Geologic Map of the Circle Mesa Quadrangle, Grant County, New Mexico

By

Steven J. Skotnicki

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New Mexico Bureau of Geology and Mineral Resources
Open-file Digital Geologic Map OF-GM 225

Scale 1:24,000

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New Mexico Bureau of Geology and Mineral Resources
801 Leroy Place, Socorro, New Mexico, 87801-4796

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Introduction

The Circle Mesa quadrangle lies between about 6 and 13 miles west of Silver City, New Mexico. Elevations range from about 4,840 feet on the western edge of the map to 7,470 feet on the top of Little Bear Mountain. The quadrangle spans the area between the northwestern-most end of the Little Burro Mountains in the south and the Silver City Range in the north. Most of the quadrangle lies within the Mangas Creek drainage basin, and only the far northeast corner of the map drains northward. The area lies near the northern edge of the Basin and Range province and the southern edge of the Mogollon-Datil volcanic field.

Within the quadrangle Proterozoic granite is nonconformably overlain by a sequence of Paleozoic and Cretaceous sedimentary rocks that are in turn overlain by red sandstone and conglomerate and voluminous mid-Tertiary ash-flow tuffs and shallow intrusive lavas. Radiometric ages from neighboring areas suggest the Tertiary rocks are Oligocene in age (~34 Ma). In the Silver City Range the ash-flow tuffs appear to have the same attitude as the underlying Mesozoic and Paleozoic strata, indicating that there was little deformation and tilting of the Mesozoic and Paleozoic strata until after emplacement of the Tertiary deposits. The absence of Mesozoic and Paleozoic rocks between Proterozoic granite and Tertiary volcanic rocks in the Big Burro Mountains, however, indicates that the areas south of the Mangas Valley experienced uplift and erosion prior to emplacement of the Tertiary rocks. Mapping was carried out during December, 2009 and June, July, and December, 2010. Most of the area is dotted with Piñon and Juniper trees, but the lower elevations and many areas underlain by Holocene sedimentary deposits commonly contain yucca. Deer, rabbits, and badger were seen during this study.

Previous Work

Hedlund (1978) mapped the geology of the Wind Mountain quadrangle to the south. Cunningham (1974) and Hildebrand and others (2008) mapped the Silver City 7.5' quadrangle to the east. Finnell (1982) mapped the Dorsey ranch 7.5' quadrangle to the north, the Cliff quadrangle to the northwest (Finnell, 1987), and the Reading Mountain quadrangle to the northeast. Wargo (1959) mapped the geology in the Schoolhouse Mountain quadrangle to the southwest. McLemore (2005) studied the mineral deposits and geology in the Wild Horse Mesa area to the southwest. Copeland and others (2010) compiled previous mapping and new mapping to create a geologic map and cross-sections of the Silver City Range. Cunningham (1997) originally mapped the geology of the Circle Mesa quadrangle. Amato and others (2008a, b) have mapped much of the geology of the big Burro Mountains to the southwest.

Precambrian Rocks

A small lenticular outcrop of quartz-muscovite schist is exposed on the southwest side of Treasure Mountain. This rock contains quartz and medium- to coarse-grained muscovite crystals, and exhibits a strong northwest-striking foliation that dips about 34° to the northeast. The same type of rock was mapped not far to the east, in the Silver City quadrangle, where its protolith was interpreted to be an impure quartzite. The lenticular outcrop is completely surrounded by granite (**YXg**). The granite is medium- to marginally coarse-grained and equigranular, and is composed of relatively equant crystals of K-feldspar, plagioclase, and quartz. Biotite is almost completely altered to hematite and most outcrops appear leucocratic as a result. The hematite disseminated throughout gives all exposures a light rusty orange color (*Photos 1 and 2*). No dikes or veins were obvious, and the granite appears relatively homogeneous in appearance.

The age of this granite is uncertain, although it is overlain by, and thus older than, the Cambrian Bliss Formation. It is locally strongly foliated in the central part of the Silver City quadrangle to the east, but foliation is absent everywhere else. No foliation is visible within the Circle Mesa quadrangle. South of the map area, from the Mangas Valley Road, distant outcrops of granite in the Little Burro Mountains weather and erode in a similar fashion, but because the exposures are entirely on private property it is not known for certain if the two areas correlate. The granite forming the broad pediment on the north side of the Big Burro Mountains to the south and southwest, however, is a different granite. Here the granite is K-feldspar-megacrystic, and contains light gray K-feldspar phenocrysts over 1 cm across surrounded by abundant fresh biotite. It is also locally foliated. It is quite distinct from the granite in the Silver City Range.

Paleozoic Rocks

The Circle Mesa quadrangle contains a well exposed section of Paleozoic rocks that are continuous with Paleozoic formations to the east in the Silver City Range. The formations include the basal Cambrian-Ordovician Bliss Formation overlain by the

Ordovician rocks of the El Paso Formation and Montoya Formation. These are in turn overlain successively by the Silurian Fusselman Dolomite, the Devonian Percha Shale, and the Mississippian Lake Valley Limestone. The total thickness of the Paleozoic section is about 2,400 feet.

The Bliss Formation spans the Cambrian to Lower Ordovician (*Photo 3*). It is a poorly sorted medium- to coarse-grained quartz sandstone/quartzite. It is medium to thick bedded and typically shows planar cross-bedding in sets tens of centimeters up to a meter or more thick. The matrix is dark reddish brown and gives the rock and overall dark brown color. Seen from a distance the formation forms step-like outcrops and locally small cliffs (*Photo 4*). Fine-grained hematite and greenish glauconite grains are common in the matrix. The lowermost layers contain abundant vertical *Skolithos* trace fossils (*Photo 5*). The upper part of the formation contains dark yellowish gray fine-grained dolomite beds.

The Lower Ordovician El Paso Formation overlies the Bliss Formation. It is mostly thin- to medium-bedded and is characteristically mottled in appearance (*Photo 6*). Intraformational carbonate-clast breccias are common as are thin stringy chert nodules that are mostly parallel to bedding planes (*Photo 7*). The formation is fairly well exposed in the map area and typically forms steep slopes. Locally, the unit contains thin lenses of yellow to reddish purple chert breccia associated with thin silicic laminae and fine-grained sandstone (*Photos 8 and 9*). These lenses are several tens of centimeters thick and several meters or more long. They resemble cave-fill deposits and cavern-roof break-down breccias. Good examples of the possible cave deposits occur near UTM 3634500, 743200.

The Upper Ordovician Montoya Formation rests in sharp contact on the El Paso Formation. It is composed of a lower more thick-bedded Poham member and the overlying thin-bedded chert-rich Aleman member. The lower Poham member is typically darker gray than the underlying El Paso, and contains abundant well rounded medium to coarse quartz sand grains, which commonly weather out to form sandy lag deposits on the surface (*Photos 10 and 11*). These beds also contain abundant fossil debris that is replaced by sparry calcite. Locally the beds are massive and show contorted internal fabrics that resemble bioturbation. The upper Aleman member is thin-bedded lighter gray dolomite interbedded with bedded light pink to gray chert that forms 1-2 cm-thick sheets parallel to bedding and typically comprising 50% or more of the member (*Photo 12*).

The overlying Lower to Middle Silurian Fusselman Dolomite is a characteristically light gull gray-colored, fine-grained dolomicrospar that tends to weather into relatively angular small cobble-sized blocks. Although not as abundant as in the Silver City quadrangle, the formation contains light gray silicified colonial corals (*Favosites?*) (*Photo 13*). They are composed of hexagonal pillars between 2-5 mm across that radiate upward from a holdfast to form mushroom-shaped (the larger forms) and balloon-shaped (the smaller forms) colonies between 2 and 30 cm across. In contrast to all the other silicified fossils in the Paleozoic section this coral is replaced by light gray coarse-grained quartz (megaquartz). These corals, and the type of silicification, are found in no other unit. This formation also contains thin layers of broken and silicified brachiopod fragments. The rock gives off a strong fetted odor when broken.

The top of the Fusselman Dolomite is locally extensively silicified. Great exposures in Cane Spring Canyon show tongues of chert filling vertical ‘channels’ in the underlying dolomite up to several feet deep, overlain by a discontinuous zone of silicification capping the formation (*Photo 14*). The deposit forms a very resistant slightly darker colored cap atop the less altered dolomite. It is composed of what appears to be yellowish brown granular microcrystalline quartz (chert) and younger, lighter-colored cavity-filling chert that appears to be fibrous chalcedony. The silicification likely formed during subaerial karsting of the Fusselman Dolomite during uplift and exposure of the formation during the Silurian. The vertical tongues of chert probably represent small solution cavities (or ‘dolines’) that formed when the formation was subaerially exposed and subjected to dissolution by rain water.

The Devonian Percha Shale is poorly exposed in the map area. It weathers recessively and, as a result, forms slopes that are almost everywhere mantled by colluvium. The formation is best exposed in steep gullies, particularly about ¼ mile south-southeast of Cane Spring, and in the steep ravine of Cottonwood Creek about one mile east of Circle Mesa. The upper portion contains abundant thin limestone layers interbedded up to several centimeters thick, interbedded with shale. The limestone layers contain brachiopod fossils and other fossil fragments. This upper part has been described elsewhere as the Box member of the Percha Shale, while the underlying portion is likely equivalent to the Ready Pay member.

Resting in sharp contact on the Percha Shale is the Mississippian Lake Valley Limestone (Armstrong et al., 2004) (*Photo 15*). This blue-gray formation is characteristically thick-bedded and contains large medium gray to pale red chert nodules up to 40 centimeters long, ten centimeters thick, and almost everywhere parallel to bedding. These chert nodules comprise a relatively small percentage of the rock but are generally a diagnostic feature of the unit (*Photos 16 and 17*). This formation is commonly fossiliferous and contains abundant crinoid stem disks and less abundant horn corals. The top of the formation locally exhibits a striking deep red deposit composed of light yellowish gray angular chert fragments surrounded by a massive, deep red matrix containing abundant hematite and silica (*Photos 18 through 20*). In some of these red areas bedding is nonexistent to faint, while in others the original stratigraphy is preserved, yet highly fractured and completely silicified. Great exposures in Cane Spring Canyon and Cottonwood Creek are locally greater than 20 feet thick (*Photos 21 and 22*). This deposit probably represents a silicified karst residuum that likely formed when the Lake Valley Limestone was uplifted and exposed to dissolution during a regional uplift event in the Mississippian. There are no overlying shale beds or interbedded shale and limestone beds of the Oswaldo Formation exposed in the map area.

Mesozoic Rocks

The Cretaceous Beartooth Quartzite forms a bold, south-facing cliff between Cane Spring Canyon and Cottonwood Creek (*Photos 23 and 24*). This clean, light gray sandstone contains well sorted, fine-grained quartz grains that are partially to completely fused together to form protoquartzite and quartzite. Sparse, thin conglomeratic layers several centimeters thick contain angular to subrounded red and yellow chert clasts, and what looks like gray quartzite clasts (*Photo 25*). Within the Circle Mesa quadrangle the Beartooth Quartzite everywhere rests on the lake Valley Limestone.

The Cretaceous Colorado Formation is composed of thin interbedded siltstone and shale (*Photo 26*), with minor fossiliferous limestone (*Photo 27*). As a result, it typically erodes into slopes and is poorly exposed. Everywhere where it is exposed it rests on the Beartooth Quartzite, but its thickness varies greatly due to post-depositional erosion. Locally, the formation has been completely eroded away. The best exposures are immediately east-northeast of Circle Mesa, exposed in the creek bed of Cottonwood Creek, where the formation rests in sharp contact with the underlying Beartooth Quartzite (*Photo 28*).

Tertiary Volcanic Rocks

The base of the Tertiary section is a dark red mostly sedimentary unit composed of interbedded sandstone and conglomerate, here called the 'older conglomerate' (map unit **Tco**) (*Photos 29 and 30*). Granule to cobble-size clasts are subrounded to well rounded and are dominated by dark purple volcanic rock containing 10-20% light gray feldspar phenocrysts up to a 1-2 mm long. As such, these clasts resemble unit **Td** above, but must have come from an older unit. Less abundant light purplish gray sandstone/quartzite resembles **Kb**. Locally, the unit contains sparse cobbles of granite, indicating that source areas of granite were already exposed nearby at this time (or were plucked from an older conglomerate). This unit is weakly lithified and crumbles relatively easily with a hammer, forming low rounded hills. East of Circle Mesa this unit contains large boulders of an intrusive rock that resemble the Tertiary intrusive rock at McComas Peak (in the Silver City quadrangle to the east) which contains large black hornblende/pyroxene crystals up to 1.5 cm long (*Photo 31*). As mapped, the unit also contains at least two crystal-poor ash-flow tuffs (locally mapped separately as **Tta**). The tuffs are weakly to moderately welded and contain only very sparse, tiny subhedral biotite crystals. No other phenocrysts are visible in hand-samples. The tuff is characteristically medium blue-gray to yellow gray and contains dark purple fiame that are probably altered flattened pumice.

The older conglomerate and associated tuffs are overlain by a thick, massive, relatively crystal-rich ash-flow tuff (**Ttq**). This tuff contains no visible flow breaks and contains phenocrysts of subhedral clear sanidine, rounded resorbed quartz, and tiny biotite that together comprise between 5-15% of the rock. Outcrops appear light tan to light bluish gray. The phenocrysts locally stand out on weathered surfaces, giving the rock a slightly granular appearance. Unlike the overlying tuff this unit contains few lithic fragments. Nowhere is the unit welded enough to exhibit a definite eutaxitic foliation.

This tuff is overlain by an even more voluminous crystal-poor ash-flow tuff (**Ttl**) that contains very sparse quartz phenocrysts and very abundant angular lithic fragments and yellowish green altered pumice (*Photos 32 and 33*). Locally, this tuff contains large blocks of older, altered ash-flow tuff (*Photo 34*) as well as quartzite and other volcanic rocks, some of which are many meters across. Some of these blocks form resistant caps on ‘pedestal rocks’ visible on the east wall in the small canyon near UTM 743300, 3637500 (*Photo 35*). Because much of the outcrop area of this tuff was on private property, it was not examined very extensively. West of Circle Mesa the unit had been subdivided by Cunningham (1997) into different members based on appearance. Indeed, standing on the west side of Circle Mesa and looking northwest it appears that there is a noticeable stratigraphy. However, variations in color and weathering style could only be traced short distances before merging into areas that appeared chaotic and mixed. Closer examination showed that all of these variations contained the same phenocryst assemblage of sparse quartz and abundant lithics. The deep canyon immediately west of Circle Mesa reveals good exposures of the various colors and textures of the unit. Only in one area west of Circle Mesa were the pumice fragments welded strongly enough to define a eutaxitic foliation.

Two distinct lavas intrude both ash-flow tuff units: an older dacite lava and a younger rhyolite lava. The dacite lava contains abundant small light gray feldspar phenocrysts in a dark brown to purple aphanitic matrix (*Photos 36 and 37*). It is possible that the rock is chemically really andesite or quartz diorite, but local flow-foliation suggests it may contain slightly more silica. The unit shows both dike-like and near-horizontal contacts. It is intruded by rhyolite lavas, which contain sparse phenocrysts of quartz, biotite, and clear feldspar. The rhyolite exposures also show dike-like relationships and, as Cunningham (1997) observed, probably represent the shallow intrusive portions of extrusive bodies (*Photos 38 through 40*).

In the northern part of the map area both dacite and rhyolite are overlain by another ash-flow tuff (**Ttr**) containing mostly abundant angular fragments of flow-banded rhyolite. Since this tuff overlies the exposed roots of the lavas, there was a period of erosion that removed some of the lavas before deposition of the younger tuff. This tuff is mostly massive, is locally bedded, and is nowhere welded.

In the southwest part of the quadrangle rhyolite intrudes bedded and massive tuff. The light tan to yellow tuff here (**Tt**) contains sparse quartz and biotite phenocrysts and abundant lithics, similar to unit **Ttl** near Circle Mesa. It is possible that these two tuffs are equivalent.

The aphyric basalt (**Tb**) that is exposed in the southern part of the map area is difficult to place stratigraphically (*Photo 41*). Everywhere within the quadrangle it is overlain unconformably by younger basin-fill sedimentary deposits. Immediately south of the map, however, the basalt appears to rest on a thick massive light gray deposit that, from a distance, resembles an ash-flow tuff unit. Without actually examining this unit, it is assumed that the unit correlates with the tuff in the southwest corner of the map and that the basalt is younger than the tuff. It is unlikely that this basalt correlates with the olivine basalt (**Tby**) interbedded with basin-fill sedimentary deposits along Cottonwood Creek. The aphyric basalt appears to be below the base of the basin-fill section while the olivine basalt appears to be somewhere near the top. Finnell (1982) also mapped thin basalt flows interbedded with basin-fill sedimentary deposits within LS Mesa immediately north of the Circle Mesa quadrangle. It is likely that unit **Tby** correlates with those flows (*Photos 42 and 43*).

Tertiary Basin-Fill Deposits

The Tertiary basin-fill deposits in the Basin and Range province have traditionally been called the 'Gila Conglomerate.' The term is more than a century old, and subsequent studies in different basins have shown that the unit contains more than just conglomerate, but also sandstone, siltstone, marl and clay-rich lacustrine deposits, as well as interbedded volcanic rocks of various types. Probably a more proper name for all of these deposits—which were deposited within fault-bounded basins from the end of the Miocene through the Pliocene—is the 'Gila Group'.

Within the Circle Mesa quadrangle the Tertiary basin-fill deposits of the Gila Group are subdivided on the basis of clast assemblages. There are at least five distinct units within this group. The oldest unit, **Tcv**, contains mostly angular pebble-size volcanic clasts in a tan silty to volcanic sand matrix (*Photo 44*). The pebble-size volcanic fragments are mostly two types: rhyolite lava and platy ash-flow tuff. In the southwest part of the map many of the ash-flow tuff fragments are weakly to moderately welded and show compressed fiame and pumice. This unit rarely contains other lithic types. In the southwest part of the map it appears to merge laterally with unit **Tci.** This unit contains abundant clasts of foliated and nonfoliated dark green diorite/amphibolite, quartzite, and minor basalt and ash-flow tuff, but the larger clasts (up to ~25 cm) are dominated by light greenish gray feldspar porphyry. The feldspar porphyry contains light gray subhedral feldspar up to 2 mm across, and acicular, needle-like phenocrysts of black amphibole (or pyroxene?). The feldspar porphyry clasts become smaller northward across Mangas Creek, and they were not mapped in outcrop in the Silver City Range, suggesting their source was to the south. **Tcb** is another volcanic-rich basal unit that directly overlies aphyric basalt in the northwestern end of the Little Burro Mountains, and contains almost exclusively clasts of aphyric basalt (*Photo 45*).

Both **Tcv, Tcb** and **Tci** appear to be rather sharply overlain by a light pink to tan mostly sandy sedimentary unit, **Tcg** (*Photos 46 through 49*). This unit contains abundant clasts of foliated to nonfoliated dark green diorite/amphibolite, white vein quartz, quartzite (resembling the Beartooth Quartzite), granite, and less abundant clasts of quartz-muscovite schist, aphyric basalt, ash-flow tuff, and smaller light greenish gray feldspar porphyry. Some granite clasts resemble unit **YXg**, exposed around Treasure Mountain, but most are characteristically lighter gray with little or no hematitic alteration, contain abundant biotite, and are slightly coarser grained (*Photo 50*). As such, the clasts more resemble the Tertiary granite exposed to the south than Precambrian granites. This unit also characteristically contains rare reddish orange clasts of altered granite that stand out in contrast to the light tan deposits (*Photos 51 and 52*). Although they are sparse (one clast was seen about every 20-30 feet of walking across the ground) they are quite obvious and were seen in no other unit. According to Virginia McLemore (personal communication) these are episyenite that are exposed in the Big Burro Mountains to the south (McLemore, 2005). Most of this unit is sandy and grusy, and contains a noticeable population of light gray feldspar crystals up to 1.5 cm across (*Photo 53*). The source of this unit appears to be to the south, in the Big Burro Mountains. Before maximum displacement along the Mangas fault, the deposits wrapped around and mostly buried the basalt hills near the southern edge of the quadrangle. To the northwest, this unit has a sharp contact with the underlying volcanic-clast unit (**Tcv**).

To the northeast unit **Tcg** merges and interfingers with map unit **Tcm**. The composition of this unit is quite variable. To the northwest it is dominated by volcanic clasts composed of both dacite (**Td**) and lithic-rich tuff (**Ttl**) (*Photos 54 through 56*). In the central part of the map it is a mixture of volcanic and sedimentary (Paleozoic and Cretaceous) clasts, and locally a significant amount of basalt clasts. To the southeast it is dominated by Paleozoic and Cretaceous clasts with a significant percentage of granite, diorite/amphibolite, and quartz-muscovite schist.

The last basin-fill unit, **Tcf**, is exposed only below LS Mesa in the northeast corner of the map. It contains clasts of andesite (or dacite?), quartzite, olivine basalt, and sparse limestone and chert. The unit has been faulted by the Bear Mountain fault, and appears to thicken to the north.

All of these units record the history of sedimentation into newly formed half-grabens created by movement along the northwest-striking Mangas and Treasure Mountain faults. At first, displacement was only enough to uplift and expose the Tertiary volcanic rocks to erosion. The subsequent volcanic debris formed the lowermost **Tcv** deposits at the base of the group. As displacement continued the crustal blocks were rotated more to the point where uplifted Paleozoic and Mesozoic rocks were exposed in the Silver City Range. But because the Paleozoic and Mesozoic rocks in the Big Burro Mountains to the south had already been stripped away prior to Tertiary volcanism (Kelly, NMBG website), the uplifted and exposed rocks in the Big Burro Mountains block shed only Proterozoic rocks and Tertiary intrusive rocks. The deposits of **Tci** and **Tcg** reflect this change in source terrain. At the same time material was continually being shed from the steep Treasure-Mountain fault scarp in the Silver City Range, forming the mixed, variable-lithology deposits that interfinger with the deposits being transported northward. Although the axis of the former basin likely migrated in response to movement along the faults, its original location is approximately the dashed contact where units **Tcg** and **Tcm** meet on the map. Only much later did the modern-day Mangas Creek cut a valley considerably southwestward of the original valley axis.

Quaternary Deposits

The Quaternary sedimentary deposits can be subdivided on the basis of the extent of soil development and height above the modern drainage. Nearly all of these units form very thin deposits, a few meters thick, that form nearly flat, gently sloping constructional surfaces. As such, most researchers tend to call these deposits 'terrace deposits.'

The oldest Quaternary deposits (**Qo**) form mostly small remnants capping the topographically highest parts of the basin-fill deposits. They typically rest about 150-200 feet above the modern creek beds (*Photo 57*). These deposits typically contain dark reddish brown clay-rich argilic soil horizons (*Photos 58 and 59*). One particular remnant exposed on the south side of Cottonwood Creek, near the west side of the map, contains abundant carbonate clasts and exhibits a poorly exposed petrocalcic horizon, or 'caliche' (unit **Qoc**) (*Photos 60 and 61*). LS Mesa in the northeast corner of the quadrangle is capped by the most extensive **Qo** deposits, which form a flat, gently sloping surface.

Qm deposits are between about 50 and 80 feet above the modern drainages (*Photos 62 and 63*). These deposits are typically a few meters thick at most and are characterized by a well developed dark reddish brown clay-rich soil on the upper surface. Throughout the map are they characteristically contain abundant subangular to subrounded clasts of foliated diorite/amphibolite, quartzite, dacite, tuff, less abundant rounded limestone, angular chert, and minor granite, basalt, vein quartz, and quartz-muscovite schist, even in deposits in the northwestern part of the map.

Ql deposits are typically between 10 and 30 feet above the modern drainages. Soil development is characterized by moderate clay accumulations and generally well developed dark organic horizons within a few feet of the surface. As mapped, this unit also contains what would be considered colluvium, in particular south of Treasure Mountain.

Qy deposits are dominated by fine silt and sand, but also contain lenses of coarse gravel and cobbles. These deposits form the relatively flat valley floors (*Photos 64 and 65*), but have been dissected by the modern streams. Steep cliff exposures along some arroyos reveal multiple clay-rich soil horizons. The deepest dissection, up to 15-20 feet, is visible along Mangas Creek (*Photos 66 through 69*). Dark organic horizons are common within 0.5 meters of the surface.

Structure

Folding

Cunningham (1997) recognized that the Paleozoic rocks at Treasure Mountain are slightly folded, and suggested that the cause might be doming of an intrusive rock below at some depth. Rather steeply south-tilted Paleozoic rocks are also exposed in a small window between two faults on the south side of Treasure Mountain. Cross-section B-B′ is drawn through this area. Instead of doming, the folding here is interpreted to be the result of Laramide crustal compression. If the Paleozoic rocks in cross-section B-B′ are restored to their pre-faulted positions it is evident that they form a small uplift, a little more than a mile across. The fault on the north side of Treasure Mountain and the fault on the immediate south side of Treasure Mountain are interpreted to have originally been reverse faults, which subsequently reversed their sense of motion and underwent normal displacement during mid-Tertiary extension and formation of the Mangas Valley. See Copeland and others (2010) for more cross-sections across the Silver City Range that show folding.

Northeast-striking Faults

There appear to be two distinct orientations of faults in the map area: those that strike to the northeast and those that strike to the northwest. There are several major northeast-striking faults exposed in the northeast part of the map. Almost all of them show a down-to-the-west sense of movement. The largest of them, here called the Bear

Mountain Fault, drops the Paleozoic section, and the entire Tertiary section, down over 2,000 feet with respect to the Paleozoic rocks at Little Bear Mountain on the east side of the fault (*Photo 70*). This fault slices northward where it offsets Tertiary basin-fill deposits in the Silver City and Reading Mountain quadrangles (Hildebrand et al., 2008, and Finnell 1976, respectively) and continues northward. Based on the offset of the Bliss Formation on the west side of Treasure Mountain, however, offset on the Bear Mountain Fault appears to be much less in the south than it is in the north. Alternatively, the Bear Mountain Fault may actually be continuous with the northwest-striking fault on the north side of Treasure Mountain, which exhibits considerably more offset than does the fault to the west. A smaller northeast-striking fault, near the middle of Treasure Mountain, is the only north-northeast-striking fault that shows a down-to-the-east sense of displacement. Here, the Bliss Formation has been down-dropped on the east side by about 150 feet.

Two northeast-striking faults near the southeast corner of the map bound a small graben. The graben down-drops light tan granitic-rich basin-fill sediments (**Tcg**) against basalt and basalt-rich conglomerate (**Tcb**). The visible relationships indicate a minimum displacement of several hundred feet. Although the fault planes are not visible to the north were there is only **Tcg** on the south side of the highway there is an obvious difference between weakly cemented outcrops on the west and strongly cemented outcrops to the east, in the vicinity of mile marker 105. North of the highway there is a marked lineation that follows a drainage, where hills to the west stick up high while those to the east are low. These relationships suggest one of the graben-bounding faults projects northward across the highway in this area. Gillerman (1970) identified several other northeast-striking faults to the south in the Tyrone district.

Northwest-striking Faults

The northeast-striking faults appear to terminate at and be cut by the large northwest-striking Treasure Mountain fault. Previous studies have assigned the name ‘Treasure Mountain fault’ to the northwest-striking fault that bounds the south side of the Silver City Range. However, because the structure had not been mapped in detail until now it was not recognized that it is actually a series of en echelon faults and not one distinct feature. As such, it may seem somewhat inaccurate to name each en echelon branch the Treasure Mountain Fault. Assigning a new name to each branch, though, would likely be even more confusing. So herein the name Treasure Mountain fault is applied to the two major branches shown on the map, as well as the en echelon branch in the Silver City quadrangle to the east that projects across the north side of Treasure Mountain.

Based on the 10-15° northeast dip of bedding within conglomerate (**Tcb**) immediately overlying basalt near the south side of the map the Treasure Mountain fault has displaced the Tertiary volcanic rocks a vertical distance of at least 4,500 feet (see cross-section B-B′). The steeper 30-45° dips of tuffs in the southwest corner of the map suggest that displacement may be even greater (see cross-section A-A′). The observation that the Tertiary basin-fill sedimentary deposits on the south and southwestern sides of the map—the deposits immediately overlying the volcanic rocks—exhibit the steepest northeast dips, while the sedimentary deposits northeast of the Mangas Valley are very close to flat lying, suggests that the Tertiary basin-fill deposits form a fanning-dip sequence (*Photo 71*). Sediments shed off the Silver City Range and the Big and Little Burro Mountains filled a half-graben that became continually deeper with each episode of faulting and displacement. The older deposits became progressively more steeply tilted as the fault blocks rotated and the basin deepened, while the newer sediments were deposited in nearly horizontal layers.

From the south side of Treasure Mountain, the Treasure Mountain fault projects northwestward for about 4 miles where it crosses Cottonwood Creek. Here the fault splits into several small splays that all have the same sense of displacement. One main branch of the fault continues northwestward, roughly paralleling the creek where it appears to terminate at a ridge-like outcrop of rhyolite (**Tr**). The southernmost branch of the fault also appears to terminate at, or very near, the same rhyolite. Careful mapping shows that this rhyolite forms a dike-like outcrop that widens to the north. West of the rhyolite are exposures of lithic-rich ash-flow tuff (interpreted to be **Ttl**), while west of it are units much lower in the stratigraphic section. It is here interpreted that the rhyolite intruded along a branch of the Treasure Mountain fault which had already displaced the section more than 2,000 feet. Therefore, movement on at least this part of the Treasure Mountain fault occurred after deposition of **Ttl** but prior to rhyolite emplacement. Further north the rhyolite is depositionally overlain by the rhyolite-rich tuff (**Ttr**). Private property limitations prevented detailed mapping of the headwaters of Cottonwood Creek, but from a distance it looks as though the rhyolite body extends at least another mile north where it forms a large cliff-like outcrop north of Blacksmith Canyon.

West of Cottonwood Creek another branch of the Treasure Mountain faults is well defined and projects to the northwest. The area in between the two en echelon branches, however, is somewhat confusing. Basin-fill sediments rich in volcanic clasts (**Tcv**) dip up to 25° to the southeast. The contact between **Tcv** and **Td** shows no signs of faulting and is here interpreted and depositional. The sediments themselves are strongly cemented with calcite west of Cottonwood Creek and grade into less lithified, and less tilted, deposits eastward. On the east side of the creek **Tby** forms an obvious break between the volcanic-rich sediments of the **Tcv** and the more mixed assemblage of **Tcm**. The basalt pinches out on the west side of the creek but even so the contact between the two basin-fill units is easy to place because of the different assemblages and because of the different attitudes of the beds. What is difficult to reconcile is the apparent termination of both major en echelon branches of the treasure Mountain fault within the basin-fill sediments.

The Mangas fault is exposed near the southern boundary of the map, along the northern tip of the Little Burro Mountains. Here it displaces light tan to pink granitic-rich sediments (**Tcg**) down on the west against basalt and basalt-rich conglomerate on the east. The fault is fairly well exposed in two places in this area; just north of the southern map boundary at about UTM 3626400, 741200, and a bit further north near UTM 3627100, 740600. Neither exposure is quite good enough to allow a measurement of the dip of the fault, but it is apparent that the structure dips rather steeply to the southwest. The **Tcg** deposits along the fault are not obviously tilted. Immediately north of the second locality, the deposits of **Tcg** on the east side of the fault are moderately lithified and form a steep resistant hill, while the deposits on the west side of the fault are poorly lithified and form low hills. It is not possible to map the fault north of this area. There is no obvious lineation on aerial photos and the hills in the area erode easily and are mantled with obscuring regolith (*Photos 72 and 73*).

Mineralization

The only visible areas of mineralization occur at Treasure Mountain and the westernmost fault that crosses Spring Canyon. In both of these areas the Paleozoic rocks are intensely fractured and extensively replaced by stockwork-like veins of silica, in some areas nearly 100% of the rock exposures (*Photo 74*). The rectilinear pattern of silica veining suggests that silica-rich fluids permeated and filled fractures in these areas, while in the same areas it appears that silica has replaced original carbonate. The abundance of silicification at Treasure Mountain may be a consequence of more intense fracturing that occurred during formation of the uplift. The silicification along the fault to the west, particularly where it makes a sharp bend, suggests it is also related to fracturing associated with the fault.

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Unit Descriptions

Circle Mesa 7.5′ Quadrangle

Quaternary Deposits

Qy **Holocene alluvial deposits.** Dominated by fine silt and sand, but also contains lenses of coarse gravel and cobbles. These deposits form the relatively flat valley floors, but have been dissected by the modern streams. Steep cliff exposures along some arroyos reveal multiple clay-rich soil horizons. The deepest dissection, up to 15-20 feet, is visible along Mangas Creek.

Ql **Late Pleistocene alluvial deposits.** Interbedded sands and gravel. These deposits are typically a few meters thick at most and are between about 10 and 30 feet above the elevation of the modern drainage. Soil development is characterized by moderate clay accumulations and generally well developed dark organic horizons within a few feet of the surface. As mapped, this unit also contains what would be considered colluvium, in particular south of Treasure Mountain.

Qlm **Middle to late Pleistocene alluvial deposits.** Mapped only in the northwest corner of the map where it is intermediate in elevation between units **Ql** and **Qm**.

Qm **Middle Pleistocene alluvial deposits.** Interbedded sand and gravel. These deposits are typically a few meters thick at most and are characterized by a well developed dark reddish brown clay-rich soil on the upper surface. Commonly contains abundant subangular to subrounded clasts of foliated diorite/amphibolite, quartzite, dacite, tuff, less abundant rounded limestone, angular chert, and minor granite, basalt, vein quartz, and quartz-muscovite schist, even in deposits in the northwestern part of the map. Forms flat, dissected terraces about 50-80 feet above the modern drainages. One exposure is anomalously thick, at the confluence of Mangas Creek and Cottonwood Creek, on the north side, where a stream-cut creates a good exposure.

Qmo **Early to middle Pleistocene alluvial deposits.** Mapped only in the northwest corner of the map and on the south side of Cottonwood Creek where it is intermediate in elevation between units **Qm** and **Qo**.

Qo **Early Pleistocene alluvial deposits.** Interbedded sand and gravel. In the northwest corner of the map these deposits are dominated by pebbles to large cobbles of hypabyssal felsic intrusive rocks that resemble the Bear Mountain intrusion, and less abundant light gray quartzite (resembles **Kb**) and sparse limestone. Forms small remnant deposits further west and south where deposits are dominated by dacite, tuff, quartzite, rounded limestone, chert, minor basalt, sparse foliated diorite, and smaller angular gravels of rhyolite. In some deposits, foliated diorite/amphibolite is quite common. Where exposed, the sandy matrix is composed mostly of volcanic fragments with minor quartz. All **Qo** deposits are characterized by thick dark reddish brown soils. Locally, pedogenic carbonate (caliche) is visible. About 2-3 meters thick (6-10 feet).

Qoc **Early Pleistocene alluvial deposits, carbonate clasts.** Interbedded sand and gravel. This unit was mapped only in one location, on the south side of Cottonwood Canyon, about one mile east of its confluence with the Mangas Valley. It contains mostly subrounded limestone cobbles to boulders, then dacite, sparse granite (resembles orange-weathering **YXg**), hornblende-bearing hypabyssal intrusive rock, quartzite, and tuff. Pedogenic carbonate (caliche) is locally visible.

<u>Tertiary Deposits</u>

Tertiary basin-fill deposits:

Tcf **Conglomerate and sandstone, northeast deposits.** The only fresh exposure is in the road-cut near the northeast corner of the map where interbedded siltstone, sandstone, and conglomerate are visible. Contains angular to subrounded granule to small boulder-size clasts of andesite(?), less abundant sandstone/quartzite, smaller chert fragments, and sparse very dark gray basalt containing olivine inclusions and black xenocrysts with no cleavage that may be spinel. This unit is almost everywhere mantled by a dark reddish brown clay-rich soil (mapped as **Qo**). Two faulted exposures on the south side of Cane Spring Canyon, on the west side of the Bear Mountain Fault, are dominated by limestone and chert clasts up to large cobble-size.

Tcg **Conglomerate and sandstone, granitic unit.** This unit is predominantly sandy, with the sand fraction containing abundant quartz and feldspar and less abundant Tertiary volcanic and Precambrian metamorphic rocks. A smaller portion of the feldspar sand is composed of large light gray feldspar grains commonly up to and exceeding 1 cm across. Subrounded gravel clasts can reach 30 cm across, but most are less than 15 cm, and are dominated by foliated to nonfoliated dark green diorite/amphibolite, vein quartz, quartzite (resembling the Beartooth Quartzite), granite, and less abundant clasts of nearly aphyric basalt, ash-flow tuff, and locally light greenish gray feldspar porphyry that characteristically contains black needles of hornblende. Some granite clasts resemble unit **YXg**, exposed around Treasure Mountain, but many are characteristically lighter gray with little or no hematitic alteration, contain abundant biotite, and are coarser grained. As such, the clasts more resemble Laramide granites than Precambrian granites. This unit also characteristically contains rare reddish orange clasts of altered granite. According to Virginia McLemore (personal communication) these are episyenite that are exposed in the Big Burro Mountains to the south. Fresh exposures of **Tcg** are rare but are characteristically light pink to tan compared with the other sedimentary deposits. This unit is more easily eroded than the other Tertiary sedimentary deposits and mostly forms low rounded hills and dissected slopes.

Tcm **Conglomerate and sandstone, mixed unit.** Interbedded conglomerate and sandstone. The composition of this unit is quite variable. To the northwest it is dominated by volcanic clasts composed of both dacite (**Td**) and lithic-rich tuff (**Ttl**). In the central part of the map it is a mixture of volcanic and sedimentary (Paleozoic and Cretaceous) clasts, and locally a significant amount of basalt clasts. To the southeast it is dominated by Paleozoic and Cretaceous clasts with a significant percentage of granite, diorite/amphibolite, and quartz-muscovite schist.

Tby **Olivine basalt.** Dark gray. Contains subhedral olivine phenocrysts between 1-5 mm, mostly altered to red iddingsite, that appear as obvious red spots against the dark gray matrix. The matrix is aphanitic and contains tiny plagioclase microlites. Outcrops are typically extensively jointed. Rocks are very hard and difficult to break even with many blows of a hammer. There are at least two flows separated by a thin layer of sedimentary deposits identical to the material above and below (unit **Tcs**). Appears to thicken northeastward, and pinches out southeastward. A small isolated ‘plug’ of basalt in the SW corner of Section 7, T17S, R15W (UTM 3636300, 739600) may be the erosional remains of a conduit. A sample of this rock was collected for geochronology and sent to Bill McIntosh at New Mexico Tech.

Tci **Conglomerate and sandstone, feldspar-porphyry unit.** No good fresh exposures seen, but probably interbedded sandstone and conglomerate. The unit contains abundant clasts of foliated and nonfoliated dark green diorite/amphibolite, quartzite, and minor basalt and ash-flow tuff, but the larger clasts (up to ~25 cm) are dominated by light greenish gray feldspar porphyry. The feldspar porphyry contains light gray subhedral feldspar up to 2 mm across, and acicular, needle-like phenocrysts of black amphibole (or pyroxene?). These clasts are all angular and resemble a shallow hypabyssal intrusive rock. This type of clast becomes much smaller to the northeast, where it is seen as far as Fleming Canyon. This type of feldspar porphyry was not seen in the Silver City Range. The contact between **Tci** and **Tcv** is uncertain and is drawn rather arbitrarily.

Tcv **Conglomerate and sandstone, volcanic unit.** This unit is exposed in the western and southwestern parts of the map, and in a small window in the upper reaches of Cottonwood Canyon. It is composed mostly of pebbly conglomerate containing dominantly angular pebble-size fragments of crystal-poor fine-grained (and lithic-rich) ash-flow tuff (some clasts show welding), and rhyolite, in a tan silty matrix. In the southwest, bedding is not easy to see, except north of Saddle Canyon where deep dissection and small cliffs reveal planar-bedded exposures dipping about 6° to the northeast. Along Cottonwood Canyon this unit characteristically contains no clasts of olivine basalt, and is tilted southeastward as much as 24°. The deposits erode into steep, resistant, gray-colored hills that are slightly darker in color than the overlying Tertiary units.

Tcb **Conglomerate and sandstone, basaltic unit.** Coarse conglomerate. This deposit contains very poorly sorted, subangular to subrounded clasts of aphyric basalt from granules to large cobbles, and locally boulders 1 meter across. Locally, the unit also includes less abundant clasts of ash-flow tuff (sanidine + biotite) also up to boulders 1 meter across, and less abundant flow-banded rhyolite. The sandy to silty tan-colored matrix contains abundant light gray sand-size to small-gravel-size clasts of ash-flow tuff. Where exposed in stream-cuts bedding is typically indistinct to non-existent. These deposits are typically strongly cemented with calcite, which locally forms sparry crystals up to 5 mm wide. This unit directly overlies the aphyric basalt (**Tb**) near the southern boundary of the map where it is tilted slightly to the northeast.

Tb **Aphyric basalt.** This basalt contains no visible phenocrysts except tiny plagioclase microlites. Small exposures on the west side of Mangas Creek show sparse anhedral, almost clear feldspar up to 3 mm and tiny greenish glassy clots. Fresh surfaces are dark gray. Weathered surfaces are typically medium to light gray. Commonly vesicular. Locally, fractures contain light gray botryoidal silica (fibrous chalcedony). Forms steep resistant hills near the southern boundary of the map. South of the map area good exposures show basalt overlying a thick light gray colored deposit that, from a distance, resembles ash-flow tuff. (250+ feet thick)

Tbc **Scoria.** Dark red and black, massive to bedded scoria. Exposed in on location within basalt (**Tb**) near the southern edge of the map.

Ttr **Yellow lithic tuff.** Both ash-flow and air-fall deposits. This unit is mostly non-bedded and massive west of the headwaters of Cane Spring Canyon and thinly bedded to the east. To the west the unit contains very abundant angular clasts of flow-banded rhyolite up to cobble-size. To the east, where bedded, clasts also include andesite-looking rocks. This unit covers an irregular topographic surface in the underlying Td lava. (300+ feet thick)

Tr **Rhyolite.** Contains 1-2% subhedral to euhedral black biotite in thin books and anhedral glassy phenocrysts (either quartz or feldspar—difficult to distinguish) between 1-2 mm across. The aphanitic matrix is typically light tan to pink and commonly flow-banded. Outcrops commonly weather into thin, platy, angular fragments with less vegetation than other rocks. Outcrops exposed along Black Tank Canyon in the southwest corner of the map contain lenses of rhyolite autobreccia that may be the remnants of rampart breccias. As mapped this unit intrudes pyroclastic rocks (**Tt** in the southwest part of the map, and **Ttl** in the northern part of the map) and is overlain by lithic-rich tuff of unit **Ttr** near the northern edge of the map. (0-700+ feet thick)

Tt **Tuff.** Contains sparse subhedral to euhedral black biotite and anhedral glassy phenocrysts (either quartz or feldspar—difficult to distinguish)—similar to the mineralogy of **Tr**. This unit was mapped in the southwest corner of the map were it is intruded by rhyolite (**Tr**). Locally, tuff also appears to be interbedded with rhyolite, suggesting the two units are coeval. Most exposures show planar bedding, which dips to the northeast between about 20° and 60°. Outcrops are commonly light yellow to light tan. Although most exposures are bedded, some are massive and resemble ash-flow tuff, particularly on the west side of Saddle Rock Canyon (near UTM 3630000, 734200). (Thickness unknown)

Td **Dacite.** Contains 10-20% light gray subhedral plagioclase 1-3 mm long in a dark tan to gray to purple aphanitic matrix. Flow-banding is locally common. Forms resistant, dark-colored and jagged outcrops. Some exposures are fragmental and appear to be autobreccias. Outcrop patterns suggest that some exposures represent dike-like bodies that intruded the ash-flow tuffs of unit **Tta**. Mineralogically, this unit resembles andesite, but the abundant flow-banding suggests the rock may be slightly more silica-rich. The term 'dacite' is here used as a useful field term. It is quite possible that a chemical analysis may reveal this rock to be andesite or quartz latite. (0-400+ feet thick)

Tda **Aphyric dacite.** Dark gray aphyric lava. Massive, pervasively fractured, and locally brecciated. Some areas appear glassy. This unit is interpreted to be part of the dacite because it appears to line up with other more obvious dacite exposures, and because it is in the same stratigraphic position as dacite.

Ttl **Lithic-rich ash-flow tuff.** This tuff contains very sparse anhedral quartz phenocrysts 1-2 mm across. Characteristically contains very abundant angular lithic fragments of various types (apparently mostly rhyolite and less abundant quartzite) from granule to cobble-size surrounded by a deep red to pinkish tan aphanitic matrix. Bedding is almost non-existent, though there are suggestions of dipping layers from a distance locally. Where exposed along deep canyons it appears to be one and possibly two homogeneous flow units with no visible breaks except for a thin bedded air-fall tuff about a third of the way up from the bottom. It is characteristically massive, with only incipient eutaxitic foliation. Pumice fragments up to a few centimeters across are common and typically altered yellowish green. The lower portion contains rather sparse angular lithic fragments, but fragments increase in abundance upward where the unit forms steep tan-colored cliffs that appear rather smooth from a distance. Locally, the upper portions contain massive blocks up to several meters across or more. These blocks are composed of older lithic-rich ash-flow tuff, andesite-like lava rock, sparse siltstone that resembles the Percha Shale, and at least one clast of a foliated mafic granitoid. Some large blocks resemble ash-flow tuff but are altered shades of pink and light gray, suggesting that these blocks are fragments of an older ash-flow tuff that had already been hydrothermally altered prior to being incorporated into the enclosing tuff. Rare blocks form pedestal rocks on steep canyon walls. The area northwest of Circle Mesa is chaotic. (1,000+ feet thick)

Ttq **Quartz-sanidine ash-flow tuff.** This tuff contains only very sparse lithic fragments, and contains between 5-15% phenocrysts of large subhedral sanidine and rounded resorbed quartz, and biotite? both up to about 3 mm across. The percentage of phenocrysts is variable, but not enough time was spent to determine what trends, if any, exist. On weathered surfaces the darker gray phenocrysts stand out slightly in relief. The base of the unit contains several meters of bedded tuff. The tuff is typically blue-gray to yellow gray and massive. A sample of this rock was collected for geochronology and sent to Bill McIntosh at New Mexico Tech. (about 800 feet thick)

Tco **Older conglomerate.** This unit consists of interbedded dark red to purple sandstone and conglomerate and, as mapped, at least two thin ash-flow tuff units. Granule to cobble-size clasts are subrounded to well rounded and are dominated by dark purple volcanic rock containing 10-20% light gray feldspar phenocrysts up to a 1-2 mm long. As such, these clasts resemble unit **Td** above, but must have come from an older unit. Less abundant light purplish gray sandstone/quartzite resembles **Kb**. Locally, the unit contains sparse cobbles of granite, indicating that source areas of granite were already exposed nearby at this time (or were plucked from an older conglomerate). This unit is weakly lithified and crumbles relatively easily with a hammer, forming low rounded hills. East of Circle Mesa this unit contains large boulders of an intrusive rock that resemble the Tertiary intrusive rock at McComas Peak (in the Silver City quadrangle to the east) which contain large black hornblende/pyroxene crystals up to 1.5 cm long. (0-300 feet thick)

Tta **Older ash-flow tuff.** This ash-flow tuff is everywhere weakly to moderately welded and contains only very sparse, tiny subhedral biotite crystals. No other phenocrysts are visible in hand-samples. This unit is characteristically medium blue-gray to yellow gray and contains dark purple fiame that are probably altered flattened pumice. Mapped only locally. In other areas it is included with map unit **Tc**. (each tuff is about 50 feet thick)

Tf **Intrusive rhyolite.** Contains sparse (<1%) phenocrysts of clear quartz 2-4 mm across and even less abundant altered dark sports that may be the remains of biotite, all in a light tan to light pink aphanitic matrix. Flow foliation in places is sub-parallel to bedding in the Paleozoic rocks it intrudes. Locally, the flow foliation is kinked and folded. Pieces eroded from this unit have an almost lineated look to them and superficially resemble petrified wood. This unit may be equivalent to the unit **Tr** but because it intrudes the Paleozoic rocks in the northeastern part of the map and into the Silver City quadrangle it was mapped separately. The unit forms a thin sill-like body between the Fusselman Dolomite and Percha Shale.

Cretaceous Rocks

Kc **Colorado Formation**. Interbedded shale, siltstone, and fine-grained sandstone. Mostly medium to dark gray very fine-grained sandstone and siltstone, with subordinate shale. Some siltstone beds contain septarian concretions. Though rare some weathered-out nearly spherical concretions are up to 40 cm across (small boulder-size). Thinly laminated dark siltstones locally exhibit low-angle cross-beds in sets up to 2 cm thick. The unit forms slopes and is not well exposed. The best exposures are along the upper reaches of Cottonwood Creek, about one mile east-northeast of Circle Mesa. The contact between the Colorado Formation and the underlying Beartooth Quartzite is well exposed here in the creek bed and appears sharp. (Thickness 0-30 m)

Kb **Beartooth Quartzite.** This clean, light gray sandstone contains well sorted, fine-grained quartz grains that are partially to completely fused together to form protoquartzite and quartzite. Bedding is mostly medium to thick and commonly wavy. Ripple marks are locally visible and planar cross-beds are abundant in sets up to about 1 meter thick, but more commonly in sets 20-40 cm thick. In most outcrops, however, cross-bedding but it is mostly indistinct. Sparse, thin conglomeratic layers several centimeters thick contain angular to subrounded red and yellow chert clasts, and what looks like gray quartzite clasts. The quartzite commonly breaks into angular, resistant clasts that form a lag down-slope. Forms a small but prominent cliff between Cane Spring Canyon and Cottonwood Creek. (Thickness 30-40 m)

Paleozoic Rocks

Mlx **Red chert breccia atop the Lake Valley Limestone (Mississippian).** This striking deposit is composed of light yellowish gray angular chert fragments from sand-size to cobble-size, surrounded by a massive, deep red matrix containing abundant hematite and silica. In some areas bedding is nonexistent to faint, while in others the originally stratigraphy is preserved, yet highly fractured and completely silicified. Great exposures in Cane Spring Canyon are locally greater than 20 feet thick. This deposit represents a silicified karst residuum. (Thickness 0-7 m)

Ml **Lake Valley Limestone (Mississippian).** Thick-bedded blue-gray fossiliferous limestone. Interbedded fossiliferous grainstone beds composed of very abundant crinoid stem debris, and fossil-poor laminated micrite beds. Pinkish gray to almost black chert nodules up to a few meters long and up to 10 centimeters thick preferentially occur within the laminated beds but also occur with fossiliferous beds. Limestone laminae wrap around chert nodules. Overall, chert forms a minor component of the unit but are characteristic. Locally, a few crinoid stems and horn corals 1-2 cm across are silicified. A few widely spaced stylolites are visible on vertical faces. From top to bottom the unit looks very similar, dominated by thick, planar limestone beds. Gives off a fetted odor when broken. The thickness of the formation varies greatly because of Mississippian karsting. (Thickness 20-150 m)

Dp **Percha Shale (Devonian).** Dark green to yellowish gray shale. Poorly exposed, this unit is mostly only exposed in gullies in talus-covered slopes. Locally, especially near the top, it contains abundant lenticular fine-grained limey siltstone beds several centimeters thick that pinch out laterally to form nodules between 10-30 cm long. This upper part is probably equivalent to the Box member of the Percha Shale, while most of the mapped unit is likely equivalent to the Ready Pay member. The unit crumbles easily. (Thickness 100-150 m)

Sfx **Silicified chert breccia atop the Fusselman Dolomite (Silurian).** This deposit forms a very resistant slightly darker colored cap atop the less altered dolomite. It is composed of what appears to be yellowish brown granular microcrystalline quartz (chert) and younger, lighter-colored cavity-filling chert that appears to be fibrous chalcedony. Beautiful exposures in Cane Spring Canyon show tongues of chert filling vertical 'channels' in the underlying dolomite up to several feet deep. This deposit likely formed during subaerial karsting. (Thickness 0-5 m)

Sf **Fusselman Dolomite (Silurian).** Light gray to yellowish gray finely crystalline dolomite and microdolospar. Mostly medium bedded. Some beds contain abundant partially silicified brachiopod shell debris. The unit characteristically contains light gray silicified colonial corals (*Favosites?*). Though not as abundant as in the Silver City quadrangle to the east, they are composed of hexagonal pillars between 2-5 mm across that radiate upward from a holdfast to form mushroom-shaped (the larger forms) and balloon-shaped (the smaller forms) colonies between 2 and 30 cm across. In contrast to all the other silicified fossils in the Paleozoic section this coral is replaced by light gray coarse-grained quartz (megaquartz). These corals, and the type of silicification, are found in no other unit. Most of the dolomite is highly fractured and forms small angular fragments. Its light gull gray color and flat appearance help to distinguish this unit from the underlying darker gray and sandy Montoya Formation. (Thickness 50 m)

Oa **Aleman member of the Montoya Formation (Ordovician).** Finely crystalline dolomite and abundant planar-bedded chert. This unit characteristically contains greater than 50% thin sheet-like beds of pinkish gray chert between 1-2 cm thick, interbedded very regularly with light gray laminated dolomite about 2-4 cm apart. Sparse silicified brachiopods are exposed on the surface of some chert beds. Some 'worm-like' chert exposed on the bedding planes may be silicified horizontal burrows. The contact with the underlying Montoya Formation, where exposed, is very sharp, with light gray finely crystalline dolomite overlying darker gray dolomite that is also finely crystalline but contains abundant fossiliferous debris. The chert beds tend to erode into small, angular, rectangular fragments a few centimeters across that are useful for identifying the formation where it is poorly exposed. (Thickness 15-20 m)

Om **Montoya Formation (Ordovician).** Medium gray finely crystalline to coarsely crystalline dolomite and limestone. The lower part of the unit forms steep ledgy massive outcrops composed of thick-beds containing very sparse light gray chert. Many of these beds are not obviously fossiliferous but some contain silicified tubes up to 1 cm in diameter than may be crinoid stems. Some areas contain abundant crinoid stem debris replaced by coarse calcite spar. Sparse horn corals up to 2 cm are silicified by light gray chert. Sheet-like bryozoans are rare. Most characteristically, some beds contain very abundant medium to very coarse rounded quartz grains. The quartz grains characteristically give outcrops a granular, sandy appearance, which erode into sandy lag deposits on the surface. The quartz-rich beds show chaotic internal structures and appear to have been extensively bioturbated. The lower portion of the unit characteristically contains irregularly shaped light gray to light pinkish gray chert nodules up to 20 cm long or more in widely separated beds. Higher in the section the chert is darker gray. The base forms a prominent darker cliff (a few meters high) above the El Paso Formation. Most of this formation is rather massive and poorly bedded, more medium gray color than the overlying Fusselman Dolomite, and characteristically sandy. (Thickness 30-40 m)

Oe **El Paso Formation (Ordovician).** Thin to medium bedded finely crystalline to medium crystalline dolomite. Although beds are planar the surfaces exhibit a bumpy (erosional?) surface texture that is reflected in profile by small-scale undulations in the bedding. This unit is characteristically mottled pink and gray. Pink areas form both wispy and irregularly shaped laminae as well as 'wormy' areas that resemble in-filled, mostly bedding-parallel burrows. Thin worm-like light gray chert is very conspicuous on many bedding surfaces and may represent silicified burrows. Intraformational breccias consisting of granules to small cobble-size carbonate fragments are very common and typically form beds from a few centimeters up to a few tens of centimeters thick. Locally, larger boulder-size 'zones' of lighter gray massive dolomite are surrounded by apparently depositionally overlapping slightly darker carbonate, commonly containing carbonate clasts. This unit forms slopes exhibiting ledgy, step-like outcrops. Locally, the unit contains thin lenses of sandstone associated with thin chert breccias that resemble small cavern-fill and cavern roof break-down deposits. (Thickness 130-180 m)

ЄOb **Bliss Formation (Cambrian and Ordovician).** Quartz sandstone, dolomitic quartz sandstone, and less abundant dark greenish gray dolomite. The rusty brown matrix contains abundant granular and some specular hematite. The lowermost part consists of medium-bedded, low-angle cross-stratified quartz sandstone containing abundant vertical *Skolithos* trace fossils, particularly within the lowermost meter of the formation. The remainder of the formation consists of thin- to thick-bedded, planar and trough cross-stratified sandstone. Throughout the map area, the unit contains a thin interval of dark yellowish gray thin bedded dolomite and sandy dolomite about 1-2 meters thick within the upper third of the formation. Pale green glauconite grains are common. The unit is typically dark brown to red brown and locally forms a ledgy cliff. In other areas it forms a slope and is difficult to distinguish from the underlying granite from a distance. (Thickness 60 m)

Precambrian Rocks

YXg **Granite (Early or Middle Proterozoic).** Medium- to marginally coarse-grained and equigranular. This characteristically light orange-colored granite is almost everywhere texturally similar. It is composed of relatively equant crystals of K-feldspar, plagioclase, and quartz. Plagioclase appears altered (serricitized?). Biotite is almost completely altered to hematite and most outcrops appear leucocratic. As such, it is difficult to estimate the original percentage of the mineral. The rock is everywhere deeply weathered and outcrops are commonly grungy and crumbly. No foliation is visible within the study area, but this rock is locally foliated to the east in the Silver City 7.5' quadrangle where the northwest-striking foliation is defined by quartz crystals strung out into long lenses, and aligned mica.

Xs **Quartz-muscovite schist.** Contains quartz and coarse-grained muscovite. It is exposed in only one place in the map are, immediately east of Treasure Mountain, where it forms a lens-like enclave within **YXg** and is strongly foliated.

Photo 1. View of Proterozoic granite from the west side of Treasure Mountain, looking north along the Bear Mountain Fault.

Photo 2. Panorama looking north to west from the west side of Treasure Mountain. Little Bear Mountain is the high peak on the right.

Photo 3. Outcrops of the Bliss Formation overlying granite on the west side of Treasure Mountain, looking west.

Photo 4. Darker layered outcrops of the Bliss Formation cap Treasure Mountain and hills in the distance. View is to the northwest from near UTM 3631600, 744800.

Photo 5. The basal layers of the Bliss Formation contain abundant vertical *Skolithos* trace fossils. Outcrop is near Little Bear Mountain.

Photo 6. Typical Intraformational breccia within the El Paso Formation.

Photo 7. A bedding-plane surface of the El Paso Formation showing 'wormy' chert.

Photo 8. A chert breccia lens within the lower part of the El Paso Formation.

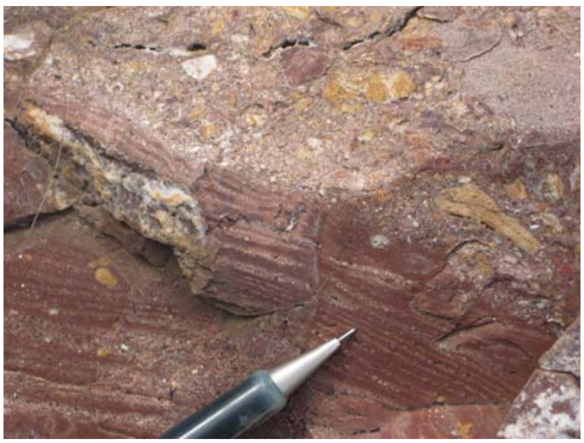

Photo 9. A close-up of laminated chert within a chert-breccia lens in the lower part of the El Paso Formation.

Photo 10. A sandy limestone outcrop of the lower part of the Montoya Formation.

Photo 11. Close-up of sandy limestone of the Montoya Formation showing possibly bioturbation.

Photo 12. Outcrop of the Aleman member of the Montoya Formation south of Treasure Mountain, showing abundant bedded chert.

Photo 13. This colonial coral in the lower part of the Fusselman Dolomite is replaced by light gray coarse-grained quartz.

Photo 14. The top of the Fusselman Dolomite in Cane Spring Canyon is locally capped by silicified karst.

Photo 15. Exposure of Lake Valley Limestone near the headwaters of Cottonwood Creek.

Photo 16. Bedding-plane view of gray chert nodules in the Lake Valley Limestone.

Photo 17. Bedding parallel view of chert nodules in the Lake Valley Limestone.

Photo 18. Red chert breccia at the top of the Lake Valley Limestone in Cane Spring Canyon is overlain by the Beartooth Q.

Photo 19. Close-up of red chert breccia at the top of the Lake Valley Limestone in Cane Spring Canyon.

Photo 20. Chert breccia forms 'channels' in the Lake Valley Limestone in Cane Spring Canyon. Overlain by Beartooth Quartzite.

Photo 21. Outcrop of red chert breccia in Cottonwood Canyon east of Circle Mesa.

Photo 22. Red chert breccia in Cottonwood Canyon east of Circle Mesa. Shows relict bedding.

Photo 23. The Beartooth Quartzite forms a prominent cliff over Devonian Percha Shale in Cottonwood Canyon.

Photo 24. Another view of cliff formed by Beartooth Quartzite along Cottonwood Canyon.

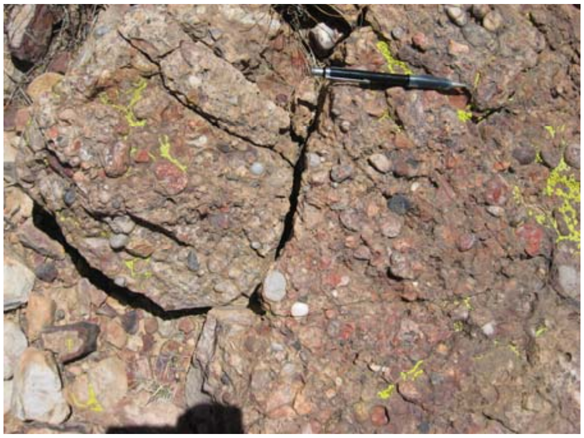

Photo 25. Outcrop of conglomeritic layer within the Beartooth Quartzite, south of Treasure Mountain.

Photo 26. Outcrop of platy siltstone beds of the Colorado Formation, northeast of Circle Mesa.

Photo 27. Some fine sandy layers of the Colorado Formation contain abundant shell fragments replaced by sparry calcite.

Photo 28. Outcrop of the contact between the Beartooth Quartzite (on the right) and the Colorado Formation (on the left).

Photo 29. Tilted red sandstone and conglomerate (**Tc**) in Cane Spring Canyon

Photo 30. Close-up of conglomerate in Cane Spring Canyon (**Tc**).

Photo 31. Boulders of pyroxene-bearing Tertiary intrusive rocks within **Tc**.

Photo 32. Typical outcrop of lithic-rich ash flow tuff (**Ttl**) south of Circle Mesa.

Photo 33. Close-up of lithic-rich ash flow tuff (**Ttl**).

Photo 34. Large blocks of ash flow tuff weathering out of **Ttl** near UTM 743200E, 3637700N.

Photo 35. A large boulder forms a cap stone within **Ttl** near location of Photo 34.

Photo 36. Outcrop of dacite in foreground. Hill in left background is also dacite.

Photo 37. Close-up of dacite (**Td**).

Photo 38. Outcrop of rhyolite on southwest side of map in Saddle Rock Canyon.

Photo 39. Outcrop of bedded tuff on southwest side of map near UTM 734500E, 3628300. Looking northwest.

Photo 40. Outcrops of rhyolite north of Circle Mesa at the north edge of the map. View is to the west.

Photo 41. Outcrop of aphyric basalt (**Tb**) in the southwest corner of the map.

Photo 42. Exposure of the younger basalt (**Tby**) overlying basin-fill deposits in Cane Spring Canyon.

Photo 43. Two basalt flows (**Tby**) are interbedded with basin-fill deposits in Cane Spring Canyon.

Photo 44. Close-up of basin-fill deposits containing dominantly volcanic fragments (**Tcv**).

Photo 45. Exposure of basalt-rich conglomerate (**Tcb**) overlying aphyric basalt in the southwest corner of the map.

Photo 46. Road-cut exposure of **Tcg** along the Mangas Valley Rd., just south of Highway 180.

Photo 47. Close-up of **Tcg** deposits (the photo was tilted 90° left to fit on this page).

Photo 48. Road-cut exposure of **Tcg** deposits along Highway 180 west of mile marker 101.

Photo 49. Road-cut exposure of **Tcg** west of mile marker 102.

Photo 50. Close-up of granite clasts within **Tcg** near UTM 738300E, 3633500N.

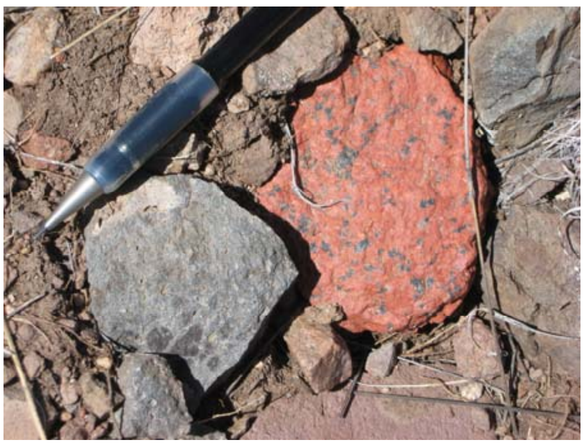

Photo 51. Orange episyenite clast within **Tcg** west of Mangas fault near south edge of map.

Photo 52. A larger clast of episyenite.

Photo 53. A selection of large K-feldspar crystals weathering out of **Tcg**.

Photo 54. Exposure of **Tcm** west of Circle Mesa near UTM 736900E, 3638300N.

Photo 55. Outcrop of **Tcm** west of Circle Mesa. Note thin clay-rich soil horizons.

Photo 56. Basin-fill deposits (**Tcm**) exposed below basalt in Can Spring Canyon.

Photo 57. Grass-covered **Qo** deposits cap grass-covered hills south of Treasure Mountain. View southwest to Burro Mtns.

Photo 58. Qo deposits on LS Mesa contain dark reddish brown soils. View is north.

Photo 59. Qo deposits on LS Mesa contain dark reddish brown soils. View is northwest.

Photo 60. This ridge, on the south side of Cottonwood Canyon, is capped by **Qoc.**

Photo 61. Close-up of clasts of carbonate and dacite within **Qoc** deposits on south side of Cottonwood Canyon.

Photo 62. Qm deposits rest on granitic-rich basin-fill deposits (**Tcg**) along Fleming Canyon, near UTM 738200E, 3630300N.

Photo 63. Qm deposits cap hills and are high above the level of the modern creeks.

Photo 64. Exposures of Holocene alluvial deposits along Mangas Creek.

Photo 65. View of flat valley filled with Holocene alluvial deposits.

Photo 66. Exposures of Holocene alluvial deposits along Mangas Creek.

Photo 67. Exposure of Holocene sedimentary deposits in dissected ravine along Mangas Creek, near the southern edge of the map. Fine-grained tan silt and sand exhibits a darker soil zone near the top, overlain by a thin layer of lighter colored silt and sand.

Photo 68. Dissected Holocene alluvial deposits in Mangas Valley, along Mangas Creek. View is to the northwest from near the southern edge of the quadrangle.

Photo 69. Dissected Holocene alluvial deposits in Mangas Valley, along Mangas Creek. View is to the southeast from near the southern edge of the quadrangle.

Photo 70. Looking east from UTM 739600E, 3636800N. Prominent cliff is Beartooth Quartzite, overlain by two dark hills of dacite (**Td**).

Photo 71. Looking northeast from near UTM 734800E, 3626700N. Rhyolite is in foreground. The Silver City Range is in the distance across Mangas Valley.

Photo 72. Looking south from UTM 741500E, 3626200N along the strike of the Mangas Fault. The fault separates Tertiary volcanic rocks in the Little Burro Mountains on the left from granitic-rich basin-fill deposits (**Tcg**) on the right.

Photo 73. Looking north from UTM 740700E, 3626800N along the strike of the Mangas Fault. The fault separates more strongly cemented basin-fill deposits (**Tcg**) on the right from weakly cemented basin-fill deposits (**Tcg**) on the left.

Photo 74. A outcrop of El Paso Formation near 743500E, 3634300N showing extensive network of silica veins in fractures.