Geologic Map of the Mescal 7.5′ Quadrangle, Pima and Cochise Counties, Arizona

by

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INTRODUCTION

The Mescal quadrangle straddles the divide between the Tucson basin to the west and the San Pedro Basin to the east. The region is dominated by Late Tertiary basin-fill deposits that form the low divide between the Whetstone Mountains to the south and the Rincon and Little Rincon Mountains to the north. Interstate 10 crosses this low area just south of the drainage divide. The Mescal 7.5′ quadrangle was mapped as part of the STATEMAP program. Fieldwork was carried out between November, 2000 and April, 2001 and was concurrent with mapping to the north in the Galleta Flat 7.5′ quadrangle.

The low, subdued nature of the area hides a complex geologic history. Shallow-water platform carbonate and mature clastic sedimentary rocks were deposited during the Paleozoic on an extensive erosion surface beveled across Proterozoic granitic and metamorphic rocks. Erosion and faulting during the Late Jurassic led to infilling of the Bisbee Basin by the upper Jurassic to middle Cretaceous Bisbee Group. The resulting succession of Paleozoic and Mesozoic strata in the Whetstone Mountains is one of the thickest sequences preserved anywhere in the state. These rocks were deformed during compression and thrust faulting during the Laramide orogeny at the end of the Cretaceous. Laramide structures are now obscure because of overprinting by younger deformation, plutonism, and extensional. The region owes its present geography to younger (Miocene) block-faulting that occurred during Basin-and-Range extension. Late Tertiary (Late Miocene to Pliocene) sediments partially filled the low areas, and these deposits have been modified by repeated cycles of dissection and deposition during the Quaternary.

PREVIOUS WORK

Creasey (1967) made a geologic map of the Benson 15’ quadrangle, which includes the Mescal 7.5′ quadrangle. He measured detailed stratigraphic sections in the sedimentary rocks and also recognized the folded nature of the Mesozoic and Paleozoic strata in the area. Drewes (1974) mapped the Happy Valley 15’ quadrangle north of the study area. Smith (1989) made a detailed study of the igneous and metamorphic fabrics in the little Rincon Mountains, also to the north. Gehrels and Smith (1991) reported U-Pb ages that helped constrain the age of thrusting, crustal extension, and peraluminous plutonism in the Little Rincon Mountains. Richard and Harris (1995) mapped the geology and geophysics of the Cienega Basin. Dickinson (1998) made a detailed study of the Martinez Ranch Fault from Happy Valley in the north southward past Interstate 10 in the Mescal 7.5′ quadrangle. Davis and others (in press) examined the rocks along the Catalina detachment fault at the southeastern end of the Rincon Mountains.

QUATERNARY AND LATE TERTIARY DEPOSITION

Quaternary Deposits

Quaternary deposits in the study area are dominated by middle Pleistocene alluvial deposits (map unit Qm) and Holocene alluvial deposits (map unit Qy). From examination of rare well-exposed stream cuts, the late Pleistocene alluvial deposits (map unit Ql) appear to be mostly buried by a thin veneer of Holocene alluvium. Some of the broad Holocene fans in the central part of the map area, south of the highway, are dissected by very shallow gullies commonly less than 1 meter deep and are very flat.

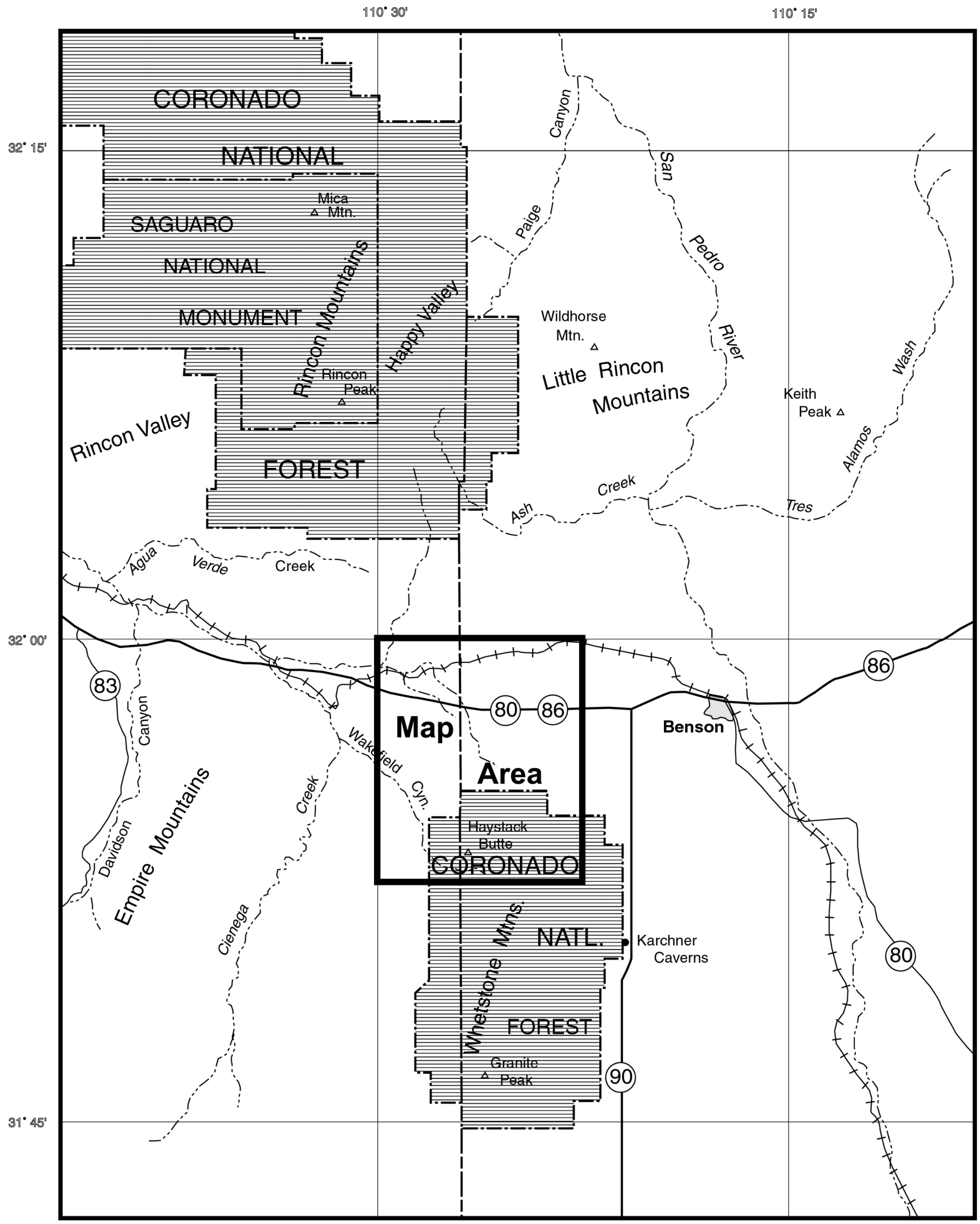


Figure 1. Index map showing location of the Mescal 7.5' quadrangle.

However, on some of these fans prickly pear cactus, mesquite and grasses grow, which are more common on the older, more clay-rich Pleistocene deposits. The roots of these plants may be tapping older soils buried a meter or so beneath the surface. Thicker, well-drained, clay-poor Holocene deposits are commonly characterized by creosote, mesquite, and spiny crucifixion thorn(?).

The surrounding rock types in part control the character of the middle Pleistocene deposits. In areas where limestones or limestone clasts are abundant the alluvial deposits are moderately to strongly cement by carbonate. Areas near predominantly granite contain little carbonate and are only weakly to moderately consolidated.

QTs Deposits

The central part of the map area is underlain by deposits that are transitional in character between Late Tertiary basin-fill deposits and early Quaternary surficial deposits. These tan to light orange deposits contain almost exclusively granite gruss and clasts of medium-grained granite, with minor, though locally abundant larger cobble-size clasts of Bolsa Quartzite. The source of these sediments was the northern Whetstone Mountains, from which they were shed northward. These deposits are dissected but not as deeply as the other Tertiary basin-fill deposits. They posses dark red-brown soils, thickest on the ridgelines, which resemble early Quaternary soils. However, except locally they do not exhibit well-preserved, planar, constructional surfaces characteristic of younger Quaternary deposits.

From a distance the tops of the ridges are all parallel and slope gently to the north, suggesting they represent the maximum level attained during aggradation. The ridge tops extend southward only a few meters higher than the granite pediment. Considering subsequent erosion of the pediment since the early Pleistocene, these deposits are probably graded to the pediment. The fact that the other Tertiary basin-fill deposits are more deeply dissected and are now locally higher than the pediment indicates that development of the pediment and deposition of map unit QTs occurred after deposition of the other basin-fill units. The other possibility is that the pediment formed before deposition of the basin-fill units and was later re-exhumed. In any case the subdued relief of map unit QTs with respect to the other basin-fill units and indicates it is younger than the later.

Tufa Deposit

Immediately downstream from Nogales Spring in section 11, T. 18 S., R. 18 E. near the southwest corner of the map, are thick tufa deposits. Outcrops are mostly covered by dense vegetation, but are exposed as small ledges and cliffs where the perennial stream has cut down into them. The deposits are composed of fine-grained calcite containing long tubes from several millimeters to 1 cm in diameter. Closely spaced linear features may be fossilized impressions of reed plants. The rock is very porous and relatively lightweight. The stream forms several deep pools in the tufa, one of which appears to be at least 2 meters deep. The streambed 200 meters upstream from Nogales Spring is dry. The water is probably flowing from subterranean caverns created by dissolution of the limestone rock in this area.

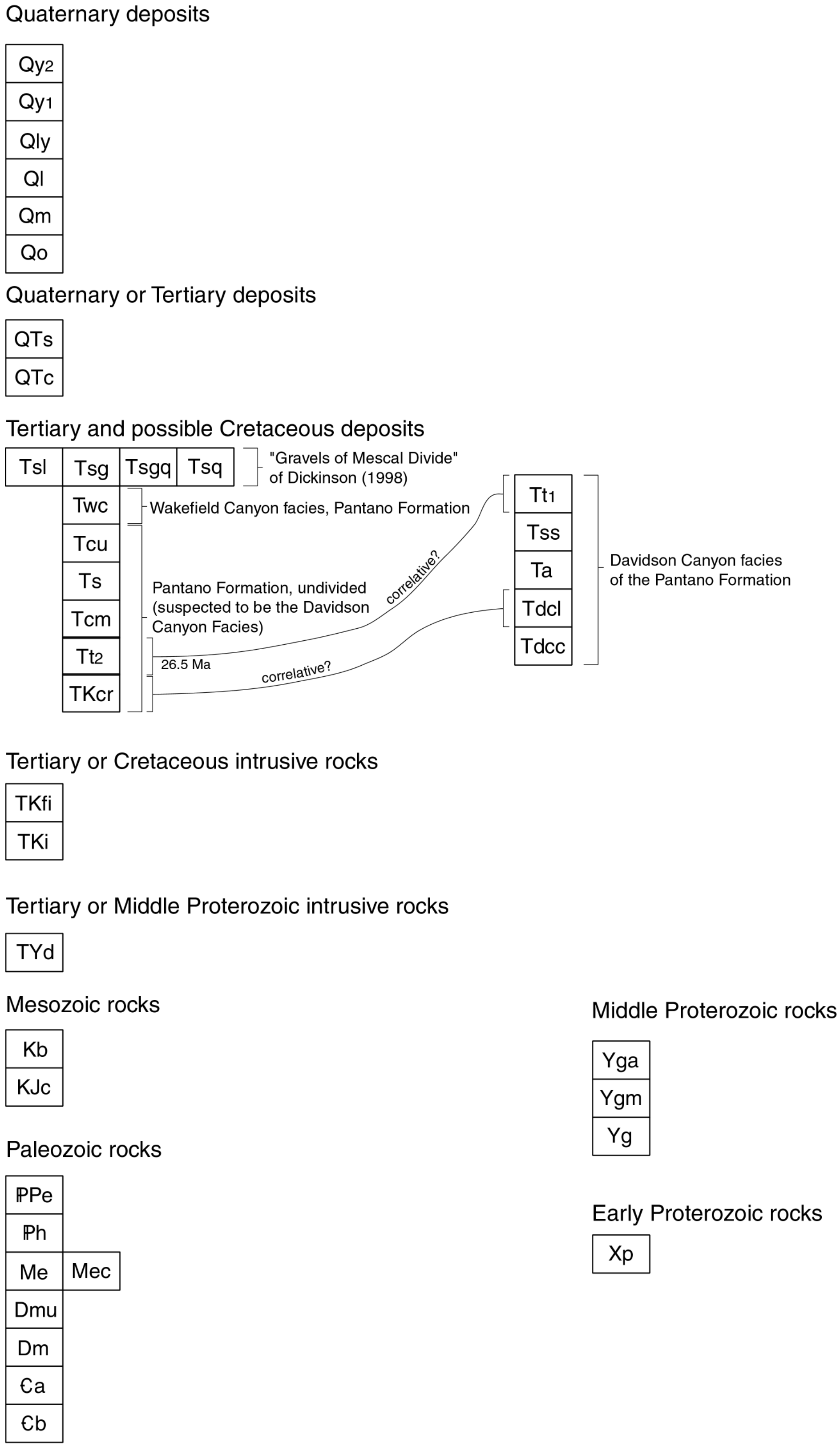


Figure 2. Correlation diagram for the Mescal 7.5' quadrangle.

Late Tertiary Fan Provenance

In the Mescal 7.5′ quadrangle at least three different middle to Late Tertiary alluvial fan deposits can be distinguished by their clast compositions. Dickinson (1998) called these deposits collectively the "Gravels of Mescal Divide." The deposits in the northwest corner of the map (map unit Tsg) are dominated by clasts of weakly to strongly foliated Tertiary and Proterozoic granites derived from the north and minor clasts of Pinal Schist, quartzite, and rare limestone. These deposits are more extensive to the west of the map area. The deposits in the south and west portions of the map (map unit Tsl) are dominated by clasts of Paleozoic limestone and Cambrian Bolsa Quartzite, locally abundant sandstone (Bisbee), and minor light gray felsite, biotite dacite and chert. In the southwest part of the quadrangle these deposits are composed of interbedded conglomerate and fine-grained, trough cross-bedded sandstone. The matrix is locally cemented by calcite and these deposits are commonly deeply dissected and typically form resistant, rounded hills. Deposits in the northern part of the study area (map unit Tsq) are dominated by clasts of limestone, quartzite (Bolsa), sandstones (Bisbee), rhyolite, andesite, bio-qtz-sanidine welded tuff and/or felsite, and chert.

The only visible source of the foliated granite clasts in map unit Tsg is in the north in the Rincon Mountains. Deposits with these clasts were probably shed southward from these highlands. The limestone and quartzite clasts in map unit Tsl were probably derived from similar rocks cropping out south of Haystack Mountain and on the west side of the Whetstone Mountains south of the study area. These clasts were probably shed northward and northeastward where they merged with deposits of map unit Tsq. Since no andesite, felsite, nor welded tuff are exposed anywhere between the northern Whetstone Mountains and the Little Rincon Mountains, the source area for map unit Tsq is uncertain. Since these clasts do not exist in the western part of the quadrangle it is reasonable to assume that they were not transported eastward. North of the study area these deposits are covered by and/or interfinger with alluvial fan deposits derived from the north that are dominated by clasts of light gray, medium-grained foliated Tertiary granite (see Skotnicki, 2001).

MIDDLE TERTIARY DEPOSITS

There are two separate, possibly related, middle Tertiary rock sequences exposed in the northwest part of the map area. One sequence forms an arcuate belt exposed mostly north of Highway 10, and is broadly equivalent to the Pantano Formation (Balcer, 1984). The basal unit is a pink- to red-colored, interbedded conglomerate, arkosic sandstone, and minor purple siltstone (map unit Tdcl). It contains clasts of quartzite, vein quartz, sandstones (Bisbee), Pinal Schist, various granites, limestone, meta(?)rhyolite, and chert, all in a dark red sandy (and rarely grussy) matrix. Many clasts are coated with clay coatings and/or a thin, red, iron oxide skin. As a result many clasts appear red in outcrops.

This basal, red conglomerate (map unit Tdcl) is locally in depositional contact with rocks of the Bisbee Group at the southern edge section 2, T. 17 S., R. 18 E., and is in fault contact with the Bisbee Group 3/4 mile to the south in the southeast corner of section 2. A dark gray, crystal-rich, porphyritic andesite (map unit Ta) overlies the basal unit. Flow breaks are not visible and the andesite is at least 30 meters thick. Thinly bedded purple siltstone and sandstone (map unit Tss) overlie the andesite, which is in turn overlain by a quartz-phyric, strongly compacted ash-flow tuff (map unit Tt_2).

This sequence is tilted slightly to moderately to the east where it is overlain by younger Tertiary basin-fill deposits. Exposures in the overlying basin-fill are rare but exposures to the north of the study area show that, locally, the base of the basin-fill deposits is slightly tilted to the east as well. The contact between the middle Tertiary rocks and the older Mesozoic rocks is almost everywhere covered by younger alluvium. As described above it is locally both a fault and a depositional contact. Bedding in the Tertiary rocks is locally nearly orthagonal to the nearby older rocks.

The other sequence of middle Tertiary rocks is exposed immediately south of the highway on the western side of the map area. The basal unit (map unit TKcr) is nearly identical to the basal red conglomerate of the sequence to the north, but is considered as a possible correlative to the Ft. Crittenden Formation because of it's rusty red color, abundant quartzite clasts, and it's position between the more obvious Tertiary strata and the underlying deformed Bisbee Group rocks. Overlying the red conglomerate is a greenish-gray conglomerate (map unit Tcm) containing predominantly sandstone clasts derived from the Bisbee Group. Locally, in between these two units is a thin, yellow, quartz-phyric ash-flow tuff that may be equivalent to the tuff to the north (map unit Tt). This tuff was dated at 26.5 ± 0.08 Ma (J. Spencer, personal comm.). The best exposure of this tuff is in the northern part of section 15, T. 17 S., R. 18 E. Overlying the green-gray conglomerate is a discontinuous purple siltstone that is thickest in section 10, T. 17 S., R. 18 E. (map unit Ts), but pinches out abruptly to the south. Overlying this siltstone is a very strongly cemented conglomerate containing clasts of sandstone (Bisbee) and characteristic light gray rhyolite clasts (map unit Tcu). This unit forms a resistant ridge. It is in turn overlain by a tan, poorly consolidated conglomerate (map unit Tw) of the Wakefield Canyon facies of the Pantano Formation (Spencer et al., 2001).

This second sequence of middle Tertiary rocks dips moderately to steeply to the west and northwest. The basal contact truncates bedding in the underlying Bisbee Group. The uppermost tan conglomerate (map unit Tw) along Anderson Canyon in section 15, T. 17 S., R. 18 E. shows fanning dips from 25° near the contact with underlying map unit Tcu to nearly horizontal downstream. Most likely, all of the map units of this sequence except for Tw are correlative with the unit of Davidson Canyon of the Pantano Formation (Spencer et al., 2001).

It seems likely that the basal red conglomerates of both sequences are related. The tuffs may be equivalent also. The mafic lava thins southward in section 2, T. 17 S., R. 18 E., so its absence south of the highway may be due to pinch out or erosion.

MESOZOIC ROCKS

Bisbee Group

The sequence of Lower Cretaceous Bisbee Group strata exposed in the Mescal quadrangle is comprised of interbedded purple siltstone and shale, light greenish gray to tan arkosic sandstone, and minor conglomerate. The finer-grained siltstone and shale erodes relatively easily and generally forms subdued, friable outcrops. The sandstones contain well-sorted, subrounded quartz and minor feldspar grains. The sandstones are commonly massive or are characterized by planar bedding showing very few cross-beds.

Some sandstones are limy and these beds show more obvious cross-bedding, where cross-beds and layering are defined by thin iron-oxide laminae. Coarse-grained, orange-tan, conglomeratic arkosic sandstones are less common than the planar-bedded sandstones and are distinguished from the latter by their crude bedding to massive nature and abundance of coarse sand- to gravel-size quartz and feldspar grains. These arkosic conglomerates are lens-shaped and locally pinch out over distances of many tens of meters. As mapped in this study, the Bisbee Group rocks include both the Shellenberger Canyon Formation and the Turkey Ranch Formation described by Tyrell (1957).

A few purple siltstone layers contain fine-grained, gray, micritic carbonate nodules up to 4 cm across. Most are isolated from neighboring nodules. Some are disk-shaped with their long axis parallel to the prominent cleavage in the rocks, while others show no preferred orientation with respect to the cleavage. These nodules do not appear to be detrital and are probably authigeneic. They resemble pedogenic carbonate nodules formed in soil horizons in more recent deposits.

Minor conglomerate layers 1-2 meters thick contain subrounded to well rounded pebble-size clasts (maximum size = 7 cm) of light gray to purple quartzite and gray chert, all in a poorly sorted, arkosic, sandy matrix. Bedding in the conglomerate is mostly planar and only rarely are cross-beds visible. These beds are uniform in thickness for many hundreds of meters. Some beds are marked on the map (see legend).

The Bisbee Group sequence in this area contains very minor, thin limestone layers commonly about 10 cm thick, but locally as thick as about 20 cm. These thin limestone beds are everywhere thinly laminated. Most show very planar to slightly wavy laminations that are most visible on weathered surfaces where some appear almost black. While some of these black layers are defined by modern algae/lichen growing on the weathered surface, the rock, when scratched, has a weak fetted odor, indication it contains minor amounts of hydrocarbons. In section 11, T. 17 S., R. 18 E., in the gully on the west side of the small late Pleistocene fan deposit (map unit Ql) a thin limestone bed displays contorted centimeter- to decimeter-scale folds sandwiched between unfolded strata above and below. The origin of these folds is unknown but they appear to have formed before the carbonate lithified. Locally, the limestone beds have been slightly metamorphosed into coarse-grained calcite intergrown with fine-grained quartz and chlorite. Chlorite commonly forms thin sheets mostly concordant to original bedding, but commonly discordant as well. In the northwest corner of section 2, T. 17 S., R. 18 E., prominent lineations defined by grooves in the quartz and chlorite have attitudes of ~N30°E.

Hematite pseudomorphs after pyrite are common in some of the sandstone layers. They are concentrated preferentially in some layers and not in others. None were found in the finer-grained siltstones and shales. The pseudomorphs are beautiful tiny cubes and framboids of multiple, intergrown cubes from less than 1 mm to almost 1 cm across. Many pseudomorphs are near-perfect cubes. Others have sides that bulge slightly and commonly display the linear groove-like striations seen on pyrite crystal faces.

The conglomerate in the northwestern corner of the map (map unit KJc) contains a western, lower subunit that contains abundant crystal-rich dacite clasts and an eastern, upper subunit that contains mostly limestone clasts. The two subunits appear to interfinger and were not mapped separately. Both contain well-sorted sandstone layers that resemble similar sandstones in the Bisbee (map unit Kb). In section 35, T. 16 S., R.

18 E., the conglomerates interfinger rather abruptly into purple shales and tan sandstones of the Bisbee Group. The contact between the conglomerate and the Bisbee strata is sharp in the southwestern corner of section 35, T. 16 S., R. 18 E., but is blurred and apparently more interfingered in the southeastern part of the same section. The absence of Bisbee-like clasts and granitic clasts, and the interfingering of conglomerates with well-sorted sandstone and purple siltstone layers, suggests this unit is equivalent to the Glance conglomerate at the base of the Bisbee Group. These rocks are folded into a large, northwest-plunging anticline.

Depositional Setting

Southeastern Arizona was an elevated area (above sea level) of locally high relief at the end of the Jurassic (Hayes, 1970). This elevated area probably shed sediments southeastward into an Early Cretaceous seaway in northern Mexico. Early Cretaceous rocks subsequently deposited in this area rest unconformably and variably on Proterozoic, Paleozoic, and older Mesozoic rocks. Bisbee Group strata to the east in the Chiracahua, Pedrogosa, and Peloncillo Mountains contain much more abundant shallow marine limestone. Bisbee Group rocks in the study area, however, contain only very minor limestone. Hayes (1970) observed that sandstones in the Bisbee Group become increasingly arkosic westward. These observations led Hayes (1970) and others to conclude that the Early Cretaceous seaway shallowed westward, and that the Bisbee Group strata in the Whetstone and Empire Mountains represent deltaic and fluvial deposits.

Thin limestone beds in the arkose of Angelica Wash in the Sierrita Mountains (Cooper, 1970) and in the Amole Arkose in the Tucson Mountains (Brown, 1939) have been interpreted as fresh-water or brackish-water limestones. Hayes (1970) stated that most of the sandstones in the northern Whetstone and Empire Mountains are cross-bedded and fine upwards. Taken with the observation that many of the sandstone beds form channels cut into underlying siltstones, Hayes (1970) interpreted these rocks as “dominantly fluviatile deposits of the subaerial portion of a delta.” The abundance of pyrite in greenish gray sandstone in the study area indicates reducing conditions during deposition. In the rocks exposed in the Mescal quadrangle the absence of mud cracks and the abundance of fine-grained shales and planar-bedded sandstones suggest the sediments in the map area were deposited subaqueously, possibly even in a deep-water environment.

PALEOZOIC ROCKS

Cambrian

The Cambrian Bolsa Quartzite is well exposed in the southern part of the map area where it forms resistant, northwest-striking ridges underlain by southwest-dipping strata. Its thin- to thick-bedded ledgy outcrops are distinctive even from hundreds of meters away. Probably the most remarkable feature of this unit is the abundance of vertical, tube-like burrows, most common in the lower to middle parts of the unit, but also exist within some of the upper part. On some outcrops the features are so abundant that many hundreds occupy a square meter. The tubes are filled with light tan quartzite that contrasts with the commonly darker maroon quartzite. Tang (1999) studied these burrows here and interpreted them as *Skotlithos*, which are common trace fossils in near-shore, high-energy clastic environments of the early Paleozoic.

Devonian

The single, unequivocal exposure of Devonian Martin Formation occurs on the resistant hill on the west side of section 7, T. 18 S., R. 19 E. This exposure consists of massive to thick-bedded tan, dolomite locally containing cemented solution breccias and terra-rossa-filled vugs and cracks. Some vugs are partially filled with coarse-grained calcite spar. Besides this hill, the other exposures of possible Martin Formation are composed of a series of step-like ledges of thin- to thick-bedded blue-gray limestone interbedded with pinkish, sandy carbonate. The rock contains worm burrows and rare crinoids but it is not obviously fossiliferous. Light gray chert is rare and the unit is mostly chert-free. Limestones in the upper part are interbedded with light tan, thinly bedded, fine-grained sandstone containing no carbonate in the matrix. These rocks were mapped as Martin Formation because they underlie a massive to thick-bedded, cliff-forming unit of blue-gray limestone that is probably the Mississippian Escabrosa Limestone. The difference in character between the lone outcrop of dolomite and the thin- to thick-bedded blue-gray limestones is great enough and over such a short distance that the latter may actually represent a younger formation—possibly the lower part of the Mississippian strata.

Mississippian

The Mississippian Escabrosa Limestone is characteristically light blue-gray, thick-bedded limestone containing very minor light gray chert nodules up to 15 cm across. The rock is composed of very abundant fragments of crinoid stems and brachiopods, all replaced by calcite spar. In the northeast corner of section 12, T. 18 S., a very continuous, irregularly shaped, black chert ribbon defines R. 18 E., the base. The ½ meter of the formation below this ribbon is composed of abundant calcite spar and shows some solution brecciation. Near the center of the formation is a very distinctive, nonbedded horizon containing abundant, dark chert nodules. The chert nodules are irregularly shaped, some forming lenses, from a few centimeters to over 1 meter across. The chert is light to dark gray, but mostly dark and vitreous. The limestone surrounding the chert nodules is pink. Overlying this horizon are more beds of light blue-gray limestone. The limestone bed immediately overlying the chert bed characteristically contains large solitary horn corals up to 10 cm long replaced by light tan chert. This is a useful marker bed where the distinctive chert horizon is missing. In the center of section 12, T. 18 S., R. 18 E., the top of the formation contains gray and red chert stringers in a 30 cm-thick zone that may be the karsted top of the unit. In most areas, though, the karst surface is nearly invisible and indistinguishable from other nearby bedding contacts. Hence, the contact between the Escabrosa and the overlying Horquila Limestone is interpretive. It was drawn at the base of the first light purple-tan shale bed.

Pennsylvanian and Permian(?)

These strata are composed of medium- to thick-bedded light gray limestone interbedded with minor lavender shale beds. The limestone is locally slightly lighter gray than the underlying Escabrosa and contains locally abundant light rusty orange to pink cherts. The cherts are irregularly shaped and sheet-like, and rarely nodular. Fossil fragments are not obvious except in some beds composed of silicified shell fragments. Where the shale beds are thicker they form less resistant slopes between small ledges of limestone. In most areas the division between the Escabrosa and the Horquilla is difficult to place because of the similarity of the units and the inability to recognize the bedding-planar disconformity between the two.

Overlying the Horquilla are interbedded limestones and sandstones interpreted to be the Upper Pennsylvanian to Lower Permian Earp Formation. Blue-gray limestone beds are thin- to medium-bedded. Tan sandstone beds are well-sorted and contain no carbonate in the matrix. Locally, fissile purple siltstone is abundant and forms slopes near the bottom of the formation. The lower contact was drawn at the base of the siltstone bed above which sandstone became more abundant. From a distance this formation is distinguished from the underlying Horquilla Limestone by the redder color of the former, and is exposed only in section 11, T. 18 S., R. 18 E., where outcrops are mostly covered by middle Pleistocene alluvium (map unit Qm).

STRUCTURE

Contact between the Bisbee Group and Proterozoic Granite

The nature of the contact between the Bisbee Group (map unit Kb) and the Proterozoic granite (map unit Yg) is unclear. Locally, the granite near the contact with the Bisbee Group rocks is extensively fractured and locally foliated. Interestingly, the only place where foliation was observed in the granite was near this contact. In areas of extensive fracturing or foliation the granite is extensively replaced by fine-grained epidote. Prominent shear planes have attitudes of N40°W, 45°NE, which is parallel to the contact. This suggests the contact is a fault. And indeed, in the southeast part of section 34, T. 17 S., R. 19 E., epidote-coated slip surfaces in microbrecciated granite dip 55°NE. At least in this one location the contact is definitely a fault. However, the lack of obvious brecciation or other deformation of the sedimentary beds of the Bisbee Group in other areas argues against a fault and suggests a depositional contact.

There is mineralization along the contact locally. In sections 34 and 35, T. 17 S., R. 19 E., deep pits were dug into very dark gray, almost black, fissile, fine-grained sedimentary rock. The black material is submetallic and resembles graphite but does not appear to be as soft. In any case the mineralization occurs a few meters north of the contact and nowhere is it actually along the contact itself. This black mineralization was found nowhere else in the Bisbee Group so it's presence near the contact means that it was either originally deposited unconformably on the granite only in this one stratigraphic horizon, or the mineralization is somehow related to faulting.

In section 30, T. 17 S., R. 19 E., the contact makes one and possibly two abrupt turns. The contact itself is mostly covered by younger alluvium but it is clearly discordant to bedding in the Bisbee Group. The apparent left-lateral offset of the Bisbee Group strata here suggests these sharp turns are northeast-striking faults. Creasey (1967) mapped these offsets as tentative faults.

Folding in Bisbee Group strata

Cross-beds that show unequivocal up-directions are rare in the Bisbee Group rocks in this area. They are most easily seen in sandstones that are cemented by calcite, as the cross-beds are etched out on the dark, weathered surfaces. Most sandstone layers are planar bedded to nearly massive. Cross-beds that showed unequivocal up-directions were marked on the map (see legend). Because of the rarity of these features, and the possible existence of tight, nearly isoclinal folds, the structural interpretations should be viewed with some caution.

In general, the Bisbee Group strata all strike about N60°W. In the northwestern corner of the map area the sediments are folded into a northwest-plunging anticline. A medium-grained diorite intrudes close to the axial plane of this fold. Farther south up-directions point consistently to the south. Barring any tight isoclinal folding this suggests that the contact between Bisbee Group strata and the Proterozoic granite in section 22, T. 17 S., R. 18 E., is probably a fault.

In the central part of the map area no unequivocal up-directions were seen so bedding in this area was mapped as simple, non-overturned strata. Bisbee Group strata in the eastern part of the map area are folded into an upright syncline, projecting southeast into the Benson Quadrangle. A prominent cleavage strikes nearly parallel to bedding and dips between 40° and 90°, mostly to the north. In the east, prominent, light gray calcite veins up to 1cm wide cross-cut the cleavage and bedding at high angles. Many of the calcite veins have attitudes of N110°E to N130°E, 55° to 65°S. Many of the veins show S-shaped internal growth laminations (when viewed looking west) that show that the veins grew during local dilational, normal extension of cracks, possibly during the folding event.

Folds in Paleozoic Rocks

The Paleozoic sedimentary rocks in the southwest part of the study area have been folded into a west-northwest-plunging syncline. The resistant Bolsa Quartzite, dipping about 50° southwest, holds up the high ridge of Haystack Mountain and the ridge to the south. The syncline was later cut by at least two major north-dipping normal faults that separated the syncline into three parts. A minor felsic intrusive rock (map unit TKfi) intrudes one of these folds. Parts of the intrusion are concordant to bedding while other parts cross-cut bedding.

Possible Jurassic Faulting

The foliation in the Proterozoic granite (map unit Yg) locally along the Bisbee-granite contact and the clear fault relationship along the eastern part of the exposures suggests all of the Bisbee-granite contact may be a fault contact. Indeed, on his map of the Benson 15' quadrangle Creasey (1967) interpreted this contact as a fault contact. However, the similarity between the steep, northerly dip of the contact and the steep, northerly dip of the Bisbee Group strata is also consistent with a depositional contact. If parts of the Bisbee-granite contact are depositional then the entire Paleozoic section exposed less than two miles to the south was removed before the Bisbee Group was deposited. Localized removal of such a thick sequence of rocks would probably require faulting and down-dropping of the southern section relative to the northern section prior to the early Cretaceous. 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. Therefore, although the Bisbee Group rests on Proterozoic granite less than two miles from where a thick sequence of Paleozoic rocks is exposed, it is conceivable the two sequences are part of one tilted fault block or are separated by one of these late Jurassic faults.

Less than one mile northeast of Haystack Mountain tiny slivers of what are interpreted to be Bisbee Group strata are preserved on the south side of a fault exposed (poorly) mostly in granite. The slivers are partly silicified and strongly brecciated, but one thin, dark gray limestone bed full of shell fragments resembles similar beds in the Bisbee. Along most of the exposures the fault is defined by a crushed, red hematite-rich zone from one to tens of meters thick (mapped where thick as map unit Yga). If the slivers are really Paleozoic rocks then it is possible this may be a large, down-to-the-south late Jurassic fault.

Martinez Ranch Fault

On aerial photographs the Martinez Ranch Fault is an obvious linear feature, but there are no known fault scarps that indicate late Quaternary fault movement (Dickinson, 1998). However, it is exposed only in the road-cut on the south side of Interstate 10 where it dips 54° to the east. In the north the fault is mostly buried beneath Quaternary alluvium. Both north and south of the Interstate the fault cuts structurally low exposures of Late Tertiary basin-fill sediments but is overlain by unfaulted basin-fill deposits of the same type. This relationship is exposed again farther south in section 22, T. 17 S., R. 18 E. These relationships show that displacement along the Martinez Ranch Fault occurred during deposition of basin-fill sediments but ended before deposition had ceased. Movement ceased but sediments continued to bury the fault. The absence of displacement in younger Tertiary and Quaternary deposits indicates faulting on the Martinez Ranch Fault ceased during the Late Tertiary (probably during the Pliocene).

The sharp, linear contact between basin-fill deposits on the west and Bisbee Group rocks on the east, in the northwest corner of the map area, is probably also a fault. It has the opposite sense (down to the west) as the Martinez Ranch Fault. Together the two faults define an uplifted keel of Mesozoic and Proterozoic rocks bordered by younger Tertiary and Quaternary sedimentary deposits. The complete residual Bouger gravity anomaly data show a gravity high in this area, the shape of which matches this keel very closely (Richard and Harris, 1995).

MINERALIZATION

A vertical shaft 6-7 meters deep was dug into fine-grained shale and sandstone in the Bisbee Group in section 19, T. 17 S., R. 19 E. Sandstone/quartzite beds 1 meter north of the shaft are iron-stained but there is no other obvious mineralization. The shaft is not marked on the topographic map.

Several exposures of the Bisbee Group (map unit Kb) north of the railroad are cross-cut by coarse-grained quartz veins up to 10 cm across. The quartz crystals in the veins are commonly euhedral and up to 5mm wide. In some veins euhedral quartz grew from the walls of the veins inwards towards the center. Locally, euhedral terminations project into cavities. Botryoidal, almost spherical forms are composed of fine-grained euhedral quartz crystals growing in layers outward from the center of the botryoid. Some quartz is coated with dark, almost black manganese. The attitude of several veins in this area is N160°E, 85°W.

Bedding of the tilted Tertiary conglomerate in the southern part of section 10, T. 17 S., R. 18 E., is obscured by abundant quartz veins. The veins locally permeate the conglomerate in anastomosing masses that branch and surround angular sandstone clasts. Some veins have attitudes of N165°E, 60°E. One large vein 30 cm wide has a coarse-grained calcite spar core. Locally, subcubic to almost rhombic shaped moulds up to 1.5 cm wide are preserved in quartz. The original crystals that formed the moulds are gone and the remaining silica forms an open latticework.

Quartz veins also cut the Tertiary upper conglomerate (map unit Tcu), indicating these veins are no older than middle Tertiary. The steep hill directly west of the number "15" in section 15, T. 17 S., R. 18 E. is cut by quartz veins. Some of the silica appears fibrous. One large vein 2-5 meters thick strikes nearly north-south and follows the ridge top. The central 10-20 centimeters of this vein is coarse-grained calcite. Much of the silica in this vein, and in others in the area, is very fine-grained and is probably a combination of fibrous chalcedony and granular microcrystalline quartz.

As stated above in the structure section several pits dug near the contact between the Proterozoic granite (map unit Yg) and the Bisbee Group (map unit Kb) into dark gray, nearly black fissile sedimentary rock. The mineralization is submetallic and resembles graphite but does not appear to be as soft. No other obvious mineralization was seen. Since the nature of the contact is not clear, it is not clear if the black mineralization was related to deposition of the Bisbee strata or if it was related to mineralized fluids rising along a fault.

REFERENCES

Balcer, R.A., 1984, Stratigraphy and depositional history of the Pantano Formation (Oligocene-Early Miocene), Pima County, Arizona: Tucson, University of Arizona, unpub. M.S. thesis, 107 p.

Bilodeau, W.L., 1982, Tectonic models for early Cretaceous rifting in southeastern Arizona: Geology, v. 10, p. 466-470.

Brown, W.H., 1939, Tucson Mountains, an Arizona basin range type: Geological Society of America Bulletin, v. 50, no. 5, p. 697-760.

Cooper, J.R., 1970, Mesozoic stratigraphy of the Sierrita Mountains, Pima County, Arizona: U.S. Geological Survey Professional Paper 658-D.

Creasey, S.C., 1967, Geologic map of the Benson quadrangle, Cochise and Pima Counties, Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-470, scale 1:48,000.

Davis, G.H., Constenius, K.N., Dickinson, W.R., Rodriguez, E.P., and Cox, L.J., (in press), Fault and fault-rock characteristics associated with Neogene extension in the Catalina-Rincon region, southeastern Arizona.

Drewes, H.D., 1972, Structural geology of the Santa Rita Mountains, southeast of Tucson, Arizona: U.S. Geological Survey Professional Paper 748, 35 p.
Drewes, H.D., 1974, Geologic map and sections of the happy Valley quadrangle, Cochise County, Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-832, scale 1:48,000.
Drewes, H.D., 1977, Geologic map and sections of the Rincon Valley quadrangle, Pima County, Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-997, scale 1:48,000.
Dickinson, W.R., 1998, Geologic relations of Martinez Ranch Fault and Happy Valley Neogene basin, east flank of Rincon Mountains, Pima County, Arizona: Arizona Geological Survey Contributed Map CM-98-B, scale 1:24,000, 16 p.
Gehrels, G.E., and Smith, C.H., 1991, U-Pb geochronologic constraints on the age of thrusting, crustal extension, and peraluminous plutonism in the Little Rincon Mountains, southern Arizona: Geology, v. 19, p. 238-241.
Hayes, P.T., 1970, Cretaceous paleogeography of southeastern Arizona and adjacent areas: U.S., Geological Survey Professional Paper 658-B.
Richard, S.M., and Harris, R.C., 1996, Geology and geophysics of the Cienega Basin area, Pima and Cochise Counties, Arizona: Arizona Geological Survey Open-File Report 96-21, 37 p.
Skotnicki, S.J., 2001, Geologic map of the Galleta Flat West 7.5′ quadrangle, Pima and Cochise Counties, Arizona: Arizona geological Survey Digital Geologic Map 01-08, scale 1:24,000, with 17 page text.
Skotnicki, S.J., (in press), Geologic map of the Benson 7.5′ quadrangle, Cochise County, Arizona.
Spencer, J.E., Ferguson C.A., Richard, S.M., Orr, T.R., and Pearthree, P.A., 2001, Geologic map of The Narrows 7.5′ quadrangle and the southern part of the Rincon Peak 7.5′ quadrangle, eastern Pima County, Arizona: Arizona Geological Survey Digital Geologic Map 01-10, scale 1:24,000 (1 sheet), with text.
Tang, C.M., 1999, Skolithos piperock in the Bolsa Quartzite (Cambrian), Whetstone Mountains, Arizona, in McCord, R.D., and Boaz, D, eds., Southwest Paleontological Symposium, Proceedings, (abstract) Mesa Southwest Museum Bulletin No. 6.
Thorman, C.H., and Drewes, H.D., 1981, Geology of the Rincon Wilderness Study Area, Pima County, Arizona: U.S. Geological Survey Bulletin 1500-A, p. A5-A62.
Tyrell, W.W., Jr., 1957, Geology of the Whetstone Mountain area, Cochise and Pima Counties, Arizona: Yale University, unpub. Ph.D. dissert.

UNIT DESCRIPTIONS
FOR THE MESCAL 7.5′ QUADRANGLE
AZGS DGM-09

Quaternary Surficial Deposits

Qy_2 **Late Holocene alluvial deposits (<100 yrs).** Unconsolidated sand and gravel in active stream channels. Deposits consist of stratified, poorly to moderate sorted sands, gravels, pebbles, cobbles, and boulders. These deposits are highly porous and permeable. Soils are generally absent.

Qy_1 **Middle to early Holocene alluvial deposits (<10 ka).** Unconsolidated sand to small boulders reaching several tens of centimeters in diameter upstream but smaller and fewer downstream. Qy_1 soils are characterized by stratified, poorly to moderately sorted sands, gravels and cobbles frequently mantled by sandy loam sediment. On the surface the main channel commonly diverges into braided channels. Locally exhibits bar and swale topography, the bars being typically more vegetated. Soil development is relatively weak with only slight texturally or structurally modified B horizons and slight calcification (Stage I). Some of the older Qy soils may contain weakly developed argillic horizons. Because surface soils have little clay or calcium carbonate, Qy_1 deposits have relatively high permeability and porosity.

Qly **Late Pleistocene and early Holocene alluvial deposits (<10 ka).** This unit consists of a thin layer (less than a few meters) of older Holocene alluvium deposited on Late Pleistocene alluvial deposits. These deposits are typically rather flat and show very little dissection except along the major washes. Grasses indicate some clay accumulation, while abundant mesquite indicates a shallow source of groundwater. On aerial photos this unit is slightly darker than more obvious Holocene deposits (map unit Qy_1) owing probably to slightly more soil development and more abundant darker shrubs.

Ql **Late Pleistocene alluvial deposits (~10 to 250 ka).** Moderately sorted, clast-supported sandstones and conglomerates containing subangular to subrounded locally derived clasts in a grussy and sandy tan to brown matrix. Ql surfaces are moderately incised by stream channels but still contain constructional, relatively flat, interfluvial surfaces. Ql soils typically have moderately clay-rich, tan to red-brown argillic horizons. They contain some pedogenic clay and some calcium carbonate, resulting in moderate infiltration rates. Thus, these surfaces favor plants that draw moisture from near the surface. Ql soils typically have Stage II calcium carbonate development.

Qm **Middle Pleistocene alluvial deposits (~250 to 750 ka).** Moderately to poorly sorted, clast-supported sandstones and conglomerates

Qo **Early Pleistocene alluvial deposits (750 ka to 2 Ma).** Relatively thin (<4 m-thick) deposits of moderately sorted, clast-supported sandstones and conglomerates containing mostly pebble- to cobble-size quartzite and limestone clasts in a sand to silt matrix. Qo deposits rest on top of high levels of Tertiary basin-fill deposits on the northern edge of the map and once exposure in the southwest part of the study area. Qo soils are characterized by a relatively thin argillic horizon (<2 m) containing dark brown soil moderately rich in clay underlain by a petrocalcic horizon of unknown thickness. Upper surface is flat and some quartzite clasts are slightly varnished. Deposits are only marginally distinguishable from the underlying basin-fill deposits (map unit Tsq), and are best delineated on aerial photographs where they appear darker than the underlying deposits.

Quaternary and Tertiary Sedimentary Deposits

QTs **Late Tertiary and Quaternary deposits (late Tertiary or early Quaternary).** Rare exposures in stream-cuts reveal interbedded tan-colored grussy sandstones and less abundant conglomerate. Larger clasts are almost nothing but granite (map units Yg and Ygm) and Bolsa Quartzite. Thin- to medium-bedded. Matrix is weakly cemented with carbonate. The top surface and slopes of these deposits is almost everywhere mantled by a red-brown soil less than 1 meter thick, locally overlying very minor pedogenic carbonate (caliche). Flat, constructional surfaces are nearly absent but the conformable upper surface as viewed from a distance suggests the soil on the top surfaces may represent either the last accumulation of the basin-fill sediments prior to down-cutting, or dissected Early Pleistocene alluvial deposits. Because of this uncertainty these deposits were mapped collectively as Late Tertiary and Early Quaternary.

QTc **Well-developed caliche deposits (late Tertiary or early Quaternary).** Thick carbonate at the base of map unit QTs. These massive, light gray, deposits are composed mostly of fine-grained carbonate but also contain irregularly shaped areas of very coarse-grained calcite spar. The spar may have filled cavities in the fine-grained carbonate. The carbonate contains very little clay or obvious detrital material. This unit is mapped only in the southeast corner of section 29, T. 17 S., R. 19 E., where it forms a well-exposed resistant layer at least 50 cm thick.

Late Tertiary Sedimentary Deposits

The Tertiary basin-fill units were mapped separately on the basis of clast-composition. Each has a distinct clast assemblage derived from different source areas, although the contacts between them are locally gradational. Gradational contacts suggest all four units were deposited penecontemporaneously. Dickinson (1998) included all of these units within what he called the "Gravels of Mescal Divide."

Tsq **Basin-fill deposits, quartzite-clast dominated (late Tertiary).** This interbedded sandstone and conglomerate unit crops out in the north and northeastern corner of the quadrangle. It contains subrounded to subangular pebbles to cobbles (up to ~20 cm) of gray limestone, light gray to purple, medium- to coarse-grained clean quartzites (Bolsa), grayish green arkosic sandstone and conglomerate (Bisbee), light gray to tan rhyolite, medium gray andesite, minor biotite-rich, quartz-sanidine welded tuff, and gray chert, all in a silty to sandy matrix. The most abundant clasts are quartzite, then limestone. The matrix locally contains abundant sand and granules of granite (map unit Tw in the Galleta Flat 7.5' quadrangle to the north), but larger granite clasts are rare.

Tsl **Basin-fill deposits, limestone-clast dominated (late Tertiary).** This interbedded conglomerate and poorly sorted pebbly sandstone unit crops out in the western part of the quadrangle. Clast compositions are variable but are generally characterized by abundant limestone and quartzite clasts. In the deeply dissected deposits in the southwest part of the quad the unit contains subangular to subrounded clasts of granite (map unit Yg), Bolsa Quartzite, rocks of the Abrigo Formation, and limestone. Here conglomerates fill abundant channels up to 2-3 meters deep. Sandstones are commonly fine-grained sand and silt and only locally grussy. Where exposed well (particularly in section 35, T. 17 S., R. 18 E.) fine-grained sandstones are commonly thinly bedded and display medium- to large-scale trough cross-bedding. Immediately south of Interstate 10 these deposits contain subangular to subrounded pebbles to cobbles of limestone, purple to pink quartzite, dark sandstones from the Bisbee Group, light gray felsite, biotite dacite (from dikes?), chert, and vein quartz. Matrix is sandy and locally grussy. The largest clasts in this unit are about 40 cm across. Matrix is commonly carbonate-rich.

Tsgq **Basin-fill deposits, granite- and quartzite-clast dominated (late Tertiary).** This conglomerate contains angular to subrounded clasts of medium- to coarse-grained granite, light gray fine- to medium-grained quartzite, limestone, and minor chert and vein quartz. This unit crops out in the northern part of the study area east of the exposures of the Bisbee Group (map unit Kb).Deposits nearest the underlying bedrock are dominated by granite that contains biotite in small books up to 3 mm across. Feldspars in the granite are commonly light green. Most clasts in this unit are pebble- to cobble-size but locally boulders are up to 1 meter across. Eastward, granite clasts are much less common and deposits are dominated by quartzite clasts. The matrix, where exposed, is moderately to strongly cemented by carbonate.

Tsg **Basin-fill deposits, granite-clast dominated (late Tertiary).** This interbedded sandstone and conglomerate unit crops out in the northwestern corner of the quadrangle. These deposits contain mostly subangular to subrounded pebbles to cobbles of medium- and coarse-grained strongly foliated granites, less abundant light blue-gray quartz-muscovite schist, muscovite schist with dark spots (of biotite?), vein quartz, dark and light gray quartzite, and rare limestone. Deposits in the extreme northwest corner of the map contain abundant boulders of coarse-grained granite up to 1 meter across. At least some of the deposits of this map unit are correlative with the "Agua Verde Creek facies" of the Pantano Formation (Spencer et al., 2001).

Tertiary Sedimentary and Volcanic Rocks *(Pantano Formation)*

Tw **Conglomerate, Wakefield Canyon facies (middle tertiary).** This thin- to medium-bedded light tan conglomerate contains subangular to subrounded pebbles and minor cobbles of sandstones and siltstones derived from the Bisbee Group (map unit Kb), and light gray, crystal-rich biotite rhyolite or dacite. The matrix is tan sand. The unit also contains interbedded sandstone layers with a tan sandy matrix containing very little grus. This unit is moderately consolidated and crumbles easily with a hammer. It contains very minor carbonate in the matrix. These deposits overlie map unit Tcu on the west side of the study area south of the highway, and dip moderately to shallowly to the west. The dip decreases up-section away from the upper conglomerate (map unit Tcu).

Tcu **Upper conglomerate (middle Tertiary).** This interbedded conglomerate and minor sandstone contains subangular to subrounded granules, pebbles, and cobbles of gray to tan sandstone (Bisbee), variously colored chert, minor limestone, and abundant light gray to tan rhyolite. The rhyolite clasts contain ~5-10% subhedral to euhedral phenocrysts of clear quartz, sanidine, and minor biotite or muscovite, all up to about 4 mm wide. The conglomerate beds are interbedded with minor medium-bedded sandstone containing weak iron-oxide laminations. The matrix is sandy and contains minute rusty spots that resemble limonite. These spots may be altered mafics or altered scoria. These deposits are very strongly cemented with silica and form a high, resistant ridge on the far western side of the quadrangle. The unit is locally cut by quartz+calcite veins.

Ts **Siltstone (middle Tertiary).** This purple siltstone and fine-grained sandstone is poorly exposed in section 10, T. 17 S., R. 18 E., where it separates units Tcm and Tcu.

Tcm **Middle Conglomerate (middle Tertiary).** This interbedded fine- to coarse-grained sandstone and pebbly conglomerate contains subangular to subrounded pebbles to boulders of mostly grayish green sandstone (Bisbee), and minor chert and vein quartz. Exposures of this unit are characteristically grayish green and contrast with the underlying red conglomerate (map unit Tcr) and the overlying strongly cemented conglomerate containing abundant light gray rhyolite clasts (map unit Tcu). This unit is mostly covered by material eroding from Tcu. In section 22, T. 17 S., R. 18 E., the conglomerate is interbedded with the tuff (map unit Tt). In section 10, T. 17 S., R. 18 E., the unit is separated from the upper conglomerate (map unit Tcu) by a siltstone unit (map unit Ts).

Tt_1 **Tuff (middle Tertiary).** This light gray to light yellow tuff is more crystal-rich than tuff Tt_2. This unit contains about 5-10% subhedral sanidine and very minor visible quartz. This tuff overlies map unit TKcr and is locally interbedded with map unit Tcm on the western edge of the map. A sample of this tuff from Anderson Canyon on the north side of section 15, T. 17 S., R. 18 E., was dated at 26.54 ± 0.083 Ma (2σ uncertainty; sample 4-26-96-1) by the $^{40}Ar/^{39}Ar$ method using single crystals of sanidine (W.C. McIntosh, New Mexico Bureau of Geology, written communication to Jon Spencer, 1997).

Tt_2 **Tuff (middle Tertiary).** This light gray to light lavender tuff contains ~1-5% phenocrysts of euhedral quartz up to 1 mm across. Light gray pumice up to about 3 cm wide is partially flattened and locally forms a weak to moderate eutaxitic foliation. South of the railroad and north of the Highway pumice has been replaced by quartz. Tiny cavities in the tuff are lined by small euhedral quartz crystals. In thin-section, sample 12.9.00.1 contains abundant partially welded glass shards in a matrix of fine-grained megaquartz.

Tss **Siltstone and sandstone, Davidson Canyon facies (middle Tertiary).** Interbedded purple shale, siltstone, and sandstone. Very fissile, weakly consolidated, and crumbles easily. Sandstone beds are typically about 10 cm thick. Exposures are poor and mostly covered by younger alluvium. This unit overlies the andesite (map unit Ta).

Ta **Porphyritic andesite (middle Tertiary).** This dark gray volcanic rock contains large, subhedral to euhedral, glassy, gray plagioclase phenocrysts 1-3 cm wide, small altered mafic minerals 1-4 mm across, and yellowish green spots 1-4 mm across, all in a gray, aphanitic matrix. Plagioclase crystals are most visible on weathered surfaces where they commonly appear either lighter or darker than the matrix. Phenocrysts comprise 50% or more of the rock. The rock is permeated by irregularly shaped, dark maroon vein-like features composed of silica and abundant fine-grained hematite(?). Many appear to fill cracks and others may be alteration features. Some are laminated. White fibrous chert and euhedral quartz locally fill vugs 1-7 cm across. In thin-section the matrix locally is composed of more than 20% of an anhedral light yellow pleochroic mineral that is replaced by what appears to be granular microcrystalline quartz. Anhedral zircon is abundant. Some opaques surround relict biotite. Plagioclase crystals are partially corroded. Highest magnification reveals long, needle-shaped crystals exhibiting clear pleochroism and dark blue birefringence (apatite?).This volcanic unit forms low, very dark-colored hills in the northwest corner of the map area.

Tdcl **Older conglomerate, Davidson Canyon facies (middle tertiary).** These sedimentary deposits below the andesite are composed of variable amounts of pebble- to cobble-conglomerate, light pinkish tan arkosic sandstone, and fine-grained purple to pink siltstone. The coarser beds contain subangular to subrounded pebbles to cobbles of light gray to purple quartzite, vein quartz, bluish gray quartz-muscovite schist, coarse-grained muscovite granite, red arkosic quartzite, limestone, meta(?)rhyolite, and pink, gray, and purple cherts. The finer-grained deposits are typically thin- to medium-bedded and crumble easily. Most exposures below the steeper volcanic deposits are covered with colluvium and are visible only in gullies. May be equivalent to the red conglomerate (map unit Tcr).

Tdcc **Limestone Conglomerate, Davidson Canyon facies (middle tertiary).** This deposit contains almost exclusively subangular to rounded limestone pebbles and cobbles in a tan to light pink sand to silt matrix. Only one small outcrop exists in the northwest corner of the map below map unit Tdcl. Although the deposit is lithologically similar to the limestone-rich conglomerates thought to be equivalent to the Glance, bedding in this deposit cross-cuts bedding in the Bisbee Group rocks.

Tertiary or Cretaceous Sedimentary Rocks

TKcr **Red conglomerate (middle Tertiary).** Interbedded granule to cobble conglomerate and maroon sandstone. The unit contains subangular to subrounded clasts of grayish green and tan sandstones (Bisbee), fine-grained purple sandstone, light gray coarse-grained quartzite (Bolsa), and at least one cobble of coarse-grained granite (Yg). All clasts are stained deep red to maroon. Abundant lighter gray-colored quartzite clasts contrast with the maroon sandy matrix. Matrix is locally grussy in the southern part of section 14, T. 17 S., R. 18 E. In the northern part of the same section the unit contains abundant clasts of granite (Yg) and, particularly, cobbles to boulders of blue-gray limestone. Bedding in this unit varies from nearly horizontal to almost vertical. Possibly equivalent to the Fort Crittenden Formation, but probably equivalent to the Davidson Canyon facies of the Pantano Formation.

Tertiary or Mesozoic Intrusive Rocks

TKi **Intermediate intrusive rock (Tertiary or Mesozoic).** This dark green rock contains large, prominent, subhedral to euhedral phenocrysts of quartz and light pink K-feldspar up to 1 cm across, in a fine-grained matrix composed of intergrown plagioclase and green needles of hornblende (or possible chlorite or actinolite). In thin-section the long, tabular phenocrysts exhibit medium orange birefringence and parallel extinction. Most are partially altered to chlorite. Smaller crystals with similar birefringence are more equant and anhedral. Some form the cores of weakly zoned feldspars. Gray feldspars are locally albitetwinned but more than 60% are not twinned, and some resemble quartz. High-relief, high-birefringent minerals are probably zircon. At first glance the quartz phenocrysts appear rounded, but they are actually doubly terminated, stubby, diamond-shaped crystals. In thin-section they are rimmed by dark opaques and chlorite. This rock intrudes nearly along the axial plane of a large fold in the Bisbee Group strata, in the northwestern part of the study area.

TKfi **Felsic intrusive rock (Tertiary or Mesozoic).** This light tan, fine- to medium-grained, equigranular intrusive rock contains abundant feldspar, less abundant quartz, and ~10% biotite mostly altered to limonite(?). The rock intrudes Pennsylvanian and older Paleozoic rocks. Outcrops erode into small angular fragments.

Tertiary or Proterozoic Intrusive Rocks

TYd **Diorite (Tertiary or Proterozoic).** This dark green rock contains 60-95% dark green amphibole 3-10 mm long, minor plagioclase, and possibly quartz. The rock crumbles easily. It is exposed as one elongate outcrop along the contact between Proterozoic granite (map unit Yg) and Bisbee Group rocks (map unit Kb) in the southern part of section 35, T. 17 S., R. 19 E.

Mesozoic Rocks

Kb **Bisbee Group (Lower Cretaceous).** The Bisbee Group in the map area is comprised of interbedded purple shales and light gray to tan sandstone and minor conglomerate. The finer-grained rocks erode relatively easily and generally form subdued, friable outcrops. Locally, they contain lens-shaped carbonate nodules up to 4 cm across. The sandstones contain well-sorted, subrounded quartz and minor feldspar grains. They are commonly massive or are characterized by planar bedding showing very few cross-beds. Some sandstones are limy and these beds show more obvious cross-bedding. Cross-beds and layering are defined by thin iron-oxide laminae. Coarse-grained, orange-tan, conglomeratic arkosic sandstones are less common than the planar-bedded sandstones and are distinguished from them by their crude bedding to massive nature and abundance of coarse sand- to gravel-size quartz and feldspar grains. These arkosic conglomerates are lens-shaped and locally pinch out over distances of several tens of meters. Conglomerate beds contain granules to cobbles up to 7 cm across of light gray to purple quartzite, locally limestone, and gray chert, all in a poorly sorted arkosic matrix. Most clasts are well rounded. Minor, thin, gray limestone layers up to 20 cm thick are thinly laminated and locally show syndepositional folds. In thin-section, these thinly laminated limestones are micrite containing <2% silt-size detrital quartz and/or feldspar grains. Also in thin-section, some dark laminae in sample 2.9.00.3 contain lighter-color prism shapes that resemble gypsum crystals, now replaced by micrite. Hematite pseudomorphs after pyrite 2-8 mm wide are common locally in some sandstones. The sequence has been folded and tilted. Sandstones are locally quartzites. Two thin-sections of sandstone contain moderately sorted, angular, sand-sized grains of quartz, feldspar, and minor opaque minerals. Many grain boundaries are sutured. Fine-grained muscovite is abundant between grains. One sample (12.8.00.2) contains minor detrital sphene and biotite(?). Calcite spar in this sample may be either cement or detrital, now recrystallized.

KJc **Conglomerate (Lower Cretaceous).** This unit contains mostly coarse conglomerate with minor thin- to medium-bedded layers of sandstone and maroon siltstone. Most clasts in exposures in the east side of section 35, T. 16 S., R. 18 E. are subrounded to rounded, pebbles to cobbles of limestone with very minor chert and other lithics, all in a sandy to silty matrix cemented by carbonate. Abundant orange cherts may have originated from Pennsylvanian carbonate strata. These deposits are strongly indurated and are mostly covered with a lag. Exposures are both matrix- and clast-supported and change character abruptly over a distance of a few meters. Locally contains minor well-rounded quartz pebbles. There are no granitic clasts. Lower contacts of some conglomeratic beds show scour channels. Exposures in the western side of the same section contain very abundant subangular to subrounded pebbles to cobbles of pink to purple dacite. The dacite contains abundant subhedral, light gray plagioclase, biotite, and possible amphibole. Exposures here contain interbedded sandstone beds similar to those in the Bisbee (map unit Kb). Some resistant sandstone layers contain spots of hematite that may have been pyrite. Both of these subunits appear to grade abruptly into map unit Kb and may be equivalent to the Upper Jurassic to Lower Cretaceous basal Glance conglomerate.

Paleozoic Rocks

Pzl **Upper Paleozoic sedimentary rocks, undivided.**

PPe **Earp Formation? (Lower Permian and Upper Pennsylvanian).** Interbedded limestone and sandstone. Blue-gray limestone beds are thin- to medium-bedded. Tan sandstone beds are well-sorted and contain no carbonate in the matrix. Locally, fissile purple siltstone is abundant and forms slopes near the bottom of the formation. The lower contact was drawn at the base of the siltstone bed above which sandstone became more abundant. From a distance this formation is distinguished from the underlying Horquilla Limestone by the redder color of the former.

Ph **Horquilla Limestone (Upper and Middle Pennsylvanian).** This unit is composed of medium- to thick-bedded light gray limestone interbedded with minor lavender shale beds. The limestone is locally slightly lighter gray than the underlying Escabrosa and contains locally abundant light rusty orange to pink cherts. The cherts are irregularly shaped and sheet-like, and rarely nodular. Fossil fragments are not obvious except in some beds composed of silicified shell fragments. In most areas the division between the Escabrosa and the ?? is difficult to place because of the similarity of the units.

Me **Escabrosa Limestone (Mississippian).** This light blue-gray, thick-bedded limestone contains very minor light gray chert nodules up to 15 cm across. The rock is composed of very abundant fragments of crinoid stems and brachiopods, all replaced by calcite spar. In the northeast corner of section 12, T. 18 S., R. 18 E., the base is defined by a very continuous, irregularly shaped, black chert ribbon. The ½ meter of the formation below this ribbon is composed of abundant calcite spar and shows some solution brecciation. The lower cliff-forming part locally contains peloid-like features faintly visible with a hand-lens. Overlying this horizon are more beds of light blue-gray limestone. The limestone bed immediately overlying the chert bed characteristically contains large solitary horn corals up to 10 cm long replaced by light tan chert. This is a useful marker bed where the distinctive chert horizon is missing. In the center of section 12, T. 18 S., R. 18 E., the top of the formation contains gray and red chert stringers in a 30 cm-thick zone that may be the karsted top of the unit.

Mec **Distinctive chert layer in the Escabrosa Limestone (Mississippian).** Near the center of the Escabrosa Limestone is a very distinctive, nonbedded horizon containing abundant chert nodules. The chert nodules are irregularly shaped, some forming lenses, from a few centimeters to over 1 meter across. The chert is light to dark gray, but mostly dark and vitreous. The limestone surrounding the chert nodules is pink. No other bed in the Paleozoic section exposed in the area resembles this subunit.

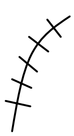
Dmu **Upper part(?) of the Martin Formation (Devonian).** These exposures are composed of a series of step-like ledges of thin- to thick-bedded blue-gray limestone interbedded with pinkish, sandy carbonate. The rock contains worm burrows and rare crinoids but it is not obviously fossiliferous. Light gray chert is rare and the unit is mostly chert-free. Limestones in the upper part are interbedded with light tan, thinly bedded, fine-grained sandstone containing no carbonate in the matrix. The unit is different from both the more typical Martin Formation (map unit Dm) and the overlying massive to thick-bedded blue-gray limestones of the Escabrosa Limestone (map unit Me).

Dm **Martin Formation (Devonian).** The outcrop capping the hill in the west-central part of section 7, T. 18 S., R. 19 E., shows a massive portion of the Martin Formation. Here the rock is massive dolomitic limestone. Bedding is indistinct. The rock contains localized solution collapse breccias with dolomite clasts surrounded by slightly lighter pink carbonate and some terra rossa. Vugs are lined with red calcite spar or are partially to completely filled with white calcite spar. Some crinoid stems are visible.

Ꞓa **Abrigo Formation (Middle and Late Cambrian).** The lower part of this heterogeneous formation is composed of tan, fine-grained, thinly bedded micaceous sandstone interbedded with less abundant blue-gray limestone. Limestone beds near the base are less than 1 meter or so thick. Near the center of the formation thicker limestone beds several meters thick contain abundant burrows 2-5 mm in diameter. The burrows are filled with darker micrite than the surrounding micrite and most are oriented with their long axis parallel to the bedding planes. Few cross bedding planes. Limestone and sandstone is interbedded in the upper half of the formation with conglomerate. The conglomerates contain rounded, elongated, locally-derived, pebble-size limestone clasts surrounded by a coarse quartz sand matrix. Calcite spar commonly cements the sandy matrix and these beds typically stand out in relief. Cross-bedded parts of the matrix and pieces of conglomerate have been rotated and/or transported before final lithification. Much of the unit appears to be composed of rip-up clasts that were retransported a short distance before lithification.

Ꞓb **Bolsa Quartzite (Middle Cambrian).** This resistant unit is composed of medium- to coarse-grained arkosic sandstone and locally interbedded granule conglomerate. The rock contains subangular to subrounded grains of light gray quartz and tan to pink feldspar up to about 1 cm across, but mostly 1-4 mm across. Some beds contain mostly quartz. Thin to thick bedding is defined by thin iron-oxide laminations. Cross-bedding is prominent, and is commonly overprinted by colored leisegang banding that mimics cross-bedding but locally cross-cuts it at random angles. Some beds are extensively bioturbated and display vertical, tube-like burrows interpreted as *Skolithos* trace-fossils (Tang, 1999). The unit forms distinctive light gray to purple ledgy outcrops and cliffs.

Middle Proterozoic Intrusive Rocks



Granitic dikes (middle Proterozoic?). These dikes are composed of medium- to coarse-grained quartz, pink K-feldspar, plagioclase, and muscovite. Locally, the rock is pegmatitic with crystals reaching about 4 cm across. Most exposures are medium to moderately coarse-grained and resemble medium-grained granite (map unit Ygm). Locally, some exposures contain minor red garnet in circular halos intergrown with other crystals.

Yga **Altered coarse-grained granite.** This region of granite is locally brecciated. Fractures are stained red with hematite. The region borders the fault in coarse-grained granite in the southern part of the map area. Most of the alteration appears to be on the north side of the fault.

Ygm **Medium-grained granite (middle Proterozoic).** Contains anhedral to subhedral phenocrysts of clear quartz, fresh biotite, light gray K-feldspar, and plagioclase. This granite is mostly equigranular, but locally contains coarser-grained areas. Biotite is slightly altered to hematite. This unit generally weathers into small angular blocks, rather than spheroidal boulders. Some surfaces exhibit weak varnish. The rock forms small intrusions and dikes cutting the older granite (map unit Yg). The contact between this unit and the coarse-grained granite is everywhere sharp.

Yg **Coarse-grained granite (middle Proterozoic).** This coarse-grained megacrystic granite contains large subhedral to euhedral, pink K-feldspar phenocrysts up to 3 cm long. Plagioclase is either difficult to distinguish or is serricitized and appears light gray. Biotite occurs as anhedral books and is mostly altered to hematite and/or chlorite. May contain minor muscovite locally. Locally, the granite near the contact with the Bisbee Group (map unit Kb) is extensively fractured and locally foliated, and contains abundant epidote. This unit forms a pediment in the southern part of the study area.

Early Proterozoic Metamorphic Rocks

Xp **Pinal Schist (early Proterozoic).** Quartz-muscovite schist. The sole exposure of this rock in the study area is in section 16, T. 17 S., R. 18 E., where it is intruded and surrounded by coarse-grained middle Proterozoic granite (map unit Yg). Exposures are poor. Some compositional layering is visible in float. Foliation directions were not consistent enough to measure a characteristic orientation.