone, and sandstone beds. This formation is made up of thousands of small and medium thickness, semi-continuous, parallel beds. The Bird Spring Formation on the Ute quadrangle is fault-bounded, internally faulted, and appears to have had its thickness tectonically attenuated. The upper and lower parts are more limestone rich and appear as ridges in the North Muddy Mountains foothills. The middle portion is more cherty and siliciclastic, and varnishes significantly more than the upper and lower parts, making it notably darker in outcrop.

Sediments eroding from the North American craton built out westward during the early Permian into a terrestrial environment (Stewart, 1980). The Esplanade Sandstone and the Seligman Member of the Toroweap Formation were part of this event. These units are made up of fine and very fine sands that commonly have dune cross-bed structures. These deposits were referred to as “Permian red beds” by Longwell et al. (1965), and the equivalent deposits in western Arizona were called the Queantoweap Sandstone by McNair (1951). The oxidized red and ocher colors and dune structures support a terrestrial setting for these sedimentary rocks. Rare limestone beds within the Esplanade Sandstone indicate an occasional marine inundation of this low, sandy platform.

Shallow marine conditions returned in the early Permian. This led to the deposition of fossiliferous limestones and dolostones of the Toroweap, Kaibab, and parts of the Moenkopi Formations. The most massive limestone members locally are the Brady Canyon Member of the Toroweap Formation, which makes up most of the steep-sided California Ridge on the Ute quadrangle, and the Fossil Ridge Member, which makes up a pronounced hill in the southeastern corner of the quadrangle. The Moenkopi Formation is Lower Triassic (Longwell et al., 1965) and has many different marine facies, including limestones, claystones, and gypsum-rich claystones. Part of the clastic input for these sediments likely came from a proposed highland to the west (Stewart, 1980). This was the last inundation of the sea into southern Nevada (Longwell et al., 1965).

The lower part of the Chinle Formation is the Upper Triassic Shinarump Conglomerate, a remarkable pebble and gravel conglomerate and sandstone that covered the southwest from Colorado to Nevada (c.f., Longwell, 1928). On the Ute quadrangle, the Shinarump Conglomerate is made up of weakly stratified, pebbly gravel conglomerate containing quartzite and chert clasts. Overlying the Shinarump Conglomerate are sandstones of the Petrified Forest Member of the Chinle Formation. These sandstones have large cross-beds indicating they formed from eolian dunes. The Petrified Forest Member sandstones are the youngest Mesozoic units exposed in the quadrangle.

The next major event recorded in the Ute quadrangle was the thrusting and folding associated with the ~140 to 50 Ma Sevier orogeny (Bohannon, 1992; DeCelles, 2004). This deformation was first noted by Longwell (1921), and the structural evolution of the Sevier fold and thrust belt was further developed by Longwell (1949), Armstrong (1968), and Bohannon (1992). The principal evidence for this thrusting in the Ute quadrangle is the steeply dipping sequence of overturned rocks in the western foothills of the North Muddy Mountains that are part of the overturned limb of the Weiser syncline. In addition to the folding, these units are commonly broken up by bedding-parallel faults that now bound packages of different formations and members. East and south of the quadrangle, the thrusts overrun local Cretaceous deposits, such as the Baseline Sandstone, which was dated by Carpenter and Carpenter (1987) as between 97 and 93 Ma.

There appears to have been a hiatus in tectonic activity during the early Tertiary. During this time the highlands produced by the Sevier orogeny were shedding sediments into flanking lowlands.

The first post-Sevier-orogeny sign of renewed tectonic activity in the area was the formation of the Miocene California Wash basin and associated sedimentation of the Miocene Horse Spring Formation. This tectonic activity continued and accommodated the deposition of the Muddy Creek Formation in the upper part of the Miocene basin. Four main types of Muddy Creek Formation deposits are exposed in the quadrangle: peach-brown-colored siltstones; reddish to reddish-brown, partly eolian sandstones; reduced-iron green siltstones and claystones; and brownish-gray sandstones.

Lacustrine sedimentary rocks make up the upper part of the Muddy Creek Formation in the Glendale basin to the north, as evidenced by reduced-iron-green claystones (Schmidt et al., 1996). The upper (?) parts of this lake encroached into the northern part of the Ute quadrangle, where the upper parts of the Muddy Creek Formation are also thin-bedded greenish mudstones.

A lacustrine environment is also indicated by the White Narrows marl deposits that conformably overlie the greenish Muddy Creek Formation deposits. The White Narrows marl deposits include silty and muddy limestones, reduced-green mudstones, gypsiferous mudstones, sandstones, reddish-brown siltstones, commonly with a whitish color from carbonate. Reduced-green claystone deposits and other limestone-rich sections indicate that the California Wash valley had intermittent, if not semi-continuous, shallow lakes during the deposition of the White Narrows marl. Schmidt et al. (1996) noted that the White Narrows marl on the Moapa West quadrangle was partly deposited in a grabens formed along the Hogan Spring fault zone, which continues to the south into the northern Ute quadrangle. Within these grabens are a stack of continuous clastic limestones and calcareous mudstones that indicate there was deeper water in this part of the formation, presumably because of continued activity of the graben-bounding faults. White Narrows marl deposits were more broadly distributed in the southern two-thirds of the quadrangle and are bounded on the east by the California Wash fault. Some minor gravel deposits comprise the eastern part of the White Narrows marl deposits near the California Wash fault and may be related to minor activity along that fault.

The Tertiary basin sediments are gently tilted to subhorizontal across the quadrangle and lack significant structural deformation, except where proximal to a fault. Near faults, the dips of bedding can be as much as 68°.

A megabreccia deposit was emplaced after the earliest Miocene sedimentary rocks were deposited, but the exact age of the block slide deposit is not known. The limestone block slide is ~1.4 km (0.9 mi) long and flowed out on a surface that had a very low gradient. Rowland et al. (1985) named this slide the Snowdrift megabreccia after a local mine and interpreted it as a debris flow deposit with a source area on the adjacent California Ridge, because the rocks match those on the ridge ~ 100 m to the east. Rowland et al. (1985) measured one block within the slide that was 400 m x 150 m x 40 m in size. Other similar megabreccias exist in this region and elsewhere in Nevada and Utah, including some that are buried within basins (e.g., Morris and Hebertson, 1996).

After the deposition of the White Narrows marl, there was a hiatus, and an unconformity was formed on top of these deposits. A significant change is indicated by the deposition of gravel conglomerates within the valley on top of the fine-grained deposits. Schmidt et al. (1996) posited that the loss of the lakes following the deposition of the Muddy Creek Formation and the White Narrows marl allowed gravels to be carried out onto the fine-grained deposits. A stream competency argument has been made for the area immediately north of the quadrangle that the gravels advance to a point where equilibrium between stream gradient, stream load, and stream discharge is reached (Gardner, 1972; Schmidt et al., 1996). The gravel conglomerates that were deposited following the deposition of the White Narrows marl were named the "regrade gravel of Moapa" by Schmidt et al. (1996), emphasizing this process. The post–White Narrows marl conglomerates on the Ute quadrangle appear to have been deposited as thin fan deposits and form a pediment. Most of what has been preserved of these deposits is a resistant petrocalcic horizon.

On the Ute quadrangle these "regrade" conglomerates are the Qoa, Qk, Qku, Qk_1, Qk_2, and Qk_3 deposits. These deposits record the highest fill levels in the basin, indicated by projecting the surfaces on the Qku, Qk_1, and Qk deposits out over other deposits. Through time these older deposits were incised and isolated, but the same depositional style continued with younger units, such as Qk_2, Qk_3, and Qaoo.

The renewed activity of the California Wash fault uplifted the North Muddy Mountains relative to the California Wash valley and induced an erosional episode on the western side of the mountains that continues to the present. Qoa breccias within the foothills include angular and subangular cobbles and boulders, which are evidence that erosion was rapid in the early part of this episode. In the later part of the Quaternary, detritus sourced from the Northern Muddy Mountains covered the western piedmont, and some extended westward to California Wash.

Older to late Quaternary alluvial deposits cover much of the valley and fill some of the largest channels in the North Muddy Mountains. The older Quaternary alluvium was a late phase of the petrocalcic gravel pediment deposits, accumulated on top of older petrocalcic deposits, and are inset into them by as much as several meters. East of California Wash, older Quaternary alluvium is present as isolated patches in the piedmont and likely as part of the compound Qk surface. Intermediate-age Quaternary alluvium makes up a significant amount of the piedmont east of the California Wash in the southern part of the quadrangle but is an inset fan or channelized alluvium in the rest of the quadrangle. Intermediate-age Quaternary alluvium also formed in stabilized broad channels along a paleo-California Wash. Qai deposits followed a significant downcutting episode, which was a relatively new phenomenon in the valley. Intermediate-age Quaternary alluvium was also deposited within grabens along the northern California Wash fault, indicating earlier fault activity. The younger alluvium is accumulating on fan surfaces and in modern drainages. The California Wash appears to have continued to propagate to the southwest during the late Quaternary and has a current knick point off of the piedmont near where Interstate 15 intersects the southwestern edge of the Ute quadrangle. Latest Pleistocene and Holocene alluvium has built small fans next to the fault on the hanging wall of the California Wash fault and in the mid-portion of the petrocalcic fan deposits, near the heads of early Quaternary fans.

In the late Holocene, gravelly alluvium was carried from the North Muddy Mountains and the western piedmont downslope to the axial channel of California Wash, where gravel continues to the northern boundary of the quadrangle, yet these gravels do not make it to the Muddy River, about 5 km downstream (Gardner, 1972). Gardner (1972) would argue that during the current interpluvial period, stream flow and competency is low, limiting how far the coarser alluvium can be carried. This could explain why the younger alluvium has been deposited mid-piedmont and immediately adjacent to a late Quaternary fault. Runoff events on the Ute quadrangle range from mild low-water events to torrential flash-flood events that can overflow the stream banks and cut new channels.

CROSS SECTIONS A–A' AND B–B'

Two cross sections were constructed to illustrate potential subsurface structure and geologic relationships, and to better understand the geology exposed at the surface. The cross sections are based on four principal sources of information:

1. the mapped geology,
2. modeling of the basin thickness using gravity and seismic-reflection data by Langenheim et al. (2001),
3. cross sections constructed by Bohannon (1992), and
4. projections of the geologic relations from mountains to the north and south of the Ute quadrangle (e.g., Bohannon, 1992; Axen et al., 1990 and references therein).

Langenheim et al. (2001) conducted a study of the California Wash basin using gravity measurements and seismic-reflection data. The seismic-reflection data are from three lines, but only one crosses a small distance into the southern Ute quadrangle. The northern part of the California Wash basin was extended into the quadrangle using gravity measurements and interpreting and contouring the results. The basin model of Langenheim et al. (2001) is reasonable and is intriguing when considered with the trace of the California Wash fault. The basin configuration shown in figure 9A of Langenheim et al. (2001) was used as a guide in constructing the depth of the basin for the cross sections. They also interpreted the relative thickness of the Horse Spring and Muddy Creek Formations within the basin using seismic-reflection data, and we adopted this interpretation in the cross sections. Langenheim et al. (2001) connected reflectors that they interpreted as the same fault. They concluded that the California Wash fault has a concave-upward or slightly listric geometry, which we incorporated into the cross sections.

Bohannon's (1992) cross section B–B' is closest to the Ute quadrangle and shows the Weiser syncline, high-angle faults, and projections of the Muddy Mountain and Summit–Willow Tank thrust faults, all of which were adopted in similar positions. The Weiser syncline was formed just below the Muddy Mountain thrust fault (Longwell, 1921) and above the Summit–Willow Tank thrust fault. The upper limb forms the steeply dipping, overturned Paleozoic beds of the western North Muddy Mountains.

Some older structures are shown in the buried hanging wall of the California Wash fault, principally a subsidiary thrust and a truncated anticline below that. These are consequences of the occurrence of the Mississippian limestone in a footwall fault sliver, which crops out near the cross-section line, and the anticline that is exposed in the Mormon Mountains (mapped by Axen et al., 1990) and in the Muddy Mountains (unpublished mapping by Taylor). The anticline is a parasitic fold on the Weiser syncline or a trailing anticline.

Steeply dipping faults were projected to depth along steeply dipping planes, and a normal dip-slip sense of displacement was used to explain the mismatches of geologic units across the faults. Some high-angle faults require a strike-slip component for retro-deformation to be possible.

DESCRIPTION OF MAP UNITS

Cenozoic Era

Quaternary Period

Qa Active alluvium (present to latest Holocene) Active alluvial channels range widely in scale from small channels to the 100-m-wide California Wash. Most streams flow briefly during localized storms and as integrated drainages every few years to every decade. Stream deposits vary in grain size and grain-size range depending on where they are located. Channels coming from the North Muddy Mountains, within the western pediment, and large basin channels have large amounts of sand and gravel with some cobbles. Small channels that drain the Tertiary sedimentary deposits are made up mostly of sand and silt. Deposits are usually thin, tens of decimeters, but can be as much as 2 m thick in bar deposits within California Wash. These channels can run bankfull with violent currents, contain large amounts of debris, and flood overbank during flash floods.

Qayy, Qfyy Youngest Quaternary alluvial deposits (Qayy) and youngest fan deposits (Qfyy); active and intermittently active alluvial channels (Holocene to latest Pleistocene) Areas of young channels, channel distribution areas on fans, and overland flow areas that show evidence of active to intermittent activity (flooded every decade to decades on average). Also includes bar deposits within channels and side-stream terraces along the larger channels.

Deposits are brown and gray, poorly sorted, poorly to moderately stratified, non-indurated, matrix- and clast-supported sandy gravels and gravelly sands. Closer to the range front, clasts are subangular and angular. In the lower parts of fans, the lower tributaries of the axial California Wash channel, and within California Wash, clasts are commonly rounded and subrounded. Qayy and Qfyy deposits have well-preserved bar-and-swale surfaces. The deposits are usually thin, 1 m thick or less.

Qay, Qfy Undivided young Quaternary alluvial deposits (Qay) and young fan deposits (Qfy) (Holocene to latest Pleistocene) Intermittently active to latest Pleistocene alluvial and fan deposits. These are parts of alluvial channels and fans that make up the modern piedmont but have not been active recently.

Deposits are brown and gray gravelly sands, sands, and sandy gravels, which are generally poorly to moderately sorted, poorly to moderately stratified, and have matrix-supported and/or clast-supported layers. Near and within the northern Muddy Mountains clasts are mostly subangular to angular, whereas in distal fan areas and the central drainage system of the valley clasts are mostly subrounded and rounded. Surfaces commonly have a slightly eroded bar-and-swale microtopography. Qay, Qfy, and Qty are undivided and can include any young Quaternary deposit that is too small to map or is difficult to more specifically categorize.

Qaey, Qey Young Quaternary alluvial and eolian deposits (Qaey), young Quaternary eolian deposits (Qey) (Holocene to latest Pleistocene) Young Quaternary alluvial deposits that include substantial amounts of reddish, eolian very fine sand and/or areas of eolian sand deposits. The dominant source of the very fine sand is the western North Muddy Mountains piedmont and the California Wash valley. Eolian deposits are less prevalent to the west of the California Wash. Deposits commonly are thin sand sheets with a massive appearance and are easily eroded and reworked by water or wind. Some accumulations of eolian sands exceed 1 m in thickness.

Qtyw, Qtyf Young Quaternary fluvial erosional surfaces (Qtyw) on Tertiary White Narrows marl and young strath surfaces on intermediate-age Quaternary fan deposits (Qtyf) (early Holocene to latest Pleistocene) Areas just downstream from a major knick point in California Wash that have large-scale, elongated, erosional bars and channels. This eroded topography appears to have been formed by large-scale, over-bank flooding where the upper part of the California Wash channel was too small to contain latest Pleistocene to early Holocene floods. Lyle et al. (2012) indicate that such a wet period occurred in this region around 17 ky ago.

Qayo, Qfyo Older young Quaternary alluvial deposits (Qayo) and older young Quaternary fan deposits (Qfyo) (early Holocene to latest Pleistocene) Older alluvial deposits commonly exist in low terraces along active and young stream channels. Brown and brown-gray gravelly sands, sands, and some sandy gravels are generally poorly to moderately sorted and poorly to moderately stratified. Near and within the North Muddy Mountains clasts within deposits are mostly subangular and angular and near the central part of the valley clasts are mostly subrounded and rounded. Surfaces on these deposits are smoothed with incipient pavements and some relict bar-and-swale microtopography. There is some etching of limestone cobbles on the surface. Soil development can include a 2- to 10-cm-thick Av horizon; a weak, thin cambic horizon (as much as 10 cm thick); a 10- to 30-cm-thick weak gypsiferous B horizon; or a stage I carbonate Bk horizon. One Qayo surface was dated at 16,105 ±355 Cal BP and has been offset by the California Wash fault by three separate earthquakes since it was deposited (Zaragoza et al., 2005). Deposits are usually less than 1 m thick.

Qac Quaternary alluvial and colluvial deposits (Holocene to middle Pleistocene) Deposits consist of active talus, colluvial, and alluvial slope deposits and small debris fans flanking the steep slopes of California Ridge and a small hill to the southeast. Talus slopes of cobbles and boulders occur directly below outcrops or steep bedrock areas and are still forming. Broader areas of Qac have more colluvium in their upper reaches and more alluvium in their lower reaches. Deposits are generally late Quaternary age, are poorly sorted, and have angular and subangular clasts. Surfaces are even with the exception of the boulder areas, areas of recent debris flows, and deep rills and gullies that are common. Deposits are commonly thin, but can be as thick as 2 m.

Qce Quaternary colluvial and eolian deposits (Holocene to middle Pleistocene) Colluvium and eolian sand deposits formed on top of Quaternary petrocalcic surfaces (Qk) to the east of California Wash. Shallow deposits (<1 m thick) of petrocalcic rubble and some limestone clasts interspersed with reddish eolian sands. Deposits are generally late Quaternary age, poorly sorted, and have angular and subangular clasts. Surfaces are generally smoothed.

Qai, Qfi Intermediate-age Quaternary alluvial deposits (Qai) and intermediate-age Quaternary fan deposits (Qfi) (late Pleistocene) Isolated late Pleistocene deposits and surfaces in piedmonts and terraced surfaces along channels. Deposits consist of brown and gray gravelly sands, sands, and sandy gravels with some cobbles, which are poorly to moderately sorted and are poorly to moderately stratified. Some boulders exist in proximal settings. Clast rounding varies from more angular in proximal settings to more rounded in the distal fan and valley channel settings. Intermediate-age alluvium ranges from slightly indurated to moderately well-indurated with carbonate and/or gypsum cement. Surfaces on these deposits are commonly smoothed and have well-formed pavements with loosely interlocking to interlocking gravel clasts covering very fine, eolian sand that can be up to 50 cm thick. Some degraded collections of cobbles and boulders indicate relict bars. Larger clasts on the surface have pronounced etching and sandy and cherty clasts have moderately to strongly developed rock varnish. Soil development consists of a 2- to 15-cm-thick, colored Bw horizon that forms in the bottom of the Av and on top of the fluvial deposit, and a stage II to stage III carbonate horizon that can be as much as 40 cm thick and can form a resistant, vertical ledge when exposed along stream channel margins. Deposit thickness ranges from 1–3 m.

Qaio Older intermediate-age Quaternary alluvial deposits (late to middle Pleistocene) Older intermediate-age Quaternary alluvial deposits are similar to intermediate-age alluvium but have a more strongly developed calcic horizon with a matrix that is cemented carbonate (strong stage III) and is as much as 1 m thick. Surfaces are very smooth with very well developed pavements of interlocking clasts. Only a few pieces of soil carbonate were observed in the surface litter. These deposits are likely middle Pleistocene age.

Qmoy Younger older Quaternary marl deposits (middle to early? Quaternary) High terrace marl deposits with a punky, irregular surface. These are generally whitish sandy and silty deposits that are impregnated with gypsum and carbonate. The unit is about 1 m thick and is found in high terraces along a stream channel eroded into Tertiary basin-fill deposits. The terrace position is akin to the older Quaternary alluvium. The deposits may have been partially formed as evaporates because of the large amount of gypsum. There are some poorly preserved beds that are thin, irregular, and discontinuous.

Qao, Qfo Older Quaternary alluvium (Qao) and older Quaternary alluvial fan deposits (Qfo) (middle to early? Quaternary) Alluvial, fan, and pediment deposits that have a prominent petrocalcic horizon. Deposits are commonly gravelly sands and sandy gravels that are poorly to moderately stratified, clast supported and matrix supported, and are as thick as ~3 m. Clast rounding ranges from angular to rounded. Surfaces range from relatively smooth to slightly irregular with a thin cover of fine sands and lag pieces to areas of denuded petrocalcic horizon. Surface litter is dominated by carbonate fragments. Where eolian sands as thick as 20 cm cover the unit, the lower part may have a Bw or possible weak Bt horizon that is about 10 cm thick where observed. Calcic horizons are 0.4 to 2.5 m thick and carbonate development is stage III to minor stage IV; the petrocalcic part of the soil is 0.4 to 0.8 m thick. Carbonate within the matrix ranges from incomplete impregnation with some minor brown sand or silt remaining to near total replacement with carbonate. Surfaces on Qao and Qfo deposits indicate a higher base level than exists today. This isolation was caused by incision from stream activity that created Qai and Qay deposits and/or uplift along the California Wash fault.

Qao_1, Qao_2, Qao_3 Older, relict surfaces and deposits. Highest level of older Quaternary alluvial deposits (Qao_1); middle level of older Quaternary alluvial deposits (Qao_2); lowest level of older alluvial deposits (Qao_3) (middle to early? Quaternary) Relict alluvial surfaces and deposits that have relative ages inferred from geomorphic position, with the older deposits (lowest number) being at the highest level. The deposits are small, commonly highly eroded, and are only 10s of centimeters thick in places. These are commonly eroded carbonate-rich calcic or petrocalcic horizons with well-developed stage III carbonate development surrounding conglomerate. The deposits have similar descriptions as Qao deposits but were deposited at different base levels relative to each other. The deposits are vestiges of higher stream levels. The different alluvial levels are the result of local tectonic movement, climatic influence, major changes in downstream base levels, or a combination of these factors.

Qaoo Oldest Quaternary alluvium (early Quaternary) Older alluvium that makes up an isolated surface originally deposited in a valley, but which is inverted topography today. This cobbly, sandy conglomerate and breccia was deposited in a channel that issued from the North Muddy Mountains and was formed partly, if not wholly, within Qoa deposits. A one- to two-meter-thick petrocalcic horizon is all that remains; the upper meter is made up of coarse layers of stage IV lamina where preserved.

Qoa Oldest Quaternary alluvial deposits (early Quaternary) Relict, discontinuous deposits of sands, gravelly sands, and sandy gravels that were generally deposited in the proximal part of piedmonts or within the western foothills of the North Muddy Mountains. In addition, some very coarse relicts of carbonate-cemented Qoa deposits lie in the bottoms of some stream channels in the foothills of the North Muddy Mountains. Qoa is made up of debris-flow and fluvial deposits. In the upper parts and more distal parts, Qoa deposits are fluvial, moderately stratified, clast-supported and matrix-supported sedimentary packages, and clasts are dominantly subrounded and rounded. In the lower parts of the Qoa located in the foothills of the North Muddy Mountains, deposits are matrix-supported and lesser clast-supported debris-flows; where these deposits overlie the Muddy Creek Formation, the matrix is largely derived from that formation. Where Ooa overlies Paleozoic units, there is a strong angular unconformity; and where it overlies the Muddy Creek Formation, Qoa deposits are parallel overlying an unconformity or have a subtle angular unconformity of a few to several degrees. The total thickness of Qoa ranges from 1 to 10 m. The deposits commonly form smoothed ballenas and original surfaces are not usually preserved unless there is a cap of resistant petrocalcic horizon. Relict petrocalcic deposits, as thick as 1 m, overlie some Qoa deposits; these appear similar to petrocalcic horizons in Qk and Qku deposits. Another kind of occurrence of Qoa is a relict deposit of carbonate-cemented boulder-cobble-breccia that occurs in the bottoms of some drainages. These were high-energy debris flows that were deposited in these drainages.

Qk Undifferentiated (middle to early Quaternary) petrocalcic deposits These petrocalcic horizons and deposits make up a large surface in the eastern half of the quadrangle, east of California Wash. Qk deposits likely span a significant time range from early to middle Quaternary and parts likely correlate with Qao, Qfo, and Qku deposits. This is because there are variations in thicknesses of the petrocalcic horizon ranging from 0.75 to 3 m and fluvial cuts along California Wash expose a second petrocalcic layer below the petrocalcic horizon at the surface. Deposits are cobble-gravel conglomerates and breccias that are engulfed by carbonate. Carbonate generally ranges from well-developed stage III to stage IV, with some areas that have stage V to stage VI development. Some surfaces have clast protrusions that help anchor silts and colluvium and make the surface irregular, whereas other parts are smoother where they are covered by tens of cm of eolian sands and surface alluvium. The Qk surface is disrupted by Quaternary faulting, including being down dropped along the North Muddy Mountains by the California Wash fault. Qk overlies an unconformity except where it is developed in the upper part of Qoa deposits.

Qku, Qk_1, Qk_2, Qk_3, Qkb Quaternary petrocalcic horizons, eroded paleosurfaces, and carbonate-matrix breccias (middle to early Quaternary) Following a Tertiary filling episode in the California Wash basin, gravel conglomerates prograded across the valley forming a pediment. Schmidt et al. (1996) identified equivalent deposits in the Moapa West quadrangle to the north and named them the "regrade gravels," positing that sedimentation was triggered by the loss of the lakes in the basin and that the alluvium was in a near equilibrium balance between gradient, bed load, and stream discharge to create these remarkable pediments. These surfaces were isolated, stabilized, and developed resistant petrocalcic horizons within them.

The Qku, Qk_1, Qk_2, Qk_3 deposits and their surfaces are preserved because of the resistant petrocalcic horizons formed in the pediment gravel conglomerates. These conglomerates are usually on the order of 1 m or so thick but can be as thick as 5 m. The deposits are well-sorted, moderately stratified, medium- and coarse-gravel conglomerates with some coarse sandstone. The central part of the petrocalcic deposit is commonly carbonate matrix that surrounds the gravel clasts. The age of Quaternary was recommended by Dr. Brenda Buck (oral communication, 2011) of UNLV because although there is evidence for stage VI carbonate formation in these deposits, it has only been through one carbonate cycle (stages I through VI) versus Tertiary petrocalcic units that have evidence of multiple generations of the carbonate cycles (e.g., Brock and Buck, 2009).

Small changes of the base levels within the valley caused some of these surfaces to be inset into each other, which is the fundamental basis for the relative age assignments. Although quite variable overall, the different, progressive thicknesses of the best developed and preserved petrocalcic deposits further support the idea that the surfaces were stabilized at different times.

Qku Undifferentiated Quaternary petrocalcic deposit Deposits have relict petrocalcic surfaces, isolated petrocalcic surfaces, or petrocalcic surfaces that are otherwise difficult to assign a relative age. Qk_1 deposits form the oldest, highest surfaces, with petrocalcic horizons as thick as 3+ m. Carbonate generally has stage III to VI development and the carbonate matrix (stage III development areas) is commonly completely replaced by re-crystallized carbonate. The well-cemented petrocalcic horizon erodes smooth and cleanly breaks across limestone clasts that are surrounded by matrix. Surfaces on Qk_1 deposits are commonly stripped down to a bare petrocalcic layer and are relatively smooth, although there are areas where eolian sand and carbonate lag fragments have built up. Pieces of the petrocalcic horizon that litter the surface are commonly slightly rounded and weathered. Qk_2 deposits and surfaces are inset into Qk_1 deposits by 0.3 to 3 m and have petrocalcic horizons at least 2 m thick, with stage III through VI carbonate development. Surfaces range from smooth to slightly irregular and are thinly covered or bare with numerous, relatively fresh-looking pieces of petrocalcic horizon material littering the surface. Qk_3 deposits are inset into Qk_2 deposits as much as 3 to 4 m and commonly have slightly irregular surfaces with petrocalcic clasts that help anchor eolian sand and colluvium and make small, low mounds. Some bare petrocalcic horizon areas exist as well. None of the Qk deposits have been directly dated within the quadrangle. They are formed in, and on top of, the White Narrows marl, indicating they are less than 4–5 Ma old, but they are thought to be Quaternary. The petrocalcic gravels overlie an unconformity on top of Tertiary basin-fill deposits. In places the Tertiary and Quaternary deposits are approximately parallel to each other and elsewhere there is a small angular unconformity between them.

Following a period of erosion in the western North Muddy Mountains, a bouldery cobble breccia and debris flows, labeled Qkb, were deposited in some of the western drainages. These are generally matrix-supported deposits, where the matrix is largely replaced by carbonate. Clasts are made up of limestone and sandstone rocks from immediately upstream. Qkb deposits are exposed in the bottom of stream channels and along channel walls are 1–2 m thick where exposed. Qoa alluvium was deposited on top of these boulder cobble breccias. The Qkb deposits may be related to the early Quaternary to late Tertiary erosional period and may be the last vestiges of many debris flows that swept through these drainages.

Tertiary Period

Tw White Narrows marl (Pliocene) The White Narrows marl is the uppermost Tertiary basin-fill deposit in the California Wash basin prior to the formation of the gravelly pediments. They were considered to be the uppermost unit of the Muddy Creek Formation by Gardner (1968), who informally named them the marls of White Narrows. Although many of the White Narrows marl deposits exposed in the Ute quadrangle have a characteristic whitish color and are highly effervescent with HCl, there is a lot of variability, such as light brown siltstones and sandstones and reduced-Fe-green lacustrine siltstones and claystones.

The deposits are white, whitish-gray, light-brown, or green carbonate-rich sandstones, siltstones, mudstones, limestones, and carbonate- and gypsum-rich marls. Deposits are moderately bedded to well-bedded, with 1- to 100-cm-thick beds and slightly irregular to even, conformable contacts. Beds are generally continuous, but there are some areas with discontinuous beds. The White Narrows marl conformably overlies, or is in fault contact with, the Muddy Creek Formation. The White Narrows marl consists of carbonate-rich basin-fill deposits that include lacustrine, fluvial, and paludal (?) environments, and commonly erode in a badlands style. The White Narrows marl is at least 10 m thick in the central part of the Ute quadrangle, where it exposed by downcutting by the California Wash along some hills with resistant petrocalcic caps. Schmidt et al. (1996) estimated the age of the White Narrows marl to be between 4 and 5 Ma based on fossils found in the Moapa West quadrangle.

Tm Muddy Creek Formation, undivided (middle to late Miocene) The Muddy Creek Formation consists of relatively fine-grained basin-floor sedimentary rocks, lacustrine deposits, eolian deposits, and fluvial deposits. These deposits filled the upper half of the California Wash basin (Langenheim et al., 2001) and were deposited on the western flank of the North Muddy Mountains, in the footwall of the California Wash fault (Bohannon, 1983). The formation is highly variable in the Ute quadrangle. Some areas of the classic salmon- or peach-colored siltstones and claystones are exposed, but there are also light-green-colored claystones and siltstones near the top of the deposits, areas of reddish-colored sandstones with eolian dune structures, and areas of gray, fluvial sandstones, all indicating a complex paleogeographic environment for the upper part of the Muddy Creek Formation.

The Muddy Creek Formation exposed on the Ute quadrangle consists of light brown, salmon-red, brown, gray-brown, and light-green, moderately indurated, well-sorted siltstones, sandstones, and claystones. There are also some minor pebble and matrix-supported gravelly conglomerate layers and minor gypsum seams within these deposits. The sediments have moderately well developed beds that range from a few centimeters to 100 cm thick and are commonly continuous with regular to irregular, indistinct to moderately distinct contacts. Some hematitic and carbonized wood fragments occur in the gray-brown sandstones.

The upper 1 to 2 m of the Muddy Creek Formation on the Ute quadrangle (especially in the northern part of the quadrangle) is commonly a light-green siltstone and claystone; this was mapped as a separate unit by Schmidt et al. (1996) in the adjacent Moapa West quadrangle, where these deposits are thicker. These deposits are siltstones, sandy mudstones, and claystones in even, continuous beds as much as 2–4 cm thick. Some parts have distinct, thin, 1- to 3-mm-thick continuous beds that were deposited in a lacustrine environment (annual beds?).

The upper contact of the Muddy Creek Formation is conformable with the White Narrows marl, thus the age given to the upper part of the formation in this area by Schmidt et al. (1996) is 5 Ma. For the age of the beginning of the deposition of the Muddy Creek Formation a regional value of 10.4 Ma was determined by Castor et al. (2000). The lower contact with the Horse Spring Formation is rarely exposed. The Muddy Creek Formation commonly erodes into badlands-like topography.

Tmr Muddy Creek Formation, red sandstone and siltstone (middle to late Miocene) Reddish-brown and light-red, well-sorted, very fine- and fine-grained sandstones, siltstones, and minor claystones. Deposits are moderately to well-bedded in discontinuous and continuous, 2- to 50-cm-thick beds. Contacts range from distinct to indistinct and from even to irregular in character. Some cross-beds were formed by small sand dunes. Eolian sand and the reddish color of the deposits indicate a subaerial environment.

Tms Muddy Creek Formation, gray sandstone (middle to late Miocene) Gray well-sorted, fine to coarse sandstones, with rare pebbles. Layering ranges in thickness from a few mm thick laminae to tens of cm beds, if some carbonate-cemented layers are single beds. Fluvial deposits with some cross-laminated beds and channel cross sections. Carbonate rhizoliths are present in some layers. Deposits are 3+ m thick and make up the lower parts of a hill east of the California Wash fault. A second patch of similar sandstones was found near the California Wash, but that unit appears to be stratigraphically higher in the formation.

Tl Tertiary freshwater limestone (middle Miocene) White freshwater limestone and rarer marl deposits in the footwall of the California Wash fault. The limestones have many holes or vugs. They appear to be shallow lacustrine or spring deposits with some reed casts and possible algal structures. Beds are 1–30 cm thick. The thickest limestone deposit is over 20 m thick. The limestones were deposited on an angular unconformity over tilted Paleozoic rocks and over thin sandstone deposits (Ts). The western and the eastern sides of the limestone outcrops are faults. Beds were generally tilted about 10° to the northwest and some beds were gently folded, particularly near the California Wash fault, where beds were drag folded >60° into the fault. Several of these limestone beds are interbedded with sandstone (Ts). The limestones form resistant terraces, shielding less-resistant underlying sandstones.

Tbs Tertiary megabreccia and debris flows (middle Miocene?) Tertiary block slide and debris flows named the "Snowdrift megabreccia" by Rowland et al. (1985), who identified blocks within the deposit to be the Kaibab Formation (Fossil Mountain Member) and the Toroweap Formation (Brady Canyon Member). They note that the largest block within the megabreccia is approximately 400 m long, 150 m wide, and 40 m thick. The eastern two-thirds of the deposit is more resistant than the rocks on which the megabreccia was deposited (e.g., Esplanade Sandstone) and forms a higher, possibly inverted topography. Blocks within the megabreccia are generally angular and are cemented by carbonate. The base of the deposit appears to be locally sheared, where the megabreccia slid out over an angular unconformity. Apparently a large number of limestone blocks from a higher, pre-erosion landscape collapsed and slid. Similar megabreccias can be found in the North Muddy Mountains and elsewhere in southern Nevada.

Ts Tertiary red, white, and ocher sandstones (middle Miocene) Red, light-red, white, light-brown, and ocher alluvial sandstones deposited on the Paleozoic rocks in the footwall of the California Wash fault. In addition to sandstone, there are locally deposited sandy siltstone and claystone, limestone, gypsum layers, minor ash-rich layers, minor light-green siltstone layers, and minor matrix-supported gravel lenses. The red and ocher sand colors are created by differing amounts of iron staining of the sand grains. Well defined continuous beds are 2–10 cm thick. Overall thickness is a little over 3–4 m. The lower contact is an angular unconformity with tilted Paleozoic rocks, and the western and eastern sides of the sandstone outcrops are commonly faulted. These sandstones were deposited on the western flank of the mid-Tertiary, paleo–North Muddy Mountains western flank. The rarity of gravel and cobbles in these deposits indicates that the sandstones were gently deposited on a stabilized landscape. Some sand grains may have been derived from local exposures of Esplanade Sandstone and the Seligman Member of the Toroweap Formation.

Th Horse Spring Formation, undivided (middle Miocene) The undivided Horse Spring Formation within the California Wash basin, as shown on the cross sections, is buried by younger Tertiary and Quaternary deposits. It includes deposits related to the initial formation of the Tertiary basin. Schmidt et al. (1996) refer to the Horse Spring Formation as a "synextensional basin-fill deposit that formed during opening and subsidence of the Glendale basin." The age of the Horse Spring Formation elsewhere in southern Nevada is between 11.9 Ma (Bohannon, 1984) and 19 Ma (Beard, 1996).

Mesozoic Era

Triassic Period

Ŧcps Chinle Formation, Petrified Forest Member (Upper Triassic) Small portion of a sandstone unit that is more extensively exposed on the Weiser Ridge quadrangle immediately to the northeast (Bohannon, 1992). The deposit is made up of light-brown, brown, and reddish-brown, medium and medium-fine sandstones, with moderate to large cross-beds indicating eolian deposition in dune structures. There are also some sandy pebble conglomerate beds. Moderately well developed, discontinuous beds with smooth and irregular contacts.

Ŧcs Chinle Formation, Shinarump Conglomerate (Upper Triassic) There is a single outcrop of the Shinarump Conglomerate on the quadrangle, but it is the southern end of a more extensive occurrence to the northeast in the Weiser Ridge quadrangle (Bohannon, 1992). The unit is a dark, reddish-brown, pebble and gravel conglomerate with rare cobbles. Clasts are commonly quartzite and chert. The deposits are stratified, but weakly bedded. The Shinarump Conglomerate is approximately 7–9 m thick in the quadrangle.

Ŧmur Moenkopi Formation, upper red member (Middle to Lower Triassic) This unit is mostly buried by alluvium and colluvium. The sole outcrop is on the western side of a resistant hill, just below the Shinarump Conglomerate. At this outcrop are gray, well-sorted, medium and coarse sands made up entirely of limestone clasts, in well-defined, even, 10- to 25-cm-thick beds. Reddish-brown and chocolate-brown siltstone and sandstone deposits of Ŧmur are present to the west of this hill, but are easily eroded and covered with Quaternary alluvium.

Ŧmsg Moenkopi Formation, siltstone and gypsum member (Middle to Lower Triassic) Reddish, reddish-brown and yellowish-brown siltstone, sandstone, and muddy sandstone; some layers are banded with 1- to 3-mm-thick, white veins of gypsum. The gypsum stringers are mostly parallel to bedding, but a number of them cross it as well. Includes well-sorted, red-brown sandstones in moderately distinct, uneven, continuous beds with distinct contacts, which are as thick as 15 cm. Siltstones and sandstones are highly fractured and jointed. This unit is relatively easily eroded and is mostly buried by alluvium and colluvium in a small valley.

Ŧmv Moenkopi Formation, Virgin Limestone Member (Lower Triassic) Light-brown, golden, white, gray, and blue-gray limestone and calcareous shale. The limestone beds are continuous, 1-mm- to 60-cm-thick, with distinct, even contacts. Shale and very thin limestone layers are in 10-cm- to 2-m-wide packages of thin sheets between thicker limestone beds. The Virgin Limestone Member is fossiliferous, including bivalves, mollusks, crinoids, and burrows. An exact thickness of the Virgin Limestone Member on the quadrangle is difficult to estimate because of Quaternary cover and structural complications, but it appears to be at least 100 m thick.

Ŧml Moenkopi Formation, lower red member and Timpoweap Member (Lower Triassic) Reddish-brown, brown, and chocolate-brown siltstone and sandstone with intercalated limestone. Locally deposits have white streaks. Limestones are in well-developed beds, ranging in thickness from thin laminae to 60 cm thick. Chocolate-brown, finely bedded shales form layers 20 cm to 2 m thick within the limestone. The shale is fractured and friable. The lower red member erodes relatively easily and forms slopes. The unit is structurally thinned in most of its occurrences on the quadrangle, but is at least 60 m thick.

Paleozoic Era

Permian Period

Pkh Kaibab Formation, Harrisburg Member (Lower Permian) Brown, gray, brownish-red, and yellow siltstone and limestone, with some gypsum. Limestone is commonly cherty and was deposited in well-developed beds as thick as 50 cm, with distinct, even to wavy contacts between them. Beds are disturbed by small faults and fractures. Breccias of limestone, some stained iron-red, occur adjacent to the fault contact with the Brady Canyon Member of the Toroweap Formation. The Harrisburg Member is generally a slope-forming unit that is over 10 m thick in the quadrangle.

Pkfm Kaibab Formation, Fossil Mountain Member (Lower Permian) The Fossil Mountain Member is a light-gray to gray, fine- to medium-grained cherty limestone. When broken, the limestone areas are gray and the more siliceous areas are whitish. Chert occurs as nodules and masses, commonly concentrated along beds; these cherty areas are varnished upon weathering, giving the unit an overall darker appearance than the nearby Brady Canyon Member of the Toroweap Formation. The Fossil Mountain Member is exposed in a small fault-bounded sliver in the California Ridge quadrangle, but is more completely exposed in a small hill in the southeasternmost part of the quadrangle and in the adjacent Weiser Ridge quadrangle (Bohannon, 1992).

Ptwr Toroweap Formation, Woods Ranch Member (Lower Permian) A small, faulted sliver of Woods Ranch Member is poorly exposed in the easternmost part of the

Ute quadrangle. Bohannon (1992) described the Woods Ranch Member as a white, gray, and pinkish limestone, dolostone, gypsum, siltstone, and sandstone in irregular, discontinuous beds. The unit forms colluvium-covered recessive slopes between the Fossil Mountain Member of the Kaibab Formation and the Brady Canyon Member of the Toroweap Formation.

Ptbc Toroweap Formation, Brady Canyon Member (Lower Permian) Gray, fine- to medium-grained limestone with chert nodules that forms the western side of California Ridge. Beds are well-developed and fairly even with moderate thicknesses (5–30 cm thick are common). There are a few intercalated, light-brown beds as well. Chert nodules are more concentrated near the upper part of the exposed section. The Brady Canyon Member is fault-bounded by bedding-parallel faults, and some of the unit has been cut out by this faulting. Some areas display internal deformation where faults, small-scale folds, and gentler-dipping beds were observed. The approximate thickness of the Brady Canyon Member on the Ute quadrangle is 70–80 m. The Brady Canyon Member is a prominent cliff-forming unit.

Pts Toroweap Formation, Seligman Member (Lower Permian) Brownish-red, fine- and very fine-grained sandstone, which is relatively easily eroded and is covered by Quaternary deposits in several places. Beds are very thin to 30 cm thick, are commonly irregular, and are sometimes wavy and discontinuous. The upper and lower contacts of the Seligman Member are faults, and there is a fairly well-developed, probable Quaternary fault within the unit. The maximum thickness of the Seligman Member on the Ute quadrangle is ~90 m.

Pe Esplanade Sandstone (Lower Permian) Light-brown, light-brownish-red, and white, very fine sandstones. Irregular to regular beds are well developed, and are thin to as thick as 1 m. Cross-bedding indicative of sand dunes is common. Some minor limestone beds occur locally, especially near the base of the unit. The upper and lower contacts are faulted, and there is also a significant amount of internal faulting within the unit, especially near the bottom. The Esplanade Sandstone is as thick as 670 m and is largely a subaerial deposit as indicated by the presence of sand dune features and raindrop impressions in some rocks.

Permian and Pennsylvanian Periods

PIPbu, PIPbm, PIPbl Bird Spring Formation (Lower Permian to Pennsylvanian) Three units were differentiated in the Bird Spring Formation: lower gray limestone (PIPbl), a middle section consisting of a red-brown silty and sandy limestone (PIPbm), and an upper gray limestone (PIPbu). The middle unit is made up of red-brown and brown-gray silty limestones and calcareous sandstones and is distinctive in color, with more varnish on the outcrops and clasts covering the ground than the other parts of the Bird Spring Formation.

Limestones are fine- to medium-grained, light-gray and gray beds. Gray and brown calcareous-cemented sandstones occur in lesser amounts. Very well bedded unit with even, continuous beds ranging from a couple of centimeters to 1 m thick. The fossiliferous marine limestones of the Bird Spring Formation have gastropods, articulated brachiopods, bivalves, corals, bryozoa, crinoids, fusulinids, and foraminifera. The upper and lower contacts of the Bird Spring Formation are faulted and some internal faults exist within the unit. The maximum thickness of the deposit exposed on the Ute quadrangle is 640 m. The Bird Spring Formation is generally a resistant unit, but a tendency to form small ledges between beds gives outcrops a rounded or step-like appearance.

Mississippian Period

Mm Monte Cristo Group (?) (Mississippian) Dark-gray limestone and minor chert. Beds are even, 15–100 cm thick, and are moderately well developed but can be hard to distinguish. Bedding contacts range from being distinct and even to indistinct. Carbonate and siliceous stringers are common. Many of the layers are bioclastic (coquinas) and are made up of sand-sized broken shell fragments. Other fossils include crinoids and broken shell fragments, collectively indicating a marine origin for the deposit. The unit is exposed in small fault-bounded remnants between the California Wash fault and the Bird Spring Formation, and there are many internal faults, fractures, and joints. Only a small portion of the unit is exposed on the quadrangle.

Unexposed Units in Cross Sections

These units are not exposed on the Ute quadrangle but are exposed in areas surrounding the quadrangle and are shown in the subsurface in the cross sections. The brief unit descriptions below come from observations in surrounding quadrangles and from published literature.

Mesozoic Era

Ja Aztec Sandstone (Jurassic) Red, white, light-yellow eolian quartz arenite in even beds with large cross-bed structures common to dune forms (Bohannon, 1992). These autochthonous rocks lie below the frontal thrust of the Sevier contractional belt and are exposed in the Weiser Ridge quadrangle to the east and in nearby ranges.

TRmd Moenkopi Formation, dolomite (Middle to Lower Triassic) White to light-gray, fine-grained dolomite that is mapped at the surface just east of the Ute quadrangle by Bohannon (1992) and projects into the subsurface on the Ute quadrangle. The slope-forming dolomite member of the Moenkopi Formation is described by Bohannon (1992) as having uniform 1 to 2 cm thick beds that are parallel, continuous, and with uneven surfaces. The unit also contains shale and gypsum beds that are 2 to 5 cm thick (Bohannon, 1992).

Paleozoic Era

MDs Sultan Limestone (Lower Mississippian to Middle Devonian) Light- and dark-gray, thin- to thick-bedded limestone and dolostone, mapped in Frenchman Mountain and the Spring Mountains (Page et al., 2005). This unit is the source of lime at an industrial mine north of the quadrangle.

Oe Ely Springs Dolomite (Upper Ordovician) Light-gray, thin- to thick-bedded, burrow-mottled and bioclastic dolostone and limestone (Page et al., 2005).

Ꞓb Bonanza King Formation (Upper to Middle Cambrian) Light to dark, dolostone, limestone, and siltstone, with alternating light and dark beds that give the unit a distinctive banded appearance (Page et al., 2005). The Bonanza King Formation is exposed in the Arrow Canyon Range to the west of the California Wash basin and to the south in the Muddy Mountains.

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