Geologic Map of the Southern Peloncillo Mountains; Skeleton Canyon, Guadalupe Spring, and Guadalupe Canyon 7.5' Quadrangles, Cochise County, Arizona, and Hidalgo County, New Mexico

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INTRODUCTION

As part of the mid-Tertiary Boot Heel volcanic field, the southern Peloncillo Mountains provide a wonderful opportunity to study two Oligocene cauldron structures, intracaldera and extracaldera ignimbrites, and caldera-fill meso- and megabreccias. The Peloncillo Mountains proper straddles the Arizona-New Mexico Border and defines a long, narrow strip from the Mexican border to well north of Steins. The area focussed on in this report is between the Mexican border on the south and about two miles north of Skeleton Canyon in the north. The range contains five regional ignimbrites that span the transition from low-angle Laramide-related subduction to transform faulting in the southwestern North American Cordillera. Earlier detailed work by Elston (1976), Deal and others (1978), and Erb (1979), among others, has recently been revised using high-precision $^{40}Ar/^{39}Ar$ geochronology (McIntosh and Byron, 2000). Combined with recent mapping this has allowed for the creation of a detailed time-stratigraphic section for the southern Peloncillo Mountains.

The eruption of the ignimbrites and associated post-caldera lava flows waned after about 27 Ma, and was followed much later, by voluminous basaltic volcanism between about 9 and 5 Ma. These basalts were erupted onto a deep erosional unconformity of considerable relief. These “older basalts” filled paleotopography in some places to over 300 meters thick. Basin-and-Range faulting has subsequently down-dropped the San Bernardino Valley on the west, leaving the older basalts as high-standing dissected ridges flanking the west side of the range. Although at least one minor fault offsets the basalt, its age is unclear and it is uncertain how these basalts relate exactly to the onset of Basin-and-Range extension in the area.

Basaltic volcanism again renewed after infilling of the San Bernardino Valley. A recent study of the valley by Biggs and others (1999a) suggests that the valley may have been filled to higher levers prior to the onset of externally integrated drainage. However, these “younger basalts”, dated with various degrees of uncertainty at between 4.7 and 0.27 Ma, appear to reside at or very near the current high-stand surface created probably in the early to middle Pleistocene. These younger basalts were erupted from fissures that tapped the asthenosphere or upper mantle and, hence, produced very unevolved, primitive lavas, locally containing peridotite and lherzolite xenoliths (Arculus et al., 1977; Lynch, 1978; Kempton et al., 1982; Kempton, 1984; Kempton et al., 1984; Kempton et al., 1987; Kempton and Dungan, 1989). In contrast to the voluminous older basalts the younger basalts of the San Bernardino/Geronimo volcanic field are very thin (tens of meters thick total). The partially eroded cinder cones are in various stages of preservation and represent the southern-most cinder-cone field in the continental United States.

This map and report includes all of the Skeleton Canyon and Guadalupe Spring 7.5 quadrangles, and the northern part of the Guadalupe Canyon 7.5 quadrangle that is within the United States. This study was initiated as part of a geologic study of the San Bernardino Valley (Biggs et al., 1999a,b), which was in itself part of a larger project known as the Malpai Borderlands Study—an effort to characterize the geology, soils, and biology of this part of the Arizona-Mexico border region for the purpose of better managing its natural resources (Gottfried et al., 1999).

ACKNOWLEDGEMENTS

Kelly (1966) mapped the Paleozoic rocks in the southwestern part of the map, and his work is included here with only minor modification. Tom Biggs mapped the surficial geology on the west and northwest sides of the Skeleton Canyon 7.5' quadrangle. This was continuous with detailed surficial mapping he did farther to the north and west. Some of the surficial unit descriptions were adopted from that report. I am very glad I had the opportunity to work with my colleagues Cathy McGuire, Bill Svetlik, and Chuck Peacock, from the Tucson Soil Survey and Gerry Gottfried and Carl Edminster from the U.S. Forest Service—all of whom worked together on the Malpai Borderlands Project. Also, my thanks to Bill McIntosh at New Mexico Tech who reviewed the map and helped calibrate my mapping with his new high-precision Ar/Ar-sanidine ages of the welded tuffs in the map area. Tim Orr at the Arizona Geological Survey digitized most of the map.

PREVIOUS STUDIES

Cooper (1959) included the southern Peloncillo Mountains in a reconnaissance geologic map of southeastern Cochise County. Wrucke and Bromfield (1961) made a reconnaissance geologic map of the bedrock in the Southern Peloncillo Mountains east of the Arizona-New Mexico border, from the Mexican border northward to latitude 31° 45'. In their map they lumped most of the felsic rocks into the general heading 'rhyolite tuffs and welded tuffs'. Dirks (1966) studied the Paleozoic rocks in the Quimby Ranch area immediately to the west of the study area, and Kelley (1966) studied the Paleozoic rocks in the Pickhandle Hills. Erb (1979) mapped the geology of the southern Peloncillo Mountains as part of a much larger study of ash-flow tuffs in southwestern New Mexico. Deal and others (1978) studied part of the area in a larger study of Cenozoic volcanic geology of the Basin-and-Range province in Hidalgo County. Hayes (1982) created a geologic map of the Bunk Robinson Peak and Whitmire Canyon Roadless Areas. Hayes and others (1983) created a map of the mineral resource potential of the same area. Watts and others (1983) produced geochemical maps of the Bunk Robinson Peak and Whitmire Canyon Roadless Areas. To the west, Biggs and others (1999a,b) mapped the bedrock and surficial geology of the San Bernardino Valley and immediately surrounding areas. Youberg and Ferguson (2001) mapped a small area at the eastern end of Whitmire Canyon as part of a fire-management watershed study for the Coronado national Forest.

PALEOZOIC ROCKS

The oldest rocks in the map area are Pennsylvanian carbonates and interbedded clastic rocks of the Earp, Colina, and Epitaph Formations. These rocks were deposited in the shallow Pennsylvanian seas that once covered this region. Paleozoic rocks younger than the Epitaph Dolomite are not exposed and were likely stripped away by erosion during the Early to Middle Mesozoic. Since Kelly (1966) had mapped these rocks in detail, and the focus of this map was the less well-defined Tertiary rocks, Kelly's mapping was included with only minor modification. See his work and that of Dirk (1966) for more detailed descriptions of the Paleozoic formations.

BISBEE GROUP

Rocks of the Bisbee Group crop out in the southwestern part of the Guadalupe Spring and Guadalupe Canyon 7.5' quadrangles. This study primarily focussed on Tertiary rocks in the region and not much time was devoted to understanding the stratigraphy of the Mesozoic rocks. In general, however, three units were distinguished: (1) the basal Glance Conglomerate [map unit KJc], locally separated into two members, (2) fine-grained sediments of the Morita Formation [map unit Km], and (3) all younger rocks lumped together that probably include the Mural Limestone and the Cintura Formation, as defined by Ransome (1904), [map unit Kb].

The Glance Conglomerate is here divided into two informal members in the southern Peloncillo Mountains. The lower member (map unit Kcc) is a moderately sorted red conglomerate containing subrounded to well-rounded pebbles to cobbles of light gray vein quartz and quartzite in a red, silty to sandy matrix. Thin interbeds of sandstone define bedding. Exposures are limited to the north side of the Guadalupe Canyon Fault immediately east of the outcrops of Paleozoic rocks. At the northern end of the exposure there the lower member thins to the north. This lower member of the Glance is overlain by another moderately- to well-sorted conglomerate—the upper member (map unit Kcl)—containing subrounded to well-rounded limestone pebbles and cobbles. Such a marked change in clast lithologies between the two members indicates a change in the source. The change may be a result of drainage reorganization or signal nearby tectonic activity. Bilodeau (1978, p. 213) found similar clast differences in members of the Bisbee Group in the Empire Mountains. He interpreted the different clast compositions as reflecting erosion from different rocks in the hanging-wall of nearby, Triassic or Jurassic, basin-bounding faults. It may also be possible that there is a considerable hiatus between the two members.

The Morita Formation in this area is mostly siltstone with minor interbedded fine-grained sandstone. The siltstone occurs in shades of brown and red and erodes easily to form slopes, now mostly covered by Late Pleistocene alluvial deposits (map unit Ql). The tan sandstone forms resistant beds a few tens of centimeters to a meter or more thick. The sandstone beds become more abundant upward. The only place the Morita Formation was mapped is on the north side of the Guadalupe Canyon Fault immediately east of the outcrops of Paleozoic rocks.

The Morita Formation is overlain by interbedded fine- to medium-grained sandstone and thin- to medium-bedded limestone (map unit Kb). This unit may be comprised of the Mural Limestone member and the Cintura Formation of the Bisbee, but because not much time was spent studying these rocks they are here lumped together. The sandstone beds are typically gray to purple-tan and vary in thickness from a few meters to tens of meters. Sandstone beds, especially in the south, are commonly limy. Limestone beds comprise 60% or more of the outcrops of the Bisbee group. The oyster *Graphea* is very abundant, and locally other bivalves and gastropods are common. A prominent limestone cliff forms a marker layer at the top of the unit and may or may not represent the Mural Limestone. The contact at the base of the cliff was drawn on the map from aerial photographs, as were all of the strike-and-dip symbols that have no numbers for the dips.

Bisbee Group rocks form long, prominent ridges and relatively smooth-sided hills. Exposures are poor to good. The best exposures are on steep slopes and in dissected ravines. The shallower slopes are commonly covered with a thick tangle of catclaw and are very difficult to walk across. Because of the vegetation, from a distance most slopes look dark-colored. Up close the rocks are shades of light gray and tan. Bedding is easily seen where not vegetated, but is more easily seen from a distance.

Structure in the Bisbee group

In general Bisbee Group rocks are tilted to the east, commonly between 10° and 30°, but locally as much as 60°. Reconnaissance mapping indicates that the rocks have been folded into at least one syncline in the southern part of the study area. This conclusion is based mostly on air-photo interpretation but the fold is fairly obvious. The axial plane of the syncline projects approximately N30°W. Limited detailed mapping of the Bisbee at its northernmost exposures revealed an anticline with its axial plane trending approximately N10°E.

Bilodeau (1982), Drewes (1972), and others have demonstrated northwest-striking Triassic and Jurassic faults in several mountain ranges in southeastern Arizona that originally bounded blocks of considerable relief. Subsequent erosion of the up-thrown blocks locally removed thick sequences of pre-late Jurassic rocks and provided the bedrock on which the Bisbee Group was deposited.

The contact between the Mesozoic rocks and the younger Tertiary rocks is everywhere a fault contact. It is unknown what rocks, if any, existed between the two sequences. Thrust faults in the Paleozoic and Mesozoic rocks record compression and uplift in southeastern Arizona and may be Laramide in age.

TERTIARY ROCKS

Tertiary outcrops in the southern Peloncillo Mountains are composed of four discrete packets of volcanic rocks. The first is a thick sequence of intermediate to silicic lava flows, ash-flow tuffs, and volcanic breccias that range in age between about 35.1 and 32.7 Ma (McIntosh and Byron, 2000). The second packet is only partly exposed in the map area and contains another, younger sequence of ash-flow tuffs and intermediate to silicic lava flows dated between about 27.4 and 26.8 Ma. A hiatus above the second sequence records a long period of erosion, during which the southern Peloncillos were very gently tilted to the east. On this very deep and incised erosion surface vast quantities of basaltic lavas—the third sequence—were erupted between about 9.2 and 5.0 Ma. The fourth packet of volcanic rocks includes minor eruptions of undeformed, primitive basaltic lavas of the San Bernardino (or Geronimo) volcanic field erupted between about 4.7 and 0.27 Ma.

The base of the Tertiary sequence is not exposed in the southern Peloncillo Mountains. However, to the west in the Perilla Mountains and in the Pedragosa Mountains the earliest volcanic rocks, now resting on older Paleozoic and Mesozoic sedimentary rocks, are andesites. The age of the andesite is not known but the presence of these intermediate-composition rocks may represent the initiation of subduction-related volcanism in the eastern Cordillera during Laramide time. Deal and others (1978) describe andesite in the Lordsburg area that has been intruded by a granodiorite porphyry stock dated at 56.6 ± 1.2 Ma.

Ash-Flow Tuff Chronology

Five ash-flow tuffs (ignimbrites) have been identified in the study area. From oldest to youngest they include (1) Oak Creek Tuff dated at 33.50 ± 0.07 Ma, (2) Gillespie Tuff dated at 32.72 ± 0.04 Ma, (3) Tuff of Woodchopper Spring dated at 28.21 ± 0.14 Ma. (4) Tuff of Skeleton Canyon dated at 27.44 ± 0.08 Ma, and (5) Tuff of Dutchman Canyon dated at 26.67 ± 0.14 Ma (all dates are $^{40}Ar/^{39}Ar$ sanidine ages from McIntosh and Byron, 2000). The high-precision $^{40}Ar/^{39}Ar$ ages allowed McIntosh and Byron (2000) to determine that the nine separate ignimbrites they studied in the Boot Heel volcanic field were erupted in two distinct pulses between 35.2-32.7 Ma and 27.6-26.8 Ma, separated by a 5.1 Ma hiatus in ignimbrite activity. In the southern Peloncillo Mountains the first pulse is represented by the Oak Creek Tuff and the Gillespie Tuff. The second pulse is represented by the Tuff of Woodchopper Spring, the Tuff of Skeleton Canyon, and the Tuff of Dutchman Canyon.

Oak Creek Tuff

In the field the Oak Creek Tuff and the Gillespie Tuff (as mapped) are nearly indistinguishable. Both are crystal-rich tuffs bearing biotite, quartz, and sanidine. On weathered surfaces of the oak Creek Tuff the quartz phenocrysts are more resistant than the matrix and stand out in relief. These two tuffs were originally mapped as the same unit. They were only separated later on the basis of the older $^{40}Ar/^{39}Ar$ age of 33.50 ± 0.07 Ma for the Oak Creek Tuff. Without much else to go on the logical place to put the boundary between the two ignimbrites was at the caldera margin (the buried southeastern extension of the Baker Canyon Fault). It is quite possible that much of the welded-tuff breccias (map unit Ttx) within the cauldron are composed of Oak Creek Tuff rather than the Gillespie Tuff. This makes sense if the walls of the caldera were composed of Oak Creek Tuff with subsequently shed into the interior of the caldera.

The Oak Creek Tuff may have been erupted from the Juniper Cauldron in the northern Animas Mountains (Erb, 1979; McIntosh, 2000). McIntosh and Byron describe it there as a very distinctive tuff containing large quartz and hornblende phenocrysts. The apparent absence of Oak Creek Tuff in the southern Peloncillo Mountains north of the Baker Canyon Fault is somewhat suspicious. Unless it is completely buried (or unrecognized) one might expect to find more exposures of Oak Creek Tuff throughout the southern Peloncillo Mountains. Therefore, it is possible, at least, that exposures of Oak Creek Tuff in the south along Guadalupe Canyon may in fact be another, as yet unrecognized ignimbrite with similar chemistry and age, that may have originated from a caldera to the south in Mexico.

Gillespie Tuff

This crystal-rich tuff contains phenocrysts of about 15-20% clear, subhedral quartz, 10% sanidine, and 1-2% biotite, all between 1-5 mm across. Biotite is scarce and is partially altered to hematite. Some sanidine is chalky white, but most are clear to light gray. Quartz is abundant and commonly sticks out in relief on weathered surfaces, which gives the rock a rough, slightly coarse-grained appearance. Fresh surfaces are light pink to tan, but the rock weathers tan and is commonly slightly varnished. Where strongly welded, the rock forms cliffs and blocky ledges. Where less welded, the tuffs erode into light-colored crumbly slopes. Erb (1978) originally called this ash-flow tuff the Tuff of

Guadalupe Canyon. McIntosh and Byron (2000) renamed it the Gillespie Tuff. Because both the Tuff of Guadalupe Canyon and the Oak Creek Tuff are exposed along Guadalupe Canyon, the name Gillespie Tuff is adopted here as well to avoid confusion.

Several welded-tuff layers are interbedded with welded-tuff breccia (map unit Ttx) in the southern Peloncillo Mountains. Elston (1984) reported that the lower part of the Gillespie Tuff has reverse zoning, and the upper part is siliceous and unzoned. McIntosh and Byron (2000), on the other hand, describe the Gillespie Tuff and normally zoned, from low- to high-silica up-section. Part of the discrepancy may arise from the presence of interbedded welded tuff and welded tuff breccias. The two rocks are not everywhere easy to distinguish, especially where covered with vegetation. Previous workers may have sampled up-section through several different breccia and tuff layers, each giving different results depending, in part, on the source of the breccias.

Erb (1979) reported a zircon fission-track age of 27.1 + 1.5 Ma for a sample of welded tuff collected along the Geronimo Trail, about ½ mile west of Miller Spring next to Cottonwood Creek. However, McIntosh and Byron (2000) reported a more reliable $^{40}Ar/^{39}Ar$ sanidine age of 32.72 ± 0.04 Ma this same unit. Similar tuffs are exposed in the southern end of the Perilla Mountains, in the southwestern corner of the project area (East of Douglas quadrangle) and may be equivalent to the tuffs in the Peloncillo Mountains.

Geronimo Trail caldera

The most widespread exposures of the Gillespie Tuff are in the south-central part where they are interbedded with great thicknesses of mesobreccia and megabreccia. The northwest-striking Baker Canyon Fault forms the southwestern boundary of exposures of breccia and minor tuff. Although the Baker Canyon Fault down-drops Tertiary rocks against Mesozoic rocks of the Bisbee Group, following this fault to the southeast, this apparent down-to-the-northeast normal fault turns into a buttress unconformity mantled by andesite breccia and mixed breccias containing andesite and welded tuff clasts. The Baker Canyon Fault and its buried extension along the buttress unconformity most likely represent the southwestern side of the structural margin for the of the Geronimo Trail caldera.

One of the most remarkable features of the Southern Peloncillo Mountains is the great abundance of mesobreccias and megabreccias. Southeast of Bunk Robinson Peak, along the east side of Guadalupe Canyon, heterolithic and monolithic mesobreccias and minor megabreccias overlie older volcanic rocks along a shallow, west-dipping contact. The contact dips less than 10° and truncates welded tuffs that resemble the Gillespie Tuff (map unit Ttg) and interbedded andesite breccias (map unit Tax). The contact also truncates a north- and northeast-trending fault. Breccias exposed along the steep, east-facing exposures contain discrete layers. The layers are lens-like and locally have both sharp and gradational contacts. Each lens is composed of a brecciated mass of rock, commonly monolithic and locally heterolithic. Lenses of andesite breccia are dark brown and purple and locally stand out in contrast to other lenses composed of a mix of welded tuff and andesite or only welded tuff. Clasts of both andesite and welded tuff in the breccias closely resemble non-brecciated rocks on the east side of Guadalupe Canyon.

Somewhere near latitude 31° 25’ the character of the breccia changes. North of this zone, and at least to Skeleton Canyon 10 miles to the north, the breccias are dominantly monolithic and composed of clasts of welded tuff resembling the Gillespie (and Oak Creek) Tuff. South of this zone the breccias are more noticeably heterolithic and contain clasts of welded tuff, andesite, and rarely limestone. All clast types commonly occur in smaller lens-like bodies or irregularly shaped masses of monolithic breccia, but rarely as isolated clasts. No thin-sections were made during this study but the matrix between clasts appears to be microbrecciated welded tuff. The shape and composition of the breccia bodies suggests they were deposited mostly as non-turbulent debris flows or rock avalanches.

In the southern part of the Guadalupe Spring quadrangle breccias form remarkably extensive, uninterrupted exposures reaching thicknesses of at least 700 feet. About 2 miles west Southwest of Bunk Robinson Peak a large, nearly horizontally bedded block of welded tuff is surrounded by monolithic welded tuff breccia. The block is at least 100 feet long and clearly could not have been transported far in a turbulent flow.

The far southeast corner of the map area contains some interesting breccia relationships. These rocks form a sequence of interbedded tuffs and breccias. The exposed base of the sequence is andesite breccia. A coherent layer of welded tuff resembling the Gillespie Tuff overlies it. The tuff is overlain by a mixed breccia unit, which in turn is overlain by a large mass of monolithic andesite breccia. Then overlying this andesite breccia is a confusing mixed breccia unit. The northern part of this upper mixed breccia unit contains a mix of andesite/welded tuff-breccias with some small lenses of limestone. The southern exposures of this mixed breccia unit contain lenses of light gray, crystal-poor ash-flow tuff interbedded with andesite breccia. The ash-flow tuff is locally fractured and slightly brecciated but forms relatively coherent layers slicing across the countryside. This particular ash-flow tuff was seen nowhere else during his study except in the southeast corner of the map. Lack of time prohibited a detailed study of this region, and more work may reveal some interesting relationships.

Apparently interbedded with these vast expanses of breccia are coherent layers of Gillespie Tuff. These tuff layers are nearly flat-lying or dip a few degrees to the east The near-horizontal attitude of the tuff layers indicates there was very little tilting both during and after eruption. But the presence of thick breccias implies considerable local relief. The disparity can be resolved if the breccias were deposited as debris flows that flowed several kilometers from the wall of the caldera into the interior. Lipman (1976) found evidence for breccia deposits having flowed many kilometers across caldera floors in Oligocene calderas in the San Juan volcanic field to the north. In fact, intercalated ash-flow tuffs and breccias are common associations within silicic calderas in the western united States (Cruson, 1972; Ratté and others, 1972; Elston and others, 1973; Ekren and others, 1974; Lambert, 1974; Lipman, 1976; Steven and Lipman, 1976). This association indicates that caldera collapse was synchronous with ignimbrite eruption, rather than as a post-eruption event (Lipman, 1976).

Post-Geronimo Trail Lavas and Breccias

Two varieties of dacite lavas were erupted after ignimbrite activity in the Geronimo Trail cauldron had ceased. Collectively called the Dacite of Outlaw Mountain (dated at 31.81 ± 0.10 Ma and 31.91 ± 0.10 Ma, McIntosh and Byron, 2000) these lavas are comprised of a lower medium-grained lava (map unit Tdm) and an upper coarse-grained lava (map unit Tdc). Both contain characteristic rectangular to subequant, translucent plagioclase phenocrysts. These plagioclase phenocrysts look very similar to large translucent plagioclase xenocrysts found in the older and younger basalts.

Associated with the Dacite of Outlaw Mountain is a locally thick pile of volcaniclastic breccias. The breccias are typically crudely bedded and contain mostly angular to subrounded clasts of dacite and rare welded tuff. Earlier workers included these dacite-bearing breccias with the older welded-tuff breccias in Hog Canyon, and gave the collective association the name Breccia of Hog Canyon. The dacite-bearing breccias are locally autobrecciated bases of dacite flow and in other places may be debris aprons shed from previously nearby dacite domes. The dacite breccias are here interpreted as post-caldera-collapse breccias because they are not interbedded with any ash-flow tuffs. The retained name, Breccia of Hog Canyon is here defined to include only the breccia deposits that are dominated by dacite clasts. The contact between the crudely bedded Breccia of Hog Canyon and the older, non-bedded welded-tuff breccia is generally sharp and easy to see.

Apparently, the Breccia of Hog Canyon was deposited onto a surface on the underlying welded-tuff breccias of considerable local relief. On the west side of the map between Cottonwood and Sycamore Creeks a sequence of dacite lavas and breccias thickens westward where it is buried by basalts. Rare marl beds within the breccia here indicate the existence of at least one closed depression. It is unclear if the paleo-relief was created by resurgence of the Geronimo Trail caldera or by erosion.

Tuff of Woodchopper Spring

Outcrops of the Tuff of Woodchopper Spring (map unit Ttw) are exposed north of Skeleton Canyon, where they typically form lighter-colored, more resistant outcrops than the underlying tuff. The tuff is crystal-rich and contains abundant phenocrysts of sanidine, biotite, and minor quartz. As mapped it overlies a similarly looking Gillespie Tuff and underlies the Tuff of Skeleton Canyon. McIntosh and Byron (2000) dated the Tuff of Woodchopper Spring at 28.21 ± 0.14 Ma. The sanidine $^{40}Ar/^{39}Ar$ ages agree with this stratigraphy. Originally named by Deal (1979, unpublished map) McIntosh and Byron tentatively correlate it with the Tuff of Horseshoe Canyon dated at 27.6 Ma.

Near the mouth of Skeleton Canyon, below mantling exposures of the tuff of Skeleton Canyon, is exposed an older sequence of volcanic rocks tilted between 10° and 15° to the west. The oldest rock exposed is a crystal-rich, non-bedded ash-flow tuff. The tuff is here tentatively correlated with the Tuff of Woodchopper Spring. The ash-flow tuff occurs in two discrete layers separated by a volcanic breccia unit (map unit Ttx). The breccia layer contains two parts. The lower part is composed of a mosaic breccia of slightly rotated clasts of ash-flow tuff surrounded by a slightly redder microbrecciated matrix of what resembles the same tuff. The upper part is a heterolithic breccia containing smaller, poorly sorted pebbles to cobbles of the same ash-flow tuff in addition to tan-colored, fine-grained sandstone clasts that look as though they were derived from Bisbee Group strata. This breccia unit thickens dramatically to the north, where it is exposed on the north side of an east-west-striking, down-to-the-south normal fault. It is not clear if the change in thickness of the breccia is related to the fault. If it is one might expect to see the thicker portion south of the fault, on the down-dropped side. Also, the breccia thins to the east on the northern side of the fault, suggesting the variation in thickness of the unit was related to local topography rather than faulting.

Although the stratigraphic relationships to the underlying Gillespie Tuff and overlying Tuff of Skeleton Canyon are fairly clear near Skeleton Canyon, its relationship to rocks farther north and south is not.

Tuff of Skeleton Canyon

The Tuff of Skeleton Canyon (map unit Tsc) contains abundant phenocrysts (~10% of rock) of clear subhedral to rounded quartz 1-2 mm wide, clear chatoyant sanidine 1-3 mm long, and minor subhedral biotite, all in a medium gray aphanitic matrix. Lenticular, flattened, light gray pumice clasts from 0.5 to 3 cm long are common. The light gray pumice in a gull gray matrix give the rock very distinct appearance compared to the other ash-flow tuffs in the area. Throughout most of the study area no flow-breaks are visible and the rock appears to consist of one cooling unit. Excellent exposures in Skeleton Canyon mantle a steep angular unconformity dipping approximately 60 degrees to the east. Based on similar $^{40}Ar/^{39}Ar$ ages McIntosh and Byron (2000) correlated the Tuff of Skeleton Canyon with the Park Tuff (27.4 Ma).

The similarity of the Tuff of Skeleton Canyon with the Rhyolite Canyon Tuff in the Chiracahua Mountains (both texturally and mineralogically) led this author to suspect that the two tuffs might really be the same. Deal and others (1978) also pointed out the similarity between these two rocks. However, precise $^{40}Ar/^{39}Ar$ ages for both units (McIntosh and Byron, 2000) indicates the two were erupted in discrete events. Also, the presence of an apparent cauldron structural margin in Skeleton Canyon bounding a thick sequence of probable intracaldera tuff, as well as a well-documented cauldron for the Rhyolite Canyon Tuff in the Chiracahua Mountains (the Turkey Creek caldera--Drewes, 1982; Du Bray and Pallister, 1991), both suggest the two tuffs were erupted from separate calderas.

Clanton Draw Cauldron

In Skeleton Canyon a gently west-tilted sequence Tuff of Woodchopper Canyon, older rhyolite, and overlying dacite are all truncated by the Tuff of Skeleton Canyon. The contact between the tuff and the older units dips about 60° to the east. There is no evidence for faulting along this contact. The non-welded base of the Tuff of Skeleton Canyon rests directly on the older rocks apparently in a buttress unconformity. McIntyre (1988) suggested the existence of a caldera in Skeleton Canyon as the source for the Skeleton Canyon Tuff (the Clanton Draw caldera). The existence of the steep, east-facing buttress unconformity and the fact that the tuff is the thickest in this area both indicate that the steep contact is the high-angle structural margin of the Clanton Draw caldera, subsequently filled by the inflow facies of the Tuff of Skeleton Canyon. The absence of any caldera-filling breccias indicates that the rocks exposed represent shallow levels of the cauldron (Lipman, 1976).

The east-west-striking fault on the north side of Skeleton Canyon was active prior to eruption of the tuff of Skeleton Canyon. If the rocks are moved such that the base of the Skeleton Canyon tuff is restored to original laterally continuity, there is about 300 feet of offset in the dacite. The fact that the fault was active immediately prior to and following deposition of the Tuff of Skeleton Canyon suggests a genetic link between the fault and the caldera. However, it's orientation cutting nearly perpendicular to the exposed structural margin suggests instead it could be either a reactivated older structure or a fault unrelated to the caldera.

Rhyolite of Clanton Draw

The Rhyolite of Clanton Draw is a thick pile of light gray, relatively crystal-poor felsic lavas dated at 27.34 ± 0.14 Ma (McIntosh and Byron, 2000). The unit is composed of multiple flows. In some areas, particularly along west-facing escarpments, several flows can be distinguished from one another. Individual flows commonly have a dark gray vitric base that grades rather abruptly into non-vitric flow-banded lava. The vitric base at the base of the sequence was mapped where it was thick enough. Flow-banding in the lavas is contorted and chaotic and its direction is rarely consistent over large areas. Locally, flows are separated by yellow, bedded tuff layers that pinch and swell along strike. Reddish gray to light gray spherulites are common, particularly in or near vitric zones, and range in size from a few millimeters in diameter to fist-size. Some of the larger spherulites are geodes whose inner walls are coated with banded chalcedony overgrown by coarse-grained quartz.

This unit is very resistant and forms a high, dissected plateau capping most of the older rocks in the area. Based on the rather crude arc-shaped outcrop pattern of the rhyolite across the mountain range at Clanton Draw Deal (1978) and Erb (1979) originally interpreted this unit as having been extruded along ring-fractures of a buried caldera. More detailed mapping during this study, however, shows that the crude arcuate outcrop pattern can more likely be explained as the product of erosion. The basal contact in the northern part of the Skeleton Canyon quadrangle is relatively planar. In the southern part of the quadrangle, however, the contact locally dives down as much as ~200 feet over paleotopography in the underlying dacite.

The very similar ages of the Rhyolite of Clanton Draw and the Tuff of Skeleton Canyon suggest that the two were erupted from the same volcanic edifice. The similarity in composition and the great volume of rhyolite lavas exposed in the area also suggest a genetic link, as Deal and others (1978) contended.

Tuff of Dutchman Canyon

The Tuff of Dutchman Canyon is the least studied ignimbrite in the study area. It crops out in only a few isolated exposures. The exposure that gives the best age-relationship based on superposition is in the north, on the east side of Skeleton Canyon. Time constraints prohibited a detailed study of these rocks on the ground and their contacts were drawn from a distance and partially drawn using aerial photos. McIntosh and Byron (2000) collected a sample of this tuff near the eastern edge of the map area and obtained a date of 26.67 ± 0.14 Ma. This is the youngest ignimbrite in the study area.

QUARTZ LATITE INTRUSIONS

This rock contains subhedral phenocrysts of light gray feldspar (sanidine?) quartz, biotite, hornblende, and minor sphene, all in a light gray aphanitic matrix. On the north side of Sycamore Creek in the Guadalupe Spring quadrangle, the contact with the underlying rocks is very sharp and inclined. Locally, there is a 1 to 2 meter thick crystal-poor sandy tuff at the base. The quartz latite form small intrusive bodies. Near Sycamore Canyon it cuts across coarse-grained dacite (map unit Tdc) but appears to be overlain by dacite breccia. In the Guadalupe Canyon quadrangle, the unit forms two small intrusions, one of which cross-cuts the Baker Canyon Fault.

NATURE OF THE BASEMENT

Nowhere is the pre-Paleozoic basement exposed in the southern Peloncillo Mountains. The only clues to the nature of the basement come from rare xenoliths entrained in what has been mapped as Gillespie Tuff (near UTM N3474000, E689000). The two xenoliths found are fist-sized and smaller, and appear to be granodioritic to dioritic in composition. The rocks are rather light-colored and contain light gray feldspar (probably plagioclase), possibly some K-feldspar and quartz, and biotite arranged in felty clumps. One of the samples is foliated. No thin-sections were made of these rocks.

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UNIT DESCRIPTIONS
FOR THE SOUTHERN PELONCILLO MOUNTAINS
AZGS DGM-25

Quaternary alluvium

Qy **Holocene alluvium (<10 ka).** Alluvial deposits in active stream channels composed of unconsolidated sand to small boulders that reach several tens of centimeters in diameter upstream but are smaller and fewer downstream. These deposits are locally dissected as much as 2 meters by narrow entrenched main channels and tributary channels (not mapped separately). Qy deposits are characterized by stratified, poorly to moderately sorted sands, pebbles, and cobbles commonly mantled by sandy loam sediment. The main channel (where not appreciably dissected) may diverge into braided channels. Surfaces locally exhibit bar and swale topography, with the bars being typically more vegetated. Soil development is weak with only slight textural and structural modifications of B horizons and slight calcification (Stage I). Some of the older Qy soils may contain weakly developed argillic horizons. Because surface soils are not indurated with clay or calcium carbonate, Qy surfaces have relatively high permeability and porosity. downstream into Qy deposits and upstream with Qcb deposits.

Qly **Holocene and Late Pleistocene alluvium, undivided (<10 to 150 ka).** Alluvial deposits along active channels that are intermediate between Qy and Ql surfaces. The surfaces are typically narrow and elongated parallel to the drainage and are of limited extent, although Qly surfaces in the southern San Simon Valley are more aerially extensive. The surfaces have weak soil development and limited incisement. Subtle differences in relative elevation are the main features used to distinguish Qly from lower Qy deposits and higher Ql surfaces.

Ql **Late Pleistocene alluvium (10 to 150 ka).** Alluvial fan deposits composed of moderately to poorly sorted, clast-supported conglomerates, sandstones, siltstones, and paleosols. Clasts are subangular to subrounded pebbles and small cobbles of felsic and mafic volcanic and, locally, sedimentary rocks. The surfaces are typically light gray to light brown in color. Ql surfaces are moderately incised by stream channels but retain constructional, relatively flat interfluvial surfaces. Ql soils typically have weak to moderately clay-rich argillic horizons, although some contain much pedogenic clay and some calcium carbonate, resulting in relatively low infiltration rates. Clasts may have thin discontinuous coatings of carbonate.

Qml **Middle and late Pleistocene alluvium, undivided (10 to 750 ka).** Discontinuous alluvial surfaces, usually confined to stream terraces and remnants along the major washes, that exhibit subtle intermediate topographic position between definite Ql deposits and higher older Qm fan surfaces.

Qm **Middle Pleistocene alluvium (150 to 750 ka).** Alluvial fan deposits composed of moderately to poorly sorted conglomerate containing subangular to subrounded clasts of felsic volcanic rocks and limestone. Lenses of channel-fill fluvial sands, unsorted and interbedded debris flows, and argillic paleosols are also locally present. Typically the Qm deposits are coarser than the younger Ql sediments and the clasts commonly have thin coatings of carbonate. These deposits may locally contain thick argillic horizons and Stage II carbonate development, resulting in rapid sheet-flow runoff and low infiltration rates. In areas of the study area adjacent to limestone bedrock, these deposits contain limestone clasts surrounded by a moderately to strongly cemented matrix of carbonate (Stage III-IV). Variable clast lithologies make it difficult to correlate the unit between different areas of the study. Typically the Qm deposits are orange to orange-brown in the northern portion of the study area, but are medium brown to gray in the southern portion. Surface clasts commonly exhibit a weak to moderate orange-brown varnish. The deposits form relatively broad flat surfaces north of Paramore Crater and in the San Simon Valley, but they are deeply incised in the Silver Creek and Hay Hollow Wash drainage basins. In these incised areas in the southern and western portions of the study area, multiple Qm surfaces can be recognized based on relative topographic position. Qm_1 The oldest and topographically the highest of the Qm alluvial deposits, Qm_1 forms a 2- to 5- meter cover over older deposits.

Qm_2 **Younger member of the middle Pleistocene alluvium.**

Qm_1 **Older member of the Middle Pleistocene alluvium.**

Qmo **Middle and Early Pleistocene alluvium, undivided (750 ka to 1.2 Ma).** These light-colored deposits occupy topographic positions intermediate between the middle Pleistocene Qm and the Pliocene-early Pleistocene TQo. In the southern portion of the study area (just west of Guadalupe Canyon quadrangle), the deposits are dominated by rhyolite-derived gravels which overlie limestone-dominated older sediments.

<u>Quaternary basalt and basaltic deposits</u>

Qab **Basaltic alluvium.** Alluvial deposits in active drainages emanating from or immediately adjacent to volcanic cones and on the surfaces of basalt lava flows. The deposits are characterized by partly stratified, poorly to moderately sorted sands, pebbles, and cobbles mantled by sandy loam sediment derived from basaltic parent material. Qab often grades downstream into Qy deposits and upstream with Qcb deposits.

Qcb **Basaltic colluvium.** Unconsolidated to weakly consolidated, poorly sorted pebble- to boulder-sized basaltic material that forms a rubble apron at the base of volcanic cones and at some margins of lava flows. May be gullied by runoff, which is a main characteristic used in aerial photograph interpretation of the deposits. Qcb is typically transitional to Qbpc or Qbpb on the flanks of cinder cones and transitional with Qab at the slope break at the base of the cones.

Qbp **Basaltic pyroclastic deposits, undifferentiated (Pleistocene).** This unit includes basaltic materials that accumulated proximal to vents and formed the cones at each eruption site. Typically, the rocks are dark gray to dark reddish brown, often oxidized to rusty brown, scoriaceous, deposits that include abundant cinders, blocks, bombs, and agglutinate. Surfaces range from gentle to steep slopes with variable cover of very angular boulders and cinders interspersed with outcrops of lava or indurated cinders or breccia. Where possible, Qbp is subdivided into predominant facies, including:

Qbf **Basalt lava (Pleistocene).** Basalt lavas erupted as thin, low viscosity flows from any of the volcanoes in San Bernardino Valley and form a series of overlapping flows ranging from <5 up to 10 meters thick. Flow surfaces are gently sloping and planar with scattered basalt cobbles and boulders, to undulatory or hummocky surfaces covered with abundant basalt boulders and cobbles. Interiors of flows are massive and columnar jointing is common where exposed in cross section. Soils developed on flow surfaces are chocolate brown smectitic vertisols of variable thicknesses. The basalts range from fine grained to aphyric to microporphyritic and contain up to 3% anhedral to subhedral phenocrysts (up to 3 mm) of olivine, plagioclase, and minor pyroxene. Ground-mass textures are holocrystalline to aphanitic and are locally trachytic. Olivine is relatively fresh or slightly yellow, but in places the crystals have altered to red opaques (iddingsite). The rock is commonly vesicular, and vesicles are typically open, rounded to flattened, and locally lined or filled with calcite. Many, if not all, flows contain subrounded to well- rounded xenoliths ranging in size from a few millimeters to more than 40 cm in diameter. Ultramafic xenoliths are common and include lherzolite, dunite, pyroxenite, and other lithologies derived from the mantle (Kempton and Dungan, 1989; Kempton et al., 1990; Kempton et al., 1984b). Crustal xenoliths include Tertiary silicic volcanic rocks, Paleozoic sedimentary rocks, and fragments of granite and gneiss. Black, glassy, subhedral xenocrysts of pyroxene, spinel, and amphibole (kearsutite), up to 4 cm long, and light gray to white, translucent xenocrysts of anhedral to subhedral plagioclase and anorthoclase (?) up to 5 cm across are also common (see Kempton et al, 1982 and 1984 for details).

<u>Late Tertiary to Early Quaternary deposits</u>

TQbf **Basalt.** Contains anhedral to subhedral phenocrysts of olivine, mostly altered to red opaques, in a dark gray aphanitic to trachytic matrix. These basalts are mineralogically very similar to the younger basalts that cover the valley floor (map unit Qbf). TQbf basalts are typically fine-grained or aphyric to locally microporphyritic, with plagioclase and olivine phenocrysts; they also contain abundant xenocrysts of black, glassy pyroxene, spinel, and amphibole. Light gray to white translucent xenocrysts of subhedral plagioclase or anorthoclase (?) up to about 2 cm long (see Kempton et al, 1982 and 1984 for details) are also present.

However, these basalts contain only rare lower-crustal xenoliths. The slightly vesicular Krentz Ranch flow (1.48 +0.02 Ma) exhibits crude vertical columnar joints with variable sub-horizontal platy joints.

Tsy **Younger Basin-fill deposits.** These deposits are composed of interbedded fine-grained, tan siltstones, thin sandstones, and conglomerates typical of braided stream deposits. The beds have a slight dip (3°-7°), but it is uncertain if this represents primary deposition or later deformation. On the west side of the Guadalupe Canyon quadrangle, the sandstone and conglomerate beds contain dominantly clasts of felsic volcanic rocks (mostly welded tuff, with minor rhyolite and dacite), and very minor basalt. On the west side of the Guadalupe Spring quadrangle, the deposits contain mostly limestone clasts moderately to strongly cemented with carbonate. In all areas most clasts are subrounded and rarely larger than 20 cm across. Silty beds are light tan and erode easily. These deposits are probably equivalent to map unit TQo of Biggs and others (1999a).

Middle Tertiary rocks

Tb **Basalt.** These basalt flows contain anhedral to subhedral phenocrysts of olivine, mostly altered to red opaques, in a dark gray aphanitic to trachytic matrix. These basalts are mineralogically very similar to the younger basalts covering the valley floor to the west (map unit Qbf). They also contain abundant xenocrysts of black, glassy pyroxene and spinel and translucent subhedral plagioclase up to about 2 cm long. However, these basalts contain only rare lower-crustal xenoliths. In exposures along Sycamore Creek, the unit is interbedded with conglomerate (only locally mapped separately as Tc). This unit forms stacks of multiple flows several hundred feet thick on the western side of the Peloncillo Mountains. The flows are nearly horizontal and only slightly tilted locally. In the Skeleton Canyon quadrangle, the unit is offset by normal faults down-to-the-east. Small exposures on the eastern side of the range suggest the basalt flows may have been more extensive before erosion. One small exposure of basalt about 1 mile north of Bunk Robinson Peak appears to be interbedded with welded-tuff breccia (map unit Ttx).

Tc **Conglomerate.** This unit is interbedded with basalt (map unit Tb). Exposures between Sycamore Creek and Cottonwood Creek contain rounded cobbles to boulders of light gray welded tuff, limestone, dacite, and basalt, all in a tan to red silty to sandy matrix, weakly to moderately cemented with calcium carbonate.

Ttd **Tuff of Dutchman Canyon (Oligocene).** The Tuff of Dutchman Canyon is the least studied ignimbrite in the study area. It crops out in only a few isolated exposures. The exposure that gives the best age-relationship based on superposition is in the north, on the east side of Skeleton Canyon. Time constraints prohibited a detailed study of these rocks on the ground and their contacts were drawn from a distance and partially drawn using aerial photos. McIntosh and Byron (2000) collected a sample of this tuff near the eastern edge of the map area and obtained a date of 26.67 ± 0.14 Ma. This is the youngest ignimbrite in the study area.

Tr **Rhyolite of Clanton Draw (Oligocene).** This unit is composed of many separate, crystal-poor rhyolite flows that commonly exhibit contorted flow-banding. Most exposures are light gray and contain very small subhedral phenocrysts of quartz, biotite, and clear-gray feldspar resembling sanidine. Phenocrysts are typically less than 1 mm wide and comprise 1-5% of individual flows. Many flows have a vitric base that commonly stands out as a dark band (locally mapped at the base of the unit). Interbedded light yellow lithic tuffs several meters thick are common, but appear to pinch out rapidly along strike. Good exposures of individual flows with interbedded tuff and vitric layers can be seen in section 35, T. 21 S., R. 32 E., and south of Clanton Draw in the southeast corner of the Skeleton Canyon quadrangle. Erb (1979) named the unit and reported a zircon fission-track age of 25.8 ± 1.2 Ma for this unit. McIntosh and Byron (2000) reported a more accurate $^{40}Ar/^{39}Ar$ sanidine age of 27.34 ± 0.14 Ma.

Trv **Vitrophyre at the base of the Rhyolite of Clanton Draw (Oligocene).**

Ttr **Welded Tuff (Oligocene).** This crystal-poor welded tuff contains very few subhedral phenocrysts of quartz, sanidine (?), and biotite (about 1% of rock or less) less than 1 mm wide. Pumice fragments are very flattened and resemble thin laminae from edge-on. Outcrops are dark tan and the rock breaks into platy fragments. Near the head of Whitmire Canyon the base of the unit is non-welded and light gray. Erb (1979) originally described this rock as the Tuff of Whitmire Canyon—the youngest rock in the area. This study has revealed that the tuff is interbedded with the Rhyolite of Clanton Draw. In the very southeast corner of the Skeleton Canyon quadrangle, a thin tuff bed interbedded with rhyolite flows contains a crystal-poor densely welded top, and may be the same unit.

Tt **Bedded lithic tuffs (Oligocene).** These crystal-poor tuffs contain minor subhedral phenocrysts of quartz and biotite in a light yellow, bedded aphanitic matrix. The rock also contains subangular to subrounded lithic fragments of pumice, rhyolite, and dacite, all commonly 2 to 10 cm across. In outcrops in section 11, T. 22 S., R. 32 E., and in section 9, T. 32 S., R. 21 E., the tuffs are strongly welded and contain flattened pumice clasts. The welded exposures at the head of Whitmire Canyon are clearly interbedded with the Rhyolite of Clanton Draw.

Tsc **Tuff of Skeleton Canyon (Oligocene).** This unit contains abundant phenocrysts (~10% of rock) of clear subhedral to rounded quartz 1-2 mm wide, clear chatoyant sanidine 1-3 mm long, and minor subhedral biotite, all in a medium gray aphanitic matrix. Lenticular, flattened, light gray pumice clasts from 0.5 to 3 cm long are common. McIntosh and Byron (2000) reported a $^{40}Ar/^{39}Ar$ age sanidine age of 27.44 ± 0.08 Ma. Throughout most of the study area no flow-breaks are visible and the rock appears to consist of one cooling unit. Excellent exposures in Skeleton Canyon mantle a steep angular unconformity dipping approximately 60 degrees to the east. This unconformity may represent the margin of a buried cauldron. Also in Skeleton Canyon, the welded tuff is locally overlain and underlain by light gray non-welded tuff, mapped separately as map unit Tscn. The light gray pumice clasts contrast sharply with the medium gray matrix and make the tuff of Skeleton Canyon very distinct from all the other welded tuffs in the southern Peloncillo Mountains. The unit is thickest in Skeleton Canyon, where it is associated with a steep unconformity, but it is also very similar to the distinctive Rhyolite Canyon Tuff associated with the Turkey Creek Caldera in the Chiricahua Mountains to the northwest (Drewes, 1982; Du Bray and Pallister, 1991).

Tscn **Tuff of Skeleton Canyon, non-welded (Oligocene).** This unit is mineralogically the same as the welded tuff of Skeleton Canyon, but forms light gray-colored slopes instead of darker gray cliffs. Pumice clasts are subspherical instead of lenticular. In the northwest corner of the Skeleton Canyon quadrangle, welded tuff is underlain by non-welded tuff locally at least 200 feet thick. In this area, on the west side of the hills in gullies next to the road (where the non-welded tuff is thickest), large spherical accretionary lapilli or "tuff balls" are abundant and weather out into spheres up to 10 cm in diameter.

Tql **Quartz latite (Oligocene).** This rock contains subhedral phenocrysts of light gray feldspar (sanidine?) quartz, biotite, hornblende, and minor sphene, all in a light gray aphanitic matrix. Exposures on the north side of Sycamore Creek contain about 15-20% phenocrysts, whereas exposures in Baker Canyon are darker gray green and contain fewer phenocrysts. On the north side of Sycamore Creek in the Guadalupe Spring quadrangle, the contact with the underlying rocks is very sharp and inclined. Locally, there is a 1 to 2 meter thick crystal-poor sandy tuff at the base. The quartz latites form small intrusive bodies. Near Sycamore Canyon it cuts across coarse-grained dacite (map unit Tdc) but appears to be overlain by dacite breccia. In the Guadalupe Canyon quadrangle, the unit forms two small intrusions, one of which cross-cuts the Baker Canyon Fault.

Tdc **Coarse-grained dacite of Outlaw Mountain (Oligocene).** This crystal-rich lava contains abundant subhedral phenocrysts of light gray to translucent plagioclase up to 1.5 cm, anhedral biotite up to 5 mm, partially altered to hematite, and less abundant hornblende in a dark purple to dark brown aphanitic matrix. Locally small anhedral quartz is present. Plagioclase crystals are very conspicuous and resemble the plagioclase in both the younger and older basalts (map unit QTbf and Tb, respectively). Glomeroporphyritic clots of plagioclase are common. This unit is interbedded with autoclastic flow-breccia well-exposed in places along a west-facing cliff forming the central part of the mountain range. Locally contains subrounded xenoliths of very fine-grained holocrystalline rocks 1-15 cm wide that look like they have a similar composition as the dacite. Named by Erb (1979). McIntosh and Bryan (2000) reported a sanidine $^{40}Ar/^{39}Ar$ age of 31.81 ± 0.10 Ma for a sample of this rock from near the headwaters of Cottonwood Creek.

Tdm **Medium-grained dacite of Outlaw Mountain (Oligocene).** This dacite lava is mostly roughly equigranular to slightly porphyritic and contains 1-2 mm wide subhedral phenocrysts of plagioclase, biotite, hornblende and minor quartz in an aphanitic matrix. The rock is purple to tan and commonly has a slightly lighter color than the coarse-grained dacite. No large plagioclase phenocrysts or inclusions were seen. This lava underlies the coarse-grained dacite of Outlaw Mountain (map unit Tdc).

Tco **Older conglomerate (Oligocene**). One small remarkable exposure of this unit overlies the fault near the center of the Guadalupe Spring quadrangle. This thinly bedded tan-colored conglomeratic sandstone contains clasts of welded tuff and dacite in a sandy matrix. Bedding within the exposure changes from 23 degrees west on the lower portion to 70 degrees west near the top.

Tdx **Dacite breccia (Oligocene).** This unit coarsens upward from fine-grained conglomeratic sandstone to boulder conglomerate and breccia. It is exposed in the central part of the mountains from Sycamore Creek on the south to about 1 km north of Outlaw Mountain. On the north side of Sycamore Creek the lower portions are composed of fine-grained, tan-colored conglomeratic sandstone that is mostly buried by younger alluvium. Exposures here are best seen in the gullies and stream-cuts. To the north, on the south side of Cottonwood Creek, conglomeratic sandstone is locally interbedded with thin siliceous carbonate layers (marl?) 10 cm or so thick. Upward in the section the unit is dominated by coarse conglomerate. Bedding is medium to thick and is most easily discerned from a distance. Lower in the section, many clasts are welded tuff, but upward almost all the clasts are subrounded to angular dacite. The upper part is locally interbedded with dacite flows and grades upwards locally into non-bedded autoclastic dacite flow-breccia (mapped as part of the dacite lavas). Near 31° 27' 30", 109° 06' 00" light gray medium-grained dacite clasts are surrounded by a light gray, crystal-rich dacite(?) matrix. It is not clear if it is a flow-breccia or sedimentary breccia. Erb (1979) named the unit the breccia of Hog Canyon for excellent exposures there.

Tro **Older rhyolite (Oligocene).** This rock is a sub-aphyric rhyolite lava and contains small phenocrysts of quartz and rare biotite less than 1 mm across. Spherulites are common. In exposures about 1 mile north of Devils Kitchen, the rhyolite is vitric near the contact with overlying dacite. A light-yellow bedded crystal-poor lithic tuff crops out at and near the base of the unit. The rhyolite is exposed only in the north along Skeleton Canyon, where the rocks weather into steep, light tan slopes with rough, jagged outcrops.

Tax **Andesite breccia (Oligocene).** This unit is composed almost entirely of dark gray to purple clasts of andesite. It is exposed in the southern part of the map area in the Guadalupe Spring and Guadalupe Canyon quadrangles. The most extensive exposures are in the Guadalupe Canyon quadrangle where they form dark gray, non-bedded, featureless deposits at least 600 feet thick. Individual clasts range from pebble-size to large boulders and are angular to subrounded surrounded by a sandy andesitic matrix. Where deposits are mixed with welded-tuff breccia they are mapped separately as map unit Ttax. About 1.5 to 2 miles south of Bunk Robinson Spring in the Guadalupe Spring quadrangle, dark gray to purple deposits containing pebble- to cobble-size clasts of andesite form dark, subdued slopes beneath and intercalated with welded-tuff breccia. South and southeast of Guadalupe Mountain, the andesite is highly fractured but the fracture/joint orientations are consistent, and the cracks are filled with andesitic sand and carbonate. Nearby exposures are brecciated and jumbled. The exposures with consistent fracture orientations may represent large relatively coherent blocks.

Tai **Intrusive andesite (Oligocene).**

Ta **Andesite (Oligocene).** This lava contains ~10-15% subhedral phenocrysts of light to medium gray plagioclase and dark gray to gray-green pyroxene, both up to 6 mm across in a purple-gray aphanitic matrix. Pyroxene crystals are often altered to hematite, and plagioclase phenocrysts are commonly chalky white. Thin siliceous veins have cut the lava, with red- and yellow-colored selvages 10 to 20 cm out from and parallel to the veins. The andesite flows appear to be interbedded with welded tuff (map unit Ttw) near the base of the section in the Guadalupe Canyon quadrangle. The rock locally cuts across foliation in the welded tuff, suggesting some exposures may be intrusive. A small body of andesite (Tai) intrudes the Bisbee Group in the very southwest corner of the Guadalupe Canyon quadrangle. In the east-central part of the Guadalupe Spring quadrangle, this unit is locally transitional between flow and breccia, which are mapped as Tax. Similar andesites are exposed in the southwestern corner of the project and are assumed to be equivalent.

Ttax **Mixed breccia (Oligocene).** These poorly sorted deposits contain clasts of andesite, dacite, various welded tuff units, and rare limestone and sandstone. Most exposures crop out in the eastern half of the Guadalupe Canyon quadrangle. West and southeast of Guadalupe Canyon these deposits contain discrete zones of andesite and fine-grained crystal-poor welded tuff that has not been recognized elsewhere in the study area. The welded tuff and andesite zones have very irregular, but sharp, contacts and with more detailed work can probably be mapped as distinct units. The crystal-poor welded tuff zones only occur in the southeast corner of the map. In this same area the unit contains very localized accumulations of limestone clasts, ranging in size from cobbles to large boulders (some are located on the map). Abundant pelecypod fossils suggest the limestone clasts were derived from the Bisbee Group.

Ttw **Tuff of Woodchopper Spring (Oligocene).** This welded ash-flow tuff unit is crystal-rich and contains 1-5 mm phenocrysts of clear quartz, light gray to almost clear sanidine, and minor biotite. In the northern part of the Skeleton Canyon quadrangle it is composed of two sub-units: a lower, slope-forming unit and an upper cliff-forming unit. Both sub-units are mineralogically similar. The rock forms light gray steep outcrops that contrast with the underlying older welded tuff (map unit Ttg). On weathered surfaces, the large quartz phenocrysts stand out in relief. In this respect it resembles map unit Ttg. McIntosh and Byron (2000) reported an $^{40}Ar/^{39}Ar$ date of 28.21 ± 0.14 Ma.

Ttwn **Non-welded Tuff of Woodchopper Spring (Oligocene).** This unit is exposed in the southern part of the Guadalupe Canyon quadrangle where it forms light-colored slopes. It underlies the Tuff of Woodchopper Spring (map unit Ttw), and also underlies dacite (map unit Tdc).

Ttl **Lithic tuffs (Oligocene).**

Ttx **Welded-tuff breccia (Oligocene).** This extensive unit is composed of very poorly sorted, angular to subangular clasts of welded tuff. The individual clasts are rotated with respect to the neighboring clasts such that the primary eutaxitic foliation is almost completely randomized and obscured. The matrix between clasts is composed of sandy, microbrecciated tuff. The clasts resemble both the Gillespie Tuff and the Oak Creek Tuff. As mapped, this unit includes both mesobreccia and megabreccia. One mile southeast of Eicks Spring (on the south side of Sycamore Creek) the unit contains an intact block over 50 meters across. From about Baker Canyon northward, the unit contains almost exclusively clasts of welded tuff. From about Baker Canyon southward, the unit contains variable amounts of clasts of welded tuff, andesite, and minor limestone. The different rock types occur as discrete lenses and layers. From a distance some of the layers can be discerned as dark- and light-colored bands, but in other areas the different rock types can only be distinguished up close. The differences are most obvious in the east-central part of the Guadalupe Spring quadrangle where dark-colored bands of andesite are intercalated with lighter-colored bands of welded tuff. Near the central part of the range the unit is over 800 feet thick. It erodes into steep, rough, featureless, tan-colored hills.

Th **Hypabyssal welded tuff (Oligocene).** This welded tuff mineralogically resembles the Gillespie Tuff but contains neither eutaxitic foliation nor visible pumice fragments. Outcrops are slightly brecciated and spaces between fragments are reddish and aphanitic. This may be a small vent for some of the Gillespie Tuff.

Ttg **Gillespie Tuff (Oligocene).** This crystal-rich welded tuff contains phenocrysts of about 15-20% clear, subhedral quartz, 10% sanidine, and 1-2% biotite, all between 1-5 mm across. Biotite is scarce and is partially altered to hematite. Some sanidine is chalky white, but most are clear to light gray. Quartz is abundant and commonly sticks out in relief on weathered surfaces, which gives the rock a rough, slightly coarse-grained appearance. Fresh surfaces are light pink to tan, but the rock weathers tan and is commonly slightly varnished. Where strongly welded, the rock forms cliffs and blocky ledges. Where less welded, the tuffs erode into light-colored crumbly slopes. Several welded tuff units are interbedded with welded-tuff breccia (map unit Ttx) in the southern Peloncillo Mountains. However, they are mineralogically very similar and not distinguished as separate units except where separated by breccia. Erb (1979) reported a zircon fission-track age of 27.1 + 1.5 Ma for a sample of welded tuff collected along the Geronimo Trail, about ½ mile west of Miller Spring next to Cottonwood Creek. McIntosh and Byron (2000) reported a more accurate $^{40}Ar/^{39}Ar$ age of 32.72 ± 0.04 Ma. Similar rocks are exposed in the southern end of the Perilla Mountains, in the southwestern corner of the project area (East of Douglas quadrangle) and may be equivalent to the tuffs in the Peloncillo Mountains.

Tto **Oak Creek Tuff (Oligocene).** This crystal-rich welded tuff contains abundant quartz and sanidine and minor biotite, all 1-3 mm across in a dark pink aphanitic matrix. The tuff also contains lithic fragments of welded tuff and dacite. In the field the Oak Creek Tuff and the Gillespie Tuff (as mapped) are nearly indistinguishable. Both are crystal-rich tuffs bearing biotite, quartz, and sanidine. On weathered surfaces of the oak Creek Tuff the quartz phenocrysts are more resistant than the matrix and stand out in relief. These two tuffs were originally mapped as the same unit. They were only separated later on the basis of the older $^{40}Ar/^{39}Ar$ age of 33.50 ± 0.07 Ma for the Oak Creek Tuff.

Tfi **Felsic hypabyssal dikes (Oligocene).** This light tan rock contains 1-3 mm phenocrysts of mostly clear quartz, minor sanadine, and rare biotite, all in a tan aphanitic matrix. It also contains what appear to be small pumice fragments less than about 2 cm across. The unit has sharp irregular contacts within both the chert conglomerate (map unit KJcc) and the limestone conglomerate (map unit KJcl) of the Bisbee Group, suggesting the rock is intrusive, although it may be interbedded. The mineralogy is similar to the ash-flow tuff unit (map unit Ttw) and may have been small vents.

Late Jurassic and Cretaceous rocks

Kb **Bisbee Group, undivided (Cretaceous).** The sedimentary rocks of the Bisbee Group form ledges on steep, rounded hills in the southeast part of the study area and in the Pedregosa and Perilla mountains. The group contains thin to medium bedded, light gray to blue-gray limestones interbedded with light tan, pink, and gray fine-grained sandstones and limy sandstones. Locally, limestone beds contain very abundant fossil pelecypods *(graphae*a) up to 10 cm long, and the limy sandstones are particularly fossiliferous. The limestone and sandstone beds are difficult to distinguish from a distance. The Bisbee Group in the area is folded and several faults are identified. In the Pedregosa and Perilla mountains, the Bisbee Group rocks were not mapped separately for this report, but the Cintura, Mural, Morita, and Glance Conglomerate formations have been identified by other investigators (Drewes and Brooks, 1988). The three lower formations of the Bisbee Group are recognized in the southeastern portion of the study area:

Km **Morita Formation (Cretaceous).** This unit contains mostly red-brown to dark purple siltstone interbedded with thin sandstone layers 10-50 cm thick. The siltstone erodes easily into slopes and the sandstone erodes into small resistant ledges. The upper contact is gradational. The upper part of the unit contains more abundant interbedded limestone layers.

KJc **Glance Conglomerate, undivided (Jurassic and Cretaceous).** Two informal members of the Glance Conglomerate are recognized in the southeastern part of the study area:

KJcl **Limestone conglomerate (Jurassic and Cretaceous).** This sub-unit of the Glance Conglomerate overlies the cherty conglomerate (map unit KJcc) and contains subrounded to well-rounded clasts of limestone, 2 to 15 cm in diameter, in a moderately to well-cemented calcium carbonate matrix. Upper and lower contacts are sharp. The unit forms a rounded, cobble-covered ridge between the underlying cherty conglomerate and the subdued slopes of the overlying fine sandstones and siltstones of the Morita Formation.

KJcc **Cherty conglomerate (Jurassic and Cretaceous).** The basal conglomerate of the Bisbee Group contains subangular to well-rounded clasts of light to dark gray and tan chert, quartzite, and sandstone, all in a red sandy matrix. Clasts range in size from about 2 to10 cm, but larger clasts are up to 20 cm across and are rounded to well-rounded. Smaller clasts are more angular. Most clasts are stained red. This unit unconformably overlies the Paleozoic rocks of the study area.

<u>Paleozoic rocks</u>

Pe **Epitaph Dolomite (Permian).** Fresh surfaces are red-black to dark gray. On weathered surfaces the rock is light to medium gray to pale brown and typically very rough. Beds are typically 1-2 feet thick, but are locally as thick as 6-10 feet. Breccias and conglomerates containing pebble-size clasts occur throughout the formation. Outcrops are highly fractured and commonly permeated by abundant, small light gray calcite veins. Locally, the unit contains abundant dark red-brown irregularly shaped chert nodules less than 5 cm across. In the study area, the unit is bounded by a thrust fault at the base and an erosional unconformity at the top. The Epitaph Dolomite is about 800 feet thick (Kelly, 1966).

Pc **Colina Limestone (Permian).** This limestone weathers light bluish gray to medium gray, but on a fresh surface it is dark gray to black. The lower portion contains abundant fossils of crinoids, echinoids, gastropods, and brachiopods. Beds are typically 2-4 feet thick. The formation can be recognized from a distance both by its ledge-forming outcrops and by its blue-gray color, which contrasts with the red siltstones of the underlying Earp Formation and with the brown dolomites of the overlying Epitaph Dolomite (Kelly, 1966).

PIPe-PIPh Earp Formation and Horquilla Limestone (Pennsylvanian and Permian). From oldest to youngest the Earp includes limestone, gray-orange pebble conglomerate up to 90 feet thick, a thick sequence of red to orange siltstone and calcarenite, and limestone, yellow dolomite, and brown cherty dolomite (see Kelly, 1966 for a more detailed description). The limestones at the base of the Earp Formation contain abundant fusulinids (probably *Triticite*s), and less abundant echinoid spines and plates, and crinoid stems. The Horquilla Limestone is composed of thin- to thick-bedded cherty gray limestone with thin interbeds of calcareous shale or siltstone. In the study area, the units are at least 380 feet thick, but exposures are limited. The conformable contact with the overlying Colina Limestone is sharp. Three isolated outcrops of the Earp-Horquilla limestones are located 2-3 km south of Paramore Crater forming inselbergs surrounded by basalt flows that cover the buried pediment. Several adjacent areas of carbonate-rich, light-colored soils, which are clearly not derived from basalt or alluvium, are probably deeply eroded limestone inselbergs.