Geologic Map of the Fort Bayard Quadrangle, Grant County, New Mexico

By

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Introduction

The Fort Bayard 7.5' quadrangle sits in an historic mining region between the Santa Rita porphyry copper deposit a few miles to the east, and the Town of Silver City immediately to the west. The oldest rocks in the area are fossiliferous Pennsylvanian carbonates, overlain by red shales and sandstones of the Permian Abo Formation. Most of the Abo Formation in the study area was stripped off during a period of erosion that lasted until the Late Cretaceous. This unconformity was covered by the clean sandstones of the Late Cretaceous Beartooth quartzite, which were in turn overlain by a thick sequence of greenish gray to tan shales and sandstones of the Late Cretaceous Colorado Formation. These latest Cretaceous rocks are similar to Late Cretaceous shales and sandstones exposed beneath the Springerville volcanic field in east-central Arizona, and may be equivalent but, as described below, may be equivalent to the Early to Mid-Cretaceous Bisbee Group (see *Figure 1* for correlation diagram).

The region was likely emergent after the late Cretaceous. Beds of the Colorado Formation are unconformably overlain by a thick pile of volcanic breccia containing intermediate-composition clasts of several different affinities, but mostly pyroxene-bearing hypabyssal to volcanic varieties of andesite or quartz diorite. The breccia sequence is mostly massive but locally contains thinly bedded volcaniclastic sandstone. These deposits were probably shed as debris flows from volcanic constructs that developed along a Cretaceous volcanic arc that was most pronounced in southern Arizona and northern Mexico (Seager, 2004).

All of these rocks were uplifted and folded during the Laramide orogeny. Where folds are visible, the attitude of some of the volcaniclastic sandstone beds is similar to the attitude of beds in the immediately underlying Colorado Formation, suggesting that folding did not occur until after deposition of the volcanic breccia. During this time several different and possibly related intermediate-composition stocks, plutons and dikes intruded much of the region and emplaced most of the mineralization in the district. In the Fort Bayard quadrangle voluminous sheeted dikes intruded the older rocks, their orientations apparently controlled by joint orientations. Most mineralization appears to be post-jointing and cross cuts several of the dikes and smaller intrusive bodies (particularly at Piños Altos).

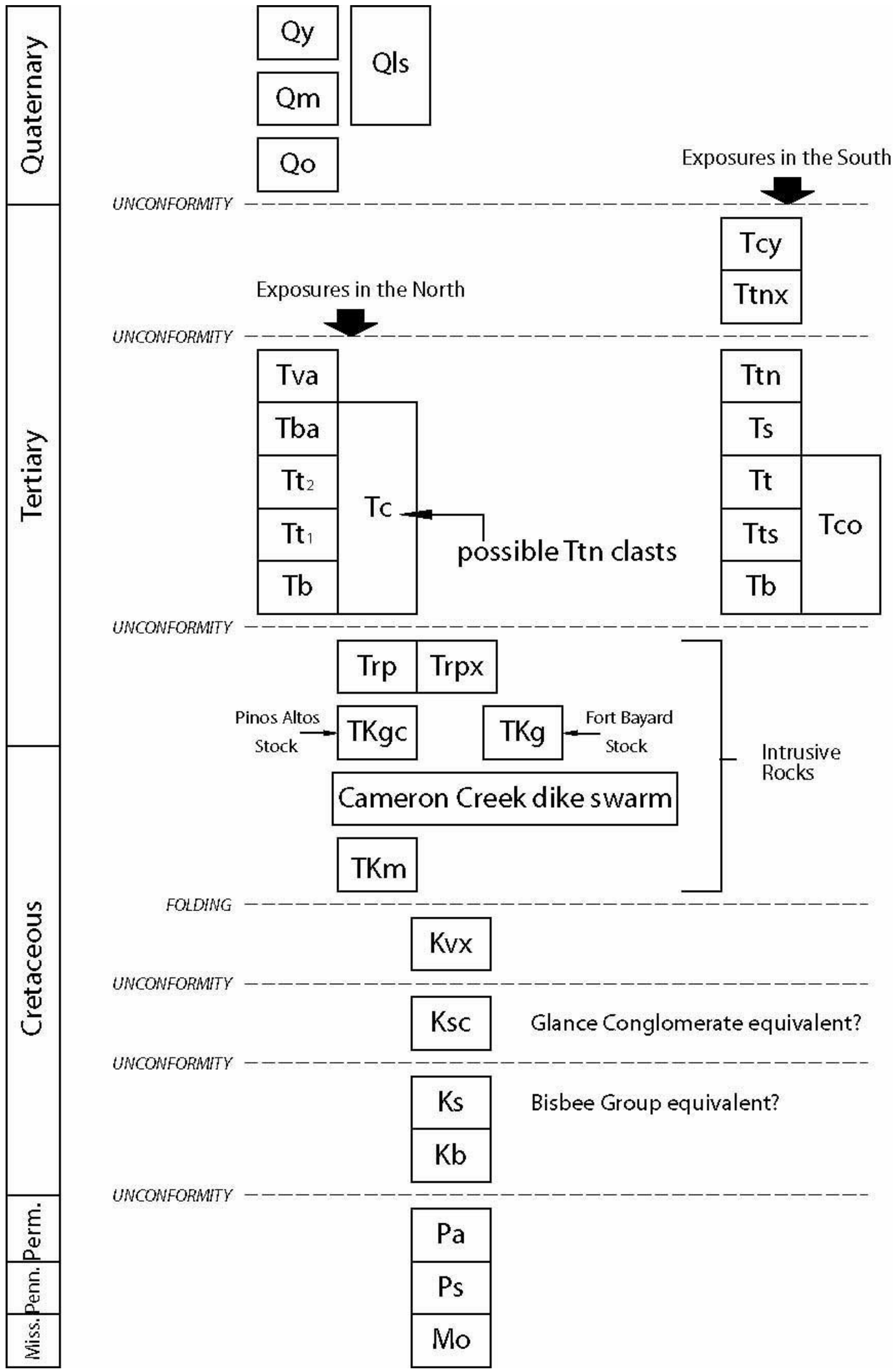

Figure 1. Correlation diagram for rocks in the Fort Bayard 7.5' quadrangle.

An erosional unconformity separates these older rocks from overlying Tertiary rocks. In the south basalt is interbedded with conglomerate and are both very gently folded. These are overlain by two welded ash-flow tuffs: the crystal-poor Sugarlump Tuff and the younger crystal-rich Kneeling Nun Tuff (Oligocene). In the north two probably different ash-flow tuffs are interbedded with a similar conglomerate and thicken northwestward into the Mogollon-Datil volcanic field. These northern tuffs are overlain a relatively thin layer of crystal-rich basaltic andesite and a thick sequence of aphyric lavas. Immediately north of the quadrangle the aphyric lavas appear to be overlain by a thick light colored tuff. The Tertiary rocks in the south are overlain by a distinctive layer composed of large rotated blocks of Kneeling Nun Tuff that were probably deposited as debris flows or rock avalanche deposits. This layer is overlain by a thick sequence of younger sandstones and conglomerates that probably represent the latest episode of basin-fill during the late Miocene and Pliocene. All of the Tertiary rocks are cut by northeast-striking faults.

The Fort Bayard quadrangle spans the transition from sparsely oak-juniper forested grassland piedmont in the south to densely forested mountain upland in the north. In the piedmont area road access is excellent, but many of the roads are on or lead to large areas of private land. Therefore map coverage of most of the southwest quarter of the quadrangle is based almost entirely on road cut exposures and local field checking of the map of Jones et al. (1970). Access in the northern and higher elevation portion of the quadrangle is much better in terms of land access, but the *Cercocarpus-Quercus-Mimosa* factor[1] intervenes to make back-country mapping and travel incredibly difficult. The thick brush infests nearly all the mountain slopes, the only exceptions being steep north-facing slopes populated chiefly by mature ponderosa and the axis of large active drainages.

Other principal species: *Pinus ponderosa, Pinus edulis, Juniperus deppeana,*
The brush understory consists of several species of mahogany *(Cercocarpus)* and oak (*Quercus)* mixed with *Mimosa biuncifera*

Previous Work

Spencer and Paige (1935) described the geology of the Santa Rita mining area, and later, Hernon and others (1964) and Jones and others (1967) created a geologic map of the Santa Rita 7.5' quadrangle. Quite a few workers have studied the mineralization associated with the Santa Rita porphyry copper deposit immediately to the east. Many of these references can be found in a recent guidebook to the area (Thoman et al., 2006). The Fort Bayard 7.5' quadrangle was mapped by Jones and others (1970). This current study was done in conjunction with mapping in the adjacent Silver City 7.5' quadrangle.

[1]A reference to the large areas of nearly impenetrable brush, composed of mountain mahogany, oak, and wait-a-minute bush that populate the mountain slopes in the area.

Paleozoic Rocks

The oldest Paleozoic sedimentary rocks in the map area are a thick sequence of limestones exposed on the eastern side of the map. These limestones comprise two mappable units. The older, lowermost unit is a sequence of massive, thick-bedded tabular limestone beds that contain no visible chert nodules. Only a very small exposure of this unit was mapped in the bottom of the drainage Beartooth Creek. A large quarry operation immediately to the east of the map boundary reveals much better quarry-cliff exposures. This limestone unit is probably equivalent to the Pennsylvanian Oswaldo Formation exposed to the east in the Santa Rita 7.5' quadrangle (Hernon et al., 1964).

Overlying the Oswaldo Formation is a sequence of very cherty limestones and minor purple shales. The limestones characteristically contain very abundant, irregularly shaped yellowish tan chert nodules. In some outcrops the cherts comprises 80% or more of the rock. This unit commonly forms rounded hills covered in a lag of yellowish tan chert, which themselves resemble fine-grained sandstone, giving the misleading impression that the underlying material is sandstone rather than gray carbonate. Fossils of brachiopods, crinoids, and bryozoans are common and are defined by darker calcite spar and only rarely by silica. This sequence is equivalent to the Pennsylvanian Syrena Formation exposed to the east in the Santa Rita 7.5' quadrangle (Hernon et al., 1964). The contact between the Oswaldo and Syrena Formations is sharp. In the quarry east of the map area the contact is locally overlain by thin red terra rossa, suggesting it may be a karst surface. However, all of the contact exposed in the Fort Bayard quadrangle appears very planar and sharp, with no obvious irregularities or terra rossa.

Overlying the Syrena Formation is the Permian Abo Formation, a sequence of thinly bedded, red to purple, fine- to medium-grained sandstone and shale. Most of this unit was eroded and removed prior to deposition of the overlying units, and current exposures are limited to a small area north of Beartooth Creek. Here, it is recessive-weathering and forms an indistinct, deep red slope mostly covered with debris shed from the overlying unit. The only exposure is the one near the northernmost peak, where quarry operations have dug into the slope to reveal interbedded red shale and sandstone.

Overlying the Abo Formation is the Cretaceous Beartooth Quartzite, comprised of very clean, well sorted quartz grains mostly fused together to form a very resistant ridge. Although minor black shale and conglomerate beds were described to the east (Hernon et al., 1964), no such beds were seen in the map area. At first, the clean, well-sorted nature of the unit suggests it may have been deposited as wind-blown sand. However, planar bedding and cross-bedding in sets between about 10 cm and 1 meter suggest a fluvial origin. It is not exactly clear why the quartz grains have been fused into a quartzite. The nearest intrusive body is several hundred meters distant, which did not apparently alter any of the other sedimentary formations. The well sorted nature of the Beartooth Quartzite implies that it originally had considerable primary porosity and permeability, more so than the underlying limstones and the overlying fine-grained units. Hence, silica-rich hydrothermal fluids associated with intrusions (?) may have migrated through the sandstone preferentially, with respect to the other units, possibly across relatively long distances, and acted to help anneal the grains.

Sitting on top of the Beartooth Quartzite is a thick sequence of thinly bedded sandstone and shale named the Colorado Formation, probably Cretaceous in age. The sandstone beds are typically fine-grained, but locally medium- and more rarely coarse-grained, and contain well sorted subangular to subrounded quartz and less abundant feldspar. Some of the sandstones contain chert-pebble conglomerate beds at their base, typically no thicker than about 20-30 cm. The shales are typically dark gray to greenish gray and are commonly interbedded with thin dark gray, fine-grained siltstone to fine sandstone layers from a few centimeters to 10 cm thick. Where exposed the sequence locally contains thin dark brown sandy limestone beds between 10 and 30 cm thick and septarian nodules up to about 30 cm across. Some siltstone beds show fine cross-bedding in sets only 1-2 cm high. The sequence weather recessively and commonly forms grass- and debris-covered slopes. For this reason, and because most of the unit has been intruded by younger dikes, good exposures are rare, even though much of the southern half of the quadrangle is underlain by this unit. In the eastern part of the study area the very top of the formation is capped by a very clean, poorly sorted sandstone and conglomerate layer between about 0-10 meters thick (map unit **Tsc**). The sandstone is typically poorly sorted angular to subrounded quartz and minor feldspar. The conglomerate contains abundant well rounded pebbles up to 6 cm across, and rarely up to 10 cm across, composed of dark gray chert, medium to light gray quartzite, and vein quartz. Petrified wood is locally abundant and has been replaced by dark gray, fine-grained chert. Some pieces of petrified wood are well rounded, indicating they may have been eroded from an older rock unit. This unit forms a thin layer a few meters thick resting on top of the Colorado Formation. Locally, pebbly conglomerate is interbedded with the Colorado Formation less than about 10 meters from the top of the unit.

Cretaceous Volcanic Breccia

The Colorado Formation is unconformably overlain by a thick pile of volcanic breccia. This unit is heterogeneous in that it contains what appear to be segments of lava flows either interbedded or intermixed with epiclastic breccia and minor thinly bedded volcaniclastic sandstone. The breccias themselves are massive, non-bedded, and poorly sorted. The clasts range from granule-size up to boulders at least 1-2 meters across, and are mostly subangular. Most of the clasts are composed of hornblende- and/or pyroxene-bearing hypabyssal or volcanic rocks that very closely resemble the mineralogy and texture of many of the younger hypabyssal pyroxene-bearing rocks that intrude the unit as dike swarms and small plutons. Because of this similarity it is locally very difficult to distinguish between the volcanic breccia and the intrusive bodies. Jones and others (1970) called this unit ‘andesite breccia’, and this is probably a good name since most of the clasts are mineralogically intermediate in composition. However, since many of the clasts resemble many of the younger hypabyssal pyroxene-bearing rocks that intrude the unit, it is possible that some of the original source rocks may have been hypabyssal in origin as well. For this reason, we’ve elected to use the generic descriptive term ‘volcanic breccia’ instead.

The enclaves or intercalations of what look like parts of lava flows are commonly at least several tens of meters across and typically contain obvious dark stubby tabular dark phenocrysts of pyroxene. The edges of these bodies are sharp to gradational and irregular in shape. Some of the bodies pinch out along 5 or 10 meters and then appear again along trend. In these respects, these bodies resemble the broken and rotated portions of lava flows that were entrained within breccias during deposition. The breccias were probably deposited as debris flows or rock avalanches shed from the steep sides of formerly existing volcanic structures.

The volcaniclastic sandstone is typically thinly bedded and beds are commonly planar or sonly slightly undulatory. The sand and granule fraction is composed of lithic grains of the various hornblende- and pyroxene-bearing rocks that are found in the breccias, as well as a significant fraction of mineral grains such as feldspar and pyroxene. The segregation of some of the darker minerals defines the bedding locally. In most areas, though, bedding in this unit is defined by thin platy partings between sandy layers. Jones and others (1970) locally mapped the volcaniclastic sandstone as a different unit than the breccia. However, in many areas, particularly in the northeast part of the quadrangle, the sandstone is interbedded with layers of breccia several meters to several tens of meters thick, so this distinction was not adopted here.

Exposures of this unit can be confusing. The rock has been highly weathered, probably during several different weathering episodes, so the matrix of the rock has been extensively propylitized, is crumbly, and is colored shades of light green to purple. On ‘fresh’ surfaces (outcrops free of soil, that is) the fragmental texture of the unit can usually be discerned. However, the individual clasts are ‘fused’ with the surrounding matrix such that there is no obvious parting or weathering break between the two. What allows the clasts to be seen, however, is the difference in coloration between many of the clasts and the surrounding matrix. In this respect it tends to resemble an intrusive breccia. However, many good exposures show that this unit is clearly a sedimentary breccia, especially since it is locally interbedded with bedded volcaniclastic sandstone.

Intrusive Rocks and Dikes

Piños Altos plutonic complex

Plutonic rocks in the vicinity of Piños Altos comprise of suite of complexly interfingering phases ranging widely in composition from granite to syenite and diorite. The mafic mineral assemblages are equally complex, comprised of a myriad of combinations of two or three but locally all five of the mineral phases: biotite, hornblende, pyroxene, magnetite, and olivine (Jones et al., 1970). The principal phase (**TKg**) is a medium- to coarse-grained 5-15% hornblende-porphyritic, biotite granite that forms three main masses; two km-scale northerly elongated elliptical bodies in the Rio de Arenas area, and a larger main body that crops out throughout the Piños Altos townsite area. The granite sharply intrudes older supracrustal rocks in a few areas, but it is mostly in intrusive or gradational contact with a myriad of fine- to medium-grained, generally darker monzonitic rocks. The fine-grained monzonitic rocks range from syenite to diorite with variable mafic mineral suites which were used by Jones et al. (1970) to define four distinct fine- to medium-grained and locally weakly porphyritic plutonic units: 1) an older augite-biotite syenodiorite[2] to monzonite, and four other apparently contemporaneous units; 2) biotite-hornblende granodiorite porphyry, 3) pyroxene porphyry, 4) augite monzonite porphyry, and 5) hornblende granodiorite[3] porphyry. Jones et al., 1970 provide detailed petrographic descriptions of each unit, and these closely match certain areas of outcrop that we observed during our mapping. However, we were not able to confirm a consistent chronologic hierarchy or map the discrete plutonic units as shown by Jones et al. (1970). Instead we recognize only two map units within the Pinos Altos complex: 1) the medium- to coarse-grained hornblende granite (**TKg**), and a generalized fine- to medium-grained monzonitic[4] unit (**TKm**) that includes the five aforementioned units of Jones et al. (1970).

The Cameron Creek dike swarm.

Intruding the volcanic breccia (**Kvx**) is swarm of intermediate to mafic dikes whose phenocryst assemblages, with one important exception, closely matches assemblages within the principal varieties of intruded andesitic lavas. A significant exception is a suite of biotite-porphyritic and fine-grained, biotite-rich monzonitic dikes. Based purely on field relationships, a strong correlation between the lavas and the main mass of younger dikes would seem obvious and acceptable if it were not for the fact that there is no obvious decrease in density of dikes upward in the volcanic pile[5]. In addition, the dikes show no evidence of being folded (unlike the volcanic breccia unit). The lack of an upward decrease in dike density implies that the pile was at some time significantly thicker, or that the dikes are unrelated to the lavas. A genetic relationship of the dikes with the area's two plutonic suites is seems to be a better fit.

Due to the poor exposure and locally thick soil cover in areas intruded by the Cameron Creek dike swarm, it is very difficult to consistently show the individual dikes. In limited areas, a detailed portrayal of the dikes is shown as an example of how they probably appear throughout a region. Apart from a rare suite of biotite-phyric dikes, two main types of dikes are differentiated on the map: 1) a relatively fine-grained and/or plagioclase-porphyrititc suite locally with sparse hornblende, and/or pyroxene phenocrysts, and2) a suite of coarse-grained hornblende and/or pyroxene-porphyritic dikes. In most areas the coarse-grained dikes intrude the fine-grained dikes. Multiple generations of both varieties of dikes are common. The dikes dip steeply and strike northeasterly thoughout the swarm with one important exception, a swarm of east-west striking dikes just east of the community of Arenas Valley[6].

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[2]Jones et al., 1970 named these rocks before establishment of the IUGS classification (Streikheisen, 19??), but the misnomer "syenodiorite" strongly implies a unit that ranges between the syenite and diorite end members of the monzonitic field, that is plutonic rocks with <5% modal quartz and 10-90% plagioclase and potassium feldspar.

[3] In the field this unit does not appear to have anywhere near 20% modal quartz, a requirement for it to be a true granodiorite. Instead these rocks probably fall within the quartz monzodiorite or monzodiorite fields.

[4] typically, modal quartz is $\leq$5%, but locally it ranges upwards into the quartz monzonitic field.

[5]A relationship that is predicted for a pile of lava intruded by its own feeder dikes. A good nearby and somewhat age-equivalent example is the andesite lava pile at the base of the Tombstone Hills volcanic field (incidentally another Silver district) in southeast Arizona (Giluly, 19??, Moore and Lipman, Ferguson et al., 2005).

[6] Still known to most of the local residents as Whiskey Creek.

The age relationship of the Cameron Creek dike swarm to the map area's two main plutonic suites suggests, contrary to previous age assignments, that the older portions of the Piños Altos suite, and the volcanic breccia (**Kvx**) are both older than the hornblende quartz diorite sill at Fort Bayard (**TKg**). The hornblende quartz diorite at Fort Bayard, unlike the andesite of Cameron Creek and the fine-grained peripheral phases of the Piños Altos stock (**TKm**), is not intruded by any of the intermediate to mafic dikes of the Cameron Creek dike swarm. Additionally, if the Fort Bayard stock is known to be Cretaceous based on relationships in the easterly adjacent Santa Rita quadrangle (Jones et al., 1970), this would make the volcanic breccia and most of the Piños Altos stock Cretaceous as well. The medium- to coarse-grained core of the Piños Altos stock (**TKgc**) is not intruded by dikes of the Cameron Creek dike swarm, indicating that it was emplaced last. This relationship suggests that the central core of the Piños Altos stock and the Fort Bayard stock my have been coeaval.

As Jones and others (1970) observed, the dike swarm locally occupies up to 80% or more of the exposures. This begs the question of how the dikes were emplaced—that is, did they intrude by displacing the country rock or by consuming it? It was beyond the scope of this study to answer this question, but the question is not trivial. If the dikes displaced the country rocks as they intruded then the area has undergone significant dilation—up to 160%. If the dikes consumed the country rock then up to 80% of the rocks were digested and assimilated. In fact, the dikes may have done both. Quite a few dikes contain xenoliths of hornblende- and/or pyroxene-bearing hypabyssal rocks similar to rocks in the volcanic breccia, suggesting some assimilation. Many dikes containing large, dark phenocrysts intrude along and between dikes of similar composition, but containing smaller phenocrysts. In this last example, the parallel intruding dikes resemble sheeted dikes.

Tertiary Volcanism and Sedimentation

Northern Exposures

Tertiary volcanic rocks are exposed only in the far northern and southeast parts of the quadrangle. In the north, the first volcanic unit visible is a small exposure of basalt (between Castle Knob and Century Hill). It is not known if this small exposure is just part of a much larger unit now buried to the north. Overlying the basalt is a relatively crystal-rich welded tuff ($\mathbf{Tt_1}$). A thin layer of bedded tuff about half way up the unit indicates that this tuff is composed of at least two flow units, and possibly more. Eutaxitic foliation is steepest at the base, where it dips up to about 35° north-northwest, and becomes shallower up-section. The change in dips of the foliation suggests that either the unit was tilted during eruption, or it was deposited against steep terrain. The basal contact is locally irregular indicating that the tuff was laid down on an erosion surface exhibiting some relief. This tuff apparently pinches out abruptly to the east near Avalanche Peak, where the underlying erosion surface rises sharply. The tuff extends northwestward out of the quadrangle and, from reconnaissance observations appears to continue and thicken for quite some distance.

Near the north-central edge of the map the crystal-rich tuff is overlain by a thick crystal-poor tuff (**Tt_2**) containing less than 5% sanidine and subhedral flakes of biotite. The tuff is mostly massive and nonbedded and appears to be composed of one flow unit. Where fresh, the tuff is slightly buish gray and almost glassy, and in this regard resembles the Sugarlump Tuff (**Tts**) exposed in the southeast corner of the map area near the Town of Bayard. East of Commanche Springs **Tt_1** and **Tt_2** are separated by sandstone and conglomerate (**Tc**) that thickens to the east. The conglomerate also overlies **Tt_2** and is interbedded with the next overlying volcanic unit, basaltic andesite (**Tba**). The basaltic andesite forms a very resistant bench visible from many miles to the south. This unit was likely overlain by **Tc** but that material has eroded back to form the bench. The basaltic andesite is very porphyritic and contains large crystals of plagioclase and pyroxene up to 1 cm or more long. On top of more overlying conglomerate is a very resistant sequence of nearly aphyric lava flows. These flows cap most of the skyline northeast of the quadrangle. From a distance, nearly horizontal bands of vegetation define what are probably 20 or 30 individual lava flows, all of similar composition. Up close, however, the break between possible flows is obscure due to weathering and vegetation cover. These flows contain minute dark red opaque phenocrysts (olivine pseudomorphs altered to iddingsite) in a purplish gray matrix, and the rock itself breaks into platy, angular blocks that are very difficult to break with a hammer.

The sandstone and conglomerate that is interbedded with the tuffs and lavas (**Tc**) contains only clasts derived from the intermediate composition, pyroxene-bearing rocks exposed within the volcanic breccia (**Kvx**) and in the various hypabyssal rocks that intrude it. No Paleozoic or Cretaceous sedimentary clasts were observed, even though Paleozoic and Cretaceous sedimentary rocks are exposed only a few miles to the south-southeast. Because **Tc** is mostly covered with soil and vegetation, paleocurrent directions were not obvious. But barring a source to the north, it makes sense that most of the material within **Tc** was shed northward from the central part of the quadrangle. The fact that the two tuff units as well as **Tc** all pinch out on Century Hill (in the northeast corner of the map), suggests that the central part of the map area may have been a topographic high at the time of deposition of the Tertiary units. This interpretation is supported also by the observation that these same units pinch out on a paleo-high on the north side of Piños Altos, just beyond the northwestern corner of the map. It is conceivable that this paleo-high continued across the Fort Bayard quadrangle to Century Hill. More evidence for this paleo-high exists in the southern part of the map, as described below.

Interestingly, however, the layer of conglomerate that separates **Tt_1** from **Tt_2** locally contains large concentrations of subrounded cobbles and small boulders of crystal-rich tuff different than **Tt_1**. These clasts weather out of the slope of **Tc** and deceptively resemble weathered, eroding outcrops of welded tuff, but they are definitely individual clasts. They also superficially resemble the crystal-rich tuff below (**Tt_1**) but are too crystal-rich, containing about 30-40% phenocrysts of sanidine, quartz, and biotite—much like the Kneeling Nun Tuff (**Ttn**). Therefore, if these clasts really are fragments of the Kneeling Nun Tuff, then either (1) the proposed drainage divide did not exist, or (2) it was low enough to allow the stratigraphically and topographically (?) higher Kneeling Nun Tuff to cross it, or (3) the Kneeling Nun Tuff was also deposited north of the divide, or (4) the clasts were derived from a different ash-flow tuff.

Southern Exposures

The oldest Tertiary unit exposed in the southern part of the map is weakly to moderately lithified interbedded sandstone and conglomerate (**Tco**). This unit is dominated by clasts of pyroxene-bearing hypabyssal and/or volcanic rocks derived from the volcanic breccia (**Kvx**) and the various hypabyssal rocks that intrude it. Paleozoic and Cretaceous sedimentary rocks are rare, and constitute less than 5-10% of the clasts only in the east near the Town of Bayard. Imbrication measurements indicate that that the transport direction was to the south-southeast.

Tco is overlain, and in one place interbedded with, highly weathered basalt (**Tb**). Jones and others (1970) originally mapped this basalt as latite and rhyodacite. The light grayish surfaces tend to make outcrops resemble more felsic rocks, but the abundance of subhedral olivine phenocrysts altered to red opaque minerals (iddingsite) suggest a more mafic origin. Weathering has obscured any flow boundaries, but because the unit is locally more than 100 feet thick it likely represents more than one flow.

Jones and others (1970) grouped the conglomerate (**Tco**) and basalt (**Tb**) into one unit they called the Rubio Peak Formation. They did not describe their reasoning for lumping these two rocks into one unit, but it may have something to do with the fact that both of these units are gently tilted (<10) and broadly folded.

Interbedded within **Tco** an unknown height stratigraphically above the basalt is the gull gray, crystal-poor Sugarlump Tuff (**Ts**) (Jones et al., 1970). It is relatively thin in the east (<3 meters thick) and becomes thinner westward (<2 meters). The welded tuff appears to be composed of only one flow unit, and, where visible, overlies a bright pink clay-rich layer 1-2 meters thick that may represent an altered air-fall deposit. The tuff is not visible everywhere, and may have been partly eroded prior to deposition of more sandstone and conglomerate of **Tco**.

As stated above, **Tco** contains only rare Paleozoic sedimentary clasts and no Tertiary volcanic clasts. This observation, along with the unit's south-southeast-pointing imbrication directions, indicate that their source terrain was almost solely from the volcanic breccia (map unit **Kvx**) and from the myriad of hypabyssal dikes intruding it The near absence of Tertiary volcanic clasts suggests that either the conglomerate was deposited prior to volcanic activity, which is unlikely considering it is interbedded with basalt and the Sugarlump Tuff, or that there may have been a paleo drainage divide across the center of the map separating the northern and southern parts of the quadrangle. It is possible that the area now underlain by the Piños Altos stock is the core of a stratovolcao that remained a topographic high well into the Oligocene and Miocene.

A very interesting sequence of rocks was deposited above the Sugarlump Tuff, but the only place it is exposed is in the very southeaster-most corner of the quadrangle. Here, the Sugarlump Tuff is overlain by more sandstone and conglomerate (**Tco**) interbedded with at least two thinly bedded lithic tuff units (**Tt**) containing clasts of maroon to dark red quartzite. Directly overlying the uppermost tuff is a sequence of strikingly green thin- to medium-bedded gravelly sandstones and thin interbedded yellow tuffs (**Ts**). In all beds the larger grains are dominated by fine-grained, light gray to maroon quartzite and other siliceous grains, some of which resemble flow-banded rhyolite. This sequence is more than 100 feet thick, but it is unclear how extensive it is since it does not appear to have been described by previous workers.

Immediately overlying the green sandstone unit in the southeast corner of the map is the Kneeling Nun Tuff (**Ttn**), dated about 10 miles to the southeast by K-Ar at 33.4 Ma (W.E. Elston, written communication in Jones et al., 1970). This crystal-rich ash-flow tuff contains 30-50% phenocrysts of quartz, sanidine, and biotite, and forms impressive cliffs just east of the Town of Bayard. Jointing is prominent, but eutaxitic foliation defined by sparse pumice clasts is weak.

North and west of Bayard an interesting breccia layer overlies the older Tertiary units. This very poorly sorted layer is composed almost exclusively of clasts of the Kneeling Nun Tuff that range widely from granules to huge blocks tens of meters across (**Ttnx**). Eutaxitic foliation visible in the clasts is random and chaotic from one clast to the next., indicating that there has been considerable movement and rotation of the individual clasts with respect to their neighbors. The prominent cliff on the north side of Bayard has a relatively planar lower contact and at first the cliff resembles an outflow sheet of intact welded tuff. Upon closer examination, however, the cliff is composed mostly of randomly oriented clasts and blocks cemented to one another. Where visible, the matrix appears to contain the same tuff, but with some calcite in the matrix. Jones and others (1970) interpreted this layer as having formed from the undermining of the softer, underlying Sugarlump Tuff followed by the consequent collapse of the overlying intact layer of Kneeling Nun Tuff. However, there are several exposures of Sugarlump Tuff that are separated from the breccia layer by tens of meters of conglomerate (**Tco**). In these areas, undermining and collapse is not a viable explanation. Jones and others (1970) may have come to this conclusion by observing what they thought was a thin layer of Sugarlump Tuff directly overlain by the main mass of the breccia deposits on the immediate northwest side of Town. From a distance there is a very light gray tuff layer a few meters thick immediately underneath the cliff-forming breccia. However, the light gray, non-welded tuff has the same phenocryst assembledge as the overlying blocks of Kneeling Nun Tuff and is likely part of it. The breccia layer is thickest in the east near Bayard and thins westward where it pinches out within 1-2 miles. This geometry, and the unit's texture, is consistent with deposition as debris flows or rock avalanche deposits. If they are, then this implies the existence of a west-facing cliff very close to the position of Bayard at least as far back as the time when this breccia layer was deposited, possibly during the Pliocene (?).

Resting on top of the Kneeling Nun Tuff breccia (**Ttnx**) is a younger sandstone and conglomerate unit (**Tcy**). This conglomerate is almost nowhere exposed, except in the road-cut between Bayard and Central. Unlike the older conglomerate (**Tco**) this unit is dominated by clasts of Paleozoic and Cretaceous sedimentary rocks. Light tan quartzite derived from the Beartooth Quartzite (**Kb**) typically forms the larger, most obvious clasts that can reach up to 60 cm across. Clasts of grayish green sandstone from the Colorado Formation (**Ks**) are common. Rounded, lighter colored clasts of crystal-rich welded tuff (resembling the Kneeling Nun Tuff) are locally common, particularly in the east, where they occur as cobbles to large boulders over 1 meter across. Farther west the unit contains more and more material derived from the volcanic breccia and hypabyssal rocks. What is also significant about this unit is that it typically contains abundant dark gray to black, dense, subrounded pebbles to large cobbles of iron. These deposits were planed off probably during the late Pliocene and overlain by a thin veneer of gravels containing mostly clasts derived from the volcanic rocks from the north side of the quadrangle (map unit **Qo**)

Quaternary deposits

The youngest deposits in the area are those filling the modern drainages. Jones and others (1970) mapped many more deposits mantling the surrounding hills, which they referred to collectively as 'Quaternary alluvium (Qal).' Their map is very useful for determining which areas of the bedrock are covered, but technically most of these mapped areas are not deposits in the strict sense. They are thick soils, many of which contain pronounced and well-developed dark brown argillic horizons, indicating that they are quite old—probably early to middle Pleistocene. During this study, most of these soils were not mapped separately from the underlying bedrock, and were mapped only where they were part of a thicker alluvial deposit.

Several separate terrace levels were identified. The youngest is defined by the modern creek bed, and older terraces are at progressively higher positions in the landscape. The oldest deposits are at a very high level and cap the rounded hills in the southern part of the map. This older unit (map unit **Qo**) is dominated by subrounded cobbles and small boulders derived from the Tertiary volcanic rocks to the north. Based on the attitude of the contact between the younger and older conglomerates below, map unit **Qo** was apparently deposited on an angular(?) unconformity on the underlying deposits. Because of its relatively flat-lying attitude and its position high in the landscape, map unit **Qo** probably represents the end of Late Tertiary/Early Pleistocene basin agradation and the beginning of incision and down-cutting that led to the present landscape.

Other poorly consolidated alluvial deposits reside between about 5 and 15 meters above the present drainages. These deposits (map unit **Qm**) are composed of mix of subrounded pebbles and cobbles derived mostly from Tertiary volcanic rocks to the north and smaller amounts of intermediate volcanic and plutonic rocks derived from the Cretaceous volcanic breccia (**Kvx**). These deposits have moderate to week argillic horizons and, as mapped, probably are middle to late Pleistocene in age.

In contrast to the older deposits, the younger Holocene deposits (map unit **Qy**) are composed dominantly of fine-grained sand, silt, and minor lenses of gravel, except in the deeper canyons to the north where they contain coarser deposits. This unit commonly forms the flat valley floors that are blanketed by grass and dense thickets of flowering plants. As mapped, this unit really encompasses at least two and possibly three different terrace levels, but they were not mapped separately at this scale. In many areas the modern creeks have incised down into these deposits, revealing 2-8-meter cross-sections in small cliffs. In some of these exposures dark gray clay-rich paleosols are visible, typically between 10-40 cm thick. The uppermost soil forming the top surface is typically dark and organic-rich.

On the eastern side of the map, Yellowdog Gulch along most of its length contains very abundant pebbles and cobbles of dense, detrital iron. The clasts were likely eroded from the original gossan cap of the Santa Rita porphyry copper deposit. In places along the creek bed, the iron clasts are concentrated as placers in small depressions or in the lee of boulders. The contrast between the dark iron clasts and the light gray limestone is quite striking.

Structure

Deformation in the study area can be divided into at least three separate episodes: (1) Cretaceous (or Later Jurassic?) faulting, (2) Latest Cretaceous folding and possible penecontemporaneous intrusion, and (3) normal faulting along northeast-southwest-striking faults.

In the northwest corner of the map area an approximately 100m thick sequence of gently east- to southeast-dipping, cross-stratified, moderately to poorly-sorted quartz sandstone, and chert-quartzite pebble conglomerate of problematic origin is present. Although the unit resembles the Beartooth Quartzite, which is how Jones et al. (1970) mapped it, the unit also overlaps a fault that juxtaposes upper Paleozoic rocks on the south with a thick section of Colorado Formation on the north. Because it overlies the Colorado Formation, it is correlated with map unit **Ksc**. However, the lower part of the unit, where it overlies Paleozoic rocks, displays vertical burrows typical of a shoreface depositional environment, and this part of the unit may be correlative with the Beartooth. In some areas hematite stained vugs in resistant pebbly quartz sandstone ledges give a petroleum odor when broken. Up-section the unit includes a thin-bedded, shale-siltstone-fine-grained possibly calcareous sandstone interval. These relationships indicate that northwest-striking faulting occurred before the pebbly conglomerate of probable Cretaceous age was deposited. The age of the pebbly conglomerate (**Ksc**) is not precisely known, but this relationship is similar to Late Jurassic-Early Cretaceous normal faulting in southern New Mexico and Arizona that was subsequently overlain by the Glance Conglomerate. It is possible, therefore, that the Colorado Formation may really be equivalent to the Bisbee Group, and the pebbly conglomerate may be equivalent to the Glance Conglomerate.

In the central and southwestern part of the map area, due to poor exposure and interference by intrusion of later plutonic units, the nature of the contact at the base of the volcanic breccia unit (**Kvx**) is poorly constrained, but since strata in the underlying unit are typically strongly inclined with respect to the contact, the contact is interpreted as an angular unconformity, a fault, or both. Jones et al. (1970) refer to the contact as an erosion surface throughout the area. They do not specifically exclude the possibility that the contact is a fault or at least a degraded fault scarp in some areas, but this seems likely, considering that the uplift that resulted in erosion of the Colorado Formation prior to emplacement of the volcanic breccia was probably accompanied by block faulting. Some uplift is indicated in the east where a relatively thin sequence of the Colorado Formation is present below the upper conglomerate unit (**Ksc**). Uplift is also indicated in the northwest where a thick succession of the upper conglomerate (**Ksc**) locally overlies Paleozoic rocks. The upper conglomerate is conspicuously absent in the central and southwestern part of the map area where the Colorado Formation is thickest. One possible interpretation of these relationships is that a broad syncline was developing in the Colorado Formation, and as folding continued, its eastern and western limbs were beveled by erosion and overlain by the volcanic breccia (**Kvx**). That folding continued during and/or after emplacement of the volcanic breccia is indicated by the map pattern in the Twin Sisters – Fort Bayard area.

The Paleozoic rocks and the overlying Late Cretaceous Colorado Formation are all gently to moderately folded across the study area. The best exposures, and the most complete sections, are along the eastern side of the map. Here, these rocks form a broad west-facing monocline that plunges westward underneath the vast expanse of volcanic breccia (**Kvx**) that underlies most of the map area.

Before this study it was not clear if the overlying volcanic breccia (**Kvx**) was also folded by the same event that folded the Paleozoic rocks. In the southeast corner of Section 13, Township 17 South, Range 13 West, Jones and others (1970) show a protrusion/reentrant of the Colorado Formation (**Ks**) into the volcanic breccia, where the contact was interpreted as an unconformity, cut by a northeast-striking fault on the north side of the protrusion. During the current study, however, no fault was identified. And interestingly, bedding orientations in volcaniclastic sandstone mimic the bedding orientations in the underlying Colorado Formation and both form a small plunging syncline about 1/3 mile across, plunging to the west-northwest. A similar relationship can be seen about 0.5 miles northeast where a layer of pebbly conglomerate (**Ksc**) at the top of the Colorado Formation appears to be tightly folded in the same manner, although much smaller, and is surrounded all along its upper surface by volcanic breccia.

About 1 mile west of Central, several northeast-striking fold axes are revealed by alternating dips within the Colorado Formation. Curiously, the contact between the Colorado Formation and the overlying volcanic breccia appears to be curved in the same sense as the folds. The map pattern gives the appearance then that the contact between the units is folded as well.

The presence of the relatively thin pebbly conglomerate almost always at or very close to the top of the Colorado Formation and just below the contact with the volcanic breccia implies that at the time when the pebbly conglomerate layer was exposed at the surface, there was only minimal relief. If there had been more relief, it is more likely that erosion would have cut down into and/or removed large sections of the pebbly conglomerate. This observation likewise supports the conclusion that the event that caused folding in the Paleozoic rocks occurred after (or possibly during) deposition of the volcanic breccia.

Within the quadrangle, strata of the Colorado Formation (**Ks**), the pebbly conglomerate (**Ksc**), and the volcanic breccia (**Kvx**) are folded together. In the central and southwestern parts of the map area, the regional map pattern suggests a syncline trough involving both units. The irregular contact between the two is interpreted as the result of broad folding of a mostly depositional contact complicated by faults (possibly growth faults), degraded and overlapped fault scarps, and paleocanyons. The two general orientations of contacts, northwesterly and northeasterly, are somewhat linear and may be, in whole or in part, faults and/or degraded fault scarps overlapped by the volcanic breccia. The northeasterly set is roughly parallel to the trend of the regional fold axes, and the dominant strike of dike emplacement. The northwest set, commonly intruded by elongate stocks of the Pinos Altos plutonic complex, appears to be a set of cross faults.

Several northeast-striking faults cut the Paleozoic and tertiary rocks on the eastern side of the quadrangle. Piercing points are not available, and the dip of the faults was not measurable, but if these faults are normal faults, then the all of the faults except the fault along Beartooth Creek show down-to-the-south displacement. East of the State Medical Center one fault clearly displaces the contact between the Colorado Formation (**Ks**) and the quartz diorite intrusive (**TKg**). Farther south (north and south of Bayard), two faults appear to cut across the younger Tertiary conglomerate (**Tcy**).

Mineralization

Mineralization was examined in great detail in previous studies, particularly in relation to the Santa Rita porphyry copper deposit, but it was not the focus of this study (also, we were not experts in mapping ore minerals). However, some observations about mineralization may be useful. In the southeastern part of the map, north of Bayard, mineralization cuts across the quartz diorite intrusion (**TKg**). Mineralization includes dark gray to rusty red and yellow fine-grained minerals that resemble hematite and limonite. Mineralization follows prominent northeast-striking jointing and selvages between 1 and several cm are common. White vein quartz is prominent along some of the same mineralized joints and in some cases forms anastamosing veins parallel to jointing and 20-30 cm thick. Other mineralized joints appear to contain fine-grained manganese and calcite. Spots of chrysacola and malachite are rare. Several of these mineralized joints are shown on the map as stippled areas. Jones and others (1970) showed them on their map as veins, and this may be correct, but much of the mineralization is more diffuse and does not show distinct, sharp boundaries. Mineralization also cuts the outcrops of Colorado Formation exposed immediately north of Bayard, and many pits and shafts were dug into these rocks, but the mineralization is not as obvious except where resistant black gossans hold up ridges.

Mineralization also follows prominent near-vertical northeast-striking jointing in the northwest part of the quadrangle near Piños Altos, and is an area that has been mined for over a century. Many thin veins up to 1-2 cm thick are dominated by white vein quartz and vuggy limonite and hematite. The vugs are likely the cavities remaining after the removal of sulfide minerals visible on many tailings piles and in several small adits and shafts. Mineralization in these areas includes chalcocite, chalcopyrite, pyrite, minor chrysacola, vuggy quartz, barite, and large pale green minerals with cleavage and possibly hexagonal crystal habit (diopside? epidote?). Mineralization in this area cross-cuts the older pyroxene porphyritic intrusive and the Piños Altos stock itself.

Suggestions for continued work.

Correlation of the Mid-Cenozoic ash-flow tuffs is an issue worth pursuing, but more importantly…relatively fresh phenocrysts of hornblende and/or pyroxene are present in nearly all of the Paleogene plutonic and volcanic rocks, and these should be dated in order to 1) clarify the age relationship of the Piños Altos plutonic complex to the Fort Bayard hornblende quartz diorite (**TKg**), and 2} help define the duration of time between emplacement of hornblende-porphyritic lavas of the volcanic breccia unit (**Kvx**) and the hornblende-porphyritic dikes that cut them. These dates are probably the most important to acquire since they would help constrain when the regional tectonic setting changed from one of folding and compression to dike emplacement, block faulting and extension. Coupled with this problem are questions about the age of the Mesozoic sedimentary rocks in the area.

The Upper Cretaceous biostratigraphic age assignment of the Beartooth Quartzite and Colorado Formation (Jones et al., 1970; Cunningham, 1974) could not be confirmed during this study. In the westerly adjacent Silver City quadrangle, where geologic investigations are continuing, limestone units similar to the Greenhorn Limestone have been noted, but we know of no diagnostic fossils that have been identified. The area is in close enough in proximity to the Lower Cretaceous Bisbee basin of southeastern Arizona, and the lithology of units in the Colorado Formation similar enough to the Bisbee Group that it is possible that the Colorado Formation is significantly older than previously thought.

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Unit Descriptions

Fort Bayard 7.5' Quadrangle

Quaternary Surficial Deposits

Qy **Younger Quaternary alluvium (Holocene).** These deposits are mostly unconsolidated silt and sand, with subordinate gravel and clay. Gravel commonly forms relatively thin layers between about 10 and 30 cm thick, while interbedded silt and sand forms the bulk of these deposits and commonly forms thin beds that are locally laminated. In good stream-cut exposures paleo-soil horizons are visible where they form darker, non-bedded, clay-rich horizons exhibited vertical cutan formation. Also in stream-cut exposures shallow paleochannels commonly between 10 and 50 cm deep are visible and commonly filled with gravel or sand. The unit forms very flat deposits along the modern stream valleys that have almost everywhere been dissected and entrenched by the modern streams. In the southern part of the quadrangle dissection is between 2-3 meters, while in the north it is up to 8-10 meters.

Qm **Middle Quaternary alluvial deposits (middle to late Pleistocene).**Interbedded silt, sand, and gravel. These deposits are typically coarser than the younger Holocene deposits (map unit Qy) and contain abundant subrounded to rounded cobbles and locally small boulders up to 40 cm across. Many of the clasts are Tertiary volcanic rocks. These deposits form elevated terraces from 5 to 10 meters above the modern stream channels, and commonly have moderately developed argillic horizons.

Qls **Landslide deposits (Pleistocene).** This deposit was mapped in the far southeast corner of the quadrangle where it is composed of small to large, poorly sorted blocks of Kneeling Nun Tuff. It is not clear if this unit is related to the breccia deposits also containing poorly sorted clasts of Kneeling Nun Tuff (**Ttnx**), but this unit appears to post-date the north-northeast-striking fault in the same area. Because it is lower in the landscape than map unit **Qo** it may be younger than **Qo**.

Qo **Older Quaternary alluvium (early Pleistocene).** This unit forms a thin, sheet-like deposit capping the highest hills in the southern part of the quadrangle. In most areas the deposits contain almost exclusively volcanic clasts composed mostly of Basaltic andesite (map unit Tba), aphyric lava (map unit Tva), vesicular basalt, and occasional clasts of welded tuff. The unit contains a very well-developed argillic horizon (abundant red-brown clay) and appears dark brown in color. Most surface clasts are moderately varnished and, where rarely exposed, carbonate is abundant in the matrix below the argillic horizon.

Tertiary Volcanic and Sedimentary Rocks in the North

Tva **Aphyric lava (Tertiary).** These light purple-tan lava flows are nearly aphyric except for minute phenocrysts <1 mm altered to red opaque minerals. Outcrops are typically very platy and resistant. Individual flows are visible because of vegetation bands on the mountain northeast of the northeast corner of the map. North of the quadrangle they appear to form a thick sequence several hundred feet that is overlain by a light tan unit that resembles a tuff from a distance.

Tba **Basaltic andesite.** This volcanic rock contains 30-40% tabular/rectangular euhedral plagioclase phenocrysts up to 6 mm long, and 2-5% green glassy pyroxene also up to 6 mm long, and small crystals <1 mm across altered to red opaques that may be olivine altered to iddingsite, all in a dark gray aphanitic matrix. Commonly vesicular. This unit forms a prominent dark cliff and bench where the overlying conglomerates have eroded back. These lava flows pinch out eastward north of Avalanche Peak.

Tc **Conglomerate and sandstone (Tertiary).** Conglomerate and sandstone. Nearly flat-lying to gently dipping (<10°) thin to medium bedded sandstone and conglomerate containing mostly clasts of pyroxene porphyry derived either from dikes of map unit TKh or from the volcanic breccia (map unit **Kvxx**). Most clasts are angular to subrounded. Locally, the unit is dominated by subrounded to rounded large cobbles and small boulders up to 60 cm across composed of crystal-rich welded tuff that resembles the Kneeling Nun Tuff (map unit **Ttn**). These tuff clasts tend to weather out of eroded slopes and give the impression that the slope is an exposure of welded tuff. Bedding in this unit is relatively planar, but paleochannels up to 1 meter deep are common. The largest clasts are between 40 and 60 cm across, but more typically between 20 and 30 cm. The sand fraction is composed of lithic fragments of the same rock types listed above. Quartz is a very minor constituent of the sand fraction. The unit is almost everywhere moderately cemented with calcite. The best exposure is on the west side of Avalanche Peak, where a cliff face exposes a 20-meter thick section. Interbedded with Tertiary volcanic rocks along the northeast side of the quadrangle. Overall this unit closely resembles the older conglomerate (map unit **Tco**) in the southern part of the quadrangle and may be partially equivalent.

Tt_2 **Crystal-poor welded tuff (Tertiary).** This welded tuff contains <1% sanidine and 2-5% subhedral biotite flakes 1-3 mm wide. The biotite is characteristically a slight copper-red color. Where exposed near the north end of Cameron Creek, the basal 3 meters of the tuff is bedded. Most outcrops are massive and non-bedded and contain partially flattened pumice fragments several centimeters across. Some places are more densely welded than others. In the northeast part of the quadrangle this tuff is separated from the stratigraphically lower, crystal-rich tuff by conglomerate (map unit **Tc**), but farther west near Cameron Creek the conglomerate pinches out and the two tuffs are in contact.

Tt_1 **Crystal-rich welded tuff (Tertiary).** This welded tuff contains about 5-15% subhedral sanidine and quartz from 1-2 mm across and 1% subhedral biotite flakes 1-2 mm across, all in a light gray aphanitic matrix. Abundant flattened pumice fragments up to 10 cm long form a moderate to strong eutaxitic foliation which dips about 35° at the southern margin (the base of the unit) and becomes less steep upward and northward. Layering is mostly visible from a distance. One thin1-2 meter thinly bedded air-fall tuff interval is exposed in the wagon road, but otherwise the tuff is rather structureless and massive.

Tb **Basalt (Tertiary).** This light bluish gray rock contains 2-5% subhedral phenocrysts all altered to red opaque minerals in a microcrystalline matrix. Large ovoid cavities up to 1 cm across superficially resemble flattened pumice but are mostly vacant and are likely vesicles. This rock is exposed in only one place at the base of the Tertiary sequence less than one mile west of Century Hill.

Tertiary Volcanic and Sedimentary Rocks in the South

Tcy **Younger conglomerate.** This unit everywhere overlies the welded tuff breccia (map unit Ttnx) but is nowhere well-exposed. The unit contains abundant subangular to subrounded clasts of greenish-gray sandstone and clean quartzite derived from the Colorado Formation and Beartooth Quartzite. In the east these clasts dominate. In the west the unit contains more abundant pyroxene-rich hypabyssal rocks derived from dikes or from the volcanic breccia (map unit **Kvx**). In all areas, more so in the east, dark, dense iron clasts from 1-40 cm across are abundant and diagnostic. Also in the east the unit contains abundant subangular clasts derived from the hornblende quartz diorite (map unit TKqd), which are commonly fresher than nearby exposures of the intrusive unit. Rounded, lighter colored clasts of crystal-rich welded tuff (resembling the Kneeling Nun Tuff) are locally common, particularly in the east, where they occur as cobbles to large boulders over 1 meter across. Forms smooth rounded hills in the southern part of the map area.

Ttnx **Welded tuff breccia.** This unit contains very poorly sorted clasts of crystal-rich welded tuff (map unit Ttn) from sand-size to large boulders >10 meters across. Eutaxitic foliation, visible in the larger clasts, is rotated mostly randomly with respect to foliation in the neighboring clasts. In some of the exposures north of Bayard a consistent eutaxitic foliation in some outcrops dips northwest between 30 and 50°. Where visible, the matrix also appears to be composed of the same crystal-rich welded tuff, or sand derived from it. This unit caps the hill north of Bayard and superficially resembles and intact flow. Elsewhere it forms a thin layer a few meters thick that is quite pervasive stratigraphically. Although Jones and others (1970) originally interpreted this unit as having formed from removal of the softer crystal-poor welded tuff below and collapse of the Kneeling Nun Tuff, intact exposures of the crystal-poor tuff below outcrops of the welded tuff breccia suggest a different genesis. Pervasive jointing in the Kneeling Nun Tuff, and the proximity of breccia deposits to steep outcrops of Kneeling Nun Tuff in the extreme southeast corner of the map, suggest that the breccia deposits may have been deposited as rock avalanches or debris flows shed from intact cliffs of welded tuff.

Ttn **Kneeling Nun welded tuff (Tertiary?).** This crystal-rich welded tuff contains about 30-50% anhedral to subhedral quartz and sanidine, and 1-2% subhedral biotite flakes, all 1-3 mm across in a light tan to brown aphanitic matrix. The rock may contain rare hornblende. Pumice clasts are partially flattened but eutaxitic foliation is difficult to discern, even on weathered surface. The base of the unit is locally nonwelded and is light gray and nonbedded, but the same phenocryst assemblage is visible. Contains sparse angular xenoliths 1-8 cm across composed of fine-grained maroon quartzite.

Ts **Green sandstone (Tertiary).** Thick sequence (100+ feet) of moderately well sorted sandstone, gravelly sandstone, and thinly bedded light tan-colored pumaceous(?) gravelly sandstone. The overall forest green color of this unit is quite striking. In all beds the larger grains are dominated by fine-grained, light gray to maroon quartzite and other siliceous grains, some of which resemble flow-banded rhyolite. The sequence is thin to medium bedded. The light yellowish tan layers are sandy and commonly more gravelly than the greener beds, and contain abundant siliceous, aphanitic gravel-size clasts that resemble pumice. Small channels less than 1 meter across and 20 cm deep contain subrounded pebbles and cobbles, but the exposures were inaccessible so their composition is uncertain.

Tt **Bedded lithic tuff (Tertiary).** These thinly bedded deposits form two distinct tuff units in the far southeast corner of the map area. The lowermost unit is thin, a few meters thick, and is interbedded with conglomerate rich containing clasts of pyroxene porphyry and/or andesite (map unit Tc). The uppermost tuff is considerably thicker (10 meters+), though exposures are poor, and is overlain by float of green sandstone (map unit Ts). Beds are thin, platy, and light yellowish gray. Both tuff layers contain abundant subangular sand to small pebbles of maroon to dark red quartzite.

Tts **Sugarlump Tuff (Tertiary).** This welded tuff contains about 1% subhedral biotite and sanidine phocrysts up to 1 mm in a light bluish gray aphanitic to partially glassy matrix. Contains abundant flattened pumice fragments. The base is very sharp and planar and overlies a light pink clay-rich layer 1-2 meters thick that may be altered nonwelded tuff. This welded tuff unit appears to be one flow unit as no distinct flow breaks are visible and the unit forms one prominent cliff up to 5 meters high.

Tb **Basalt (Tertiary).** This dark gray rock contains 1-2% phenocrysts of altered red opaque minerals (iddingsite) up to 2 mm across, in a medium to dark bluish gray aphanitic matrix. The rock weathers into thin robust platy outcrops that are very difficult to break with a hammer.

Tco **Older conglomerate (Tertiary).** Conglomerate and sandstone. Nearly flat-lying to gently dipping (<10°) thin to medium bedded sandstone and conglomerate containing mostly clasts of pyroxene porphyry derived either from dikes of map unit TKh or from the volcanic breccia (map unit Kvx). Subordinate clasts include fine- to medium-grained pyroxene-bearing hypabyssal rocks and minor sandstone derived from the Colorado Formation. North of Bayard these deposits also contain minor boulders of crystal-rich welded tuff. Most clasts are angular to subrounded. Bedding in this unit is relatively planar, but paleochannels up to 1 meter deep are common. Except for the exposures immediately north of Bayard the largest clasts are between 40 and 60 cm across, but more typically between 20 and 30 cm. The sand fraction is composed of lithic fragments of the same rock types listed above. Quartz is a very minor constituent of the sand fraction. The unit is almost everywhere moderately cemented with calcite.

Dikes and other Intrusive bodies

Trp **Rhyolite porphyry dikes and plugs (probably Tertiary).** Coarse-grained (up to 20mm) euhedral to subhedral feldspar (potassium feldspar and plagioclase), typically strongly flow-foliated porphyry dikes locally with abundant 1-4mm euhedral biotite. An isolated plug occurs in the southwest corner associated with a north-striking swarm of dikes that extend to north, nearly the entire length of the map area. The dikes and parts of the plug are typically crumbly, and weather into light-colored fragments, but locally, a dark grayish green vitric matrix is preserved. Ubiquitous biotite is typically very fresh, and the dikes are characteristally non-magnetic in contrast with most of the older dikes in the area. The unit also occurs along Twin Sisters Creek east of Fort Bayard as a north-striking chain of plugs. A minor swarm of west-northwest striking dikes occur to the northwest of the north end of this chain. The plugs in this area contain abundant xenoliths. The unit is locally differentiated into a flow-banded hypabyssal rock (**Trp**) and lithic breccia (**Trpx**).

Trpx **Ryolite porphyry lithic breccia (probably Tertiary).** Coarse-grained feldspar porphyritic, commonly flow-foliated lithic breccia containing 5-80% pebble to several-mete-diameter xenoliths of volcanic breccia (**Kvx**) and sandstone-shale of probable Colorado Formation (**Ks**). The unit resembles the megabreccia of some ash-flow tuffs, which it may grade into in some areas.

TKgc **Medium- to coarse-grained granite (Cretaceous or Tertiary).** Central core of Piños Altos stock. Contains about 15% biotite+hornblende. Biotite is euhedral and up to 3 mm across. Hornblende is tabular and up to 6 mm long. Feldspar and quartz form a granular texture, and on weathered surfaces it is difficult to distinguish the two minerals. Locally, K-feldspar is very abundant and rectangular, up to 8 mm. Forms rounded to subangular bouldersand light rusty orange sandy soil.

TKm **Pyroxene and hornblende porphyritc quartz diorite to syenite.**

TKg **Hornblende quartz diorite (Cretaceous or Tertiary?).** This medium to light gray medium-grained granitic rock contains anhedral to subhedral light gray feldspar 1-3 mm across and about 15-30% euhedral biotite 1-3 mm across and subhedral hornblende 1-6 mm long, in a fine-grained granular matrix. Quartz and feldspar are difficult to distinguish from one other in hand-samples. On some weathered surfaces K-feldspar is abundant and is visible as nearly square, medium to light gray phenocrysts up to 8 mm across. The unit forms a sill-like body north of Bayard (the Fort Bayard stock)where it intrudes sandstone and shale beds of the Colorado Formation. Fresh exposures exposed in road cuts, particularly along Highway 180, are fresher, light to medium gray in color, and reveal sparse rounded xenoliths up to about 6 cm across that have the same mineralogy but contain more hornblende and, thus, appear darker. This intrusive body exhibits several well-defined joint directions, locally mineralized. Outcrops are typically highly weathered and are rusty orange and crumble into sand, but rounded to subangular boulders are common on the surface.

Cretaceous and Paleozoic Sedimentary and Volcanic Rocks

Kvx **Volcanic breccia (Cretaceous?).** Composed of poorly sorted angular to subrounded clasts of pyroxene-bearing volcanic and hypabyssal rocks. The most extensive unit in the map area is a mixed andesitic lava, heterolithic andesitic breccia, and volcaniclastic unit (the ‘andesite breccia’ of Jones et al., 1970). The unit consists of a wide variety of andesitic lavas that are invariably intruded by intermediate to mafic dikes, the density ranging from less than 5% to greater than 80%. Three main varieties of lavas, based on phenocryst assemblages, abundances, sizes, and size ranges can be easily recognized from place to place, but due to poor exposure and the prevalence of cross-cutting dikes with similar phenocryst assemblages it would be impossible to regionally differentiate these. Most of the andesite is magnetite bearing. Three principle varieties are, in decreasing order of abundance: 1) fine-grained ($\leq$2mm) plagioclase phenocryst-rich with subordinate mafics of hornblende and/or pyroxene, plus or minus olivine, 2) medium- to coarse-grained (2-6mm, but up to 10mm) hornblende-porphyritic and/or pyroxene-porphyritic, and 3) elongate, medium-grained (2-4mm), sparsely plagioclase-porphyrititc lava with very sparse mafics. Individual lava flows, consisting of massive coherent facies lava mixed to varying degrees with autobreccia, are complexly interbedded with a wide variety of heterolithic volcanic and epiclastic breccias, and lesser amounts of mafic volcaniclastic rocks. Clasts in the breccias and volcaniclastic rocks are dominated by andesite, but locally include sparse material derived from the Colorado Formation, and possibly older quartzite. Only one builder-size clast of non-foliated coarse-grained granite was seen. This xenolith is similar to xenoliths found within the dike complex and along intrusive contacts within the fine-grained monzonitic unit of the Pinos Altos complex. In many areas the matrix and the clasts have a nearly identical composition, making distinction of the clasts from the matrix difficult.

Ksc **Pebbly conglomerate (Late Cretaceous?).** Interbedded medium- to coarse-grained sandstone and pebble conglomerate. The sand grains are composed mostly of moderately to poorly sorted subangular quartz and minor feldspar moderately cemented by silica. Pebbles are well rounded and composed of subrounded to well rounded of light to dark gray chert, light gray quartzite, and vein quartz commonly between 1-4 cm, but locally up to 10 cm across. Petrified wood is locally abundant and has been replaced by dark gray, fine-grained chert. Some pieces of petrified wood are well rounded, indicating they may have been eroded from an older rock unit. This unit forms a thin layer a few meters thick resting on top of the Colorado Formation. Locally, pebbly conglomerate is interbedded with the Colorado Formation less than about 10 meters from the top of the unit. If equivalent, exposures in the northwest corner of the map are close to 100 feet thick.

Ks **Colorado Formation (Late Cretaceous?).** Interbedded shale and sandstone. The lover part of this unit is mostly medium to dark gray very fine-grained sandstone and siltsone, with subordinate shale. Sandstone beds are locally coarse-grained and contain well sorted aubangular to subrounded quartz and subordinate feldspar grains. Coarse-grained beds in the lover part of the unit pinch and swell between 10 and 50 cm thick over a distance of about 10 meters, and typically grade downward to well rounded chert-pebble conglomerate with clasts up to 3 cm across. Some siltsone beds contain septarian concretions. Though rare on outcrop some weathered-out concretions are up to 40 cm across. Thinly laminated dark siltstones locally exhibit low-angle cross-beds in sets up to 2 cm thick. Sandstone beds dominate in the upper part of the unit, where they are also fine- to medium-grained subangular to subrounded quartz and subordinate feldspar, in tan-colored thin to medium beds. They locally exhibit planar to trough cross-beds in sets up to 70 cm thick. Thin, dark brown sandy limestone beds up to 20 cm thick form conspicuous, but mostly covered, outcrops in the upper part of the unit. Where siltstone and shale dominate the unit forms smooth, rounded hills and slopes with poor outcrop. Sandstone beds commonly from steps or small ledges a few feet high. May be equivalent to similar deposits beneath the Springerville volcanic field in east-central Arizona, or to the Bisbee Group in southern Arizona.

Kb **Beartooth Quartzite (Cretaceous).** 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.

Ps **Abo Formation (Early Permian).** Interbedded fine-grained red sandstone, and red to purple sandstone and shale. Poorly exposed near the east side of the map area where it only locally crops out beneath the Beartooth Quartzite (map unit Kq). Forms red-colored clay-rich slopes mostly mantled by clasts shed from the overlying quartzite. Small outcrops exposed by quarrying operations show thin bedding in the fine-grained red sandstones.

Ps **Syrena Formation (Pennsylvanian).** Chert-rich limestone. This light blue-gray limestone is micritic to finely crystalline. Irregularly shaped, light yellowish tan chert stringers locally occupy 50% or more of the rock and weather out to cover the surface in a tan lag that superficially resembles float of fine-grained sandstone. The chert has incompletely replaced the host carbonate such that even the chert fizzes lightly with acid. Chert stringers are commonly roughly parallel to bedding, but also cut across bedding in irregular patterns. Bedding in this unit is thin to thick, and planar. Although mostly micritic, the unit is locally coarsely crystalline, and contains abundant crinoid stems, brachipods, and byozoa, in some places silicified but in most areas are limestone. Fossils are most visible on weathered surfaces. Sequences of limestone are interbedded with purple shales that form poorly exposed slopes. The best place to see this relationship is in the road-cut along the east side of Highway 152.

Mo **Oswaldo Formation (Mississippian).** Medium to dark gray fossiliferous limestone. This unit contains almost no chert and possesses thick beds that are typically massive. Bedding is best visible from a distance. The best exposures are just outside the map area to the east in a large open-pit quarry operation. In these pits the apparent upper surface of the unit is deep red and appears karsted. However, downstream the contact between Pl and Ml is sharp and shows no evidence for dissolution.